REVIEW

A review of ecosystem service benefits from wild bees across social contexts

Denise Margaret S. Matias , Julia Leventon, Anna-Lena Rau,
Christian Borgemeister, Henrik von Wehrden

Received: 19 August 2016 / Revised: 17 October 2016 / Accepted: 20 October 2016 / Published online: 22 November 2016

Abstract In order to understand the role of wild bees in both social and ecological systems, we conducted a quantitative and qualitative review of publications dealing with wild bees and the benefits they provide in social contexts. We classified publications according to several attributes such as services and benefits derived from wild bees, types of bee–human interactions, recipients of direct benefits, social contexts where wild bees are found, and sources of changes to the bee–human system. We found that most of the services and benefits from wild bees are related to food, medicine, and pollination. We also found that wild bees directly provide benefits to communities to a greater extent than individuals. In the social contexts where they are found, wild bees occupy a central role. Several drivers of change affect bee–human systems, ranging from environmental to political drivers. These are the areas where we recommend making interventions for conserving the bee–human system.

Keywords Community · Ecosystem cascade framework · Livelihoods framework · Social–ecological systems

INTRODUCTION

Worldwide, wild bees along with managed honeybees are the main and most economically important group of pollinators (Kremen et al. 2007). Among other biotic pollinating agents, bees are the most effective because of their high flower reliability and flower constancy (Roubik 1995; Garibaldi et al. 2013; Rader et al. 2016). This means that

bees actively seek out flowers and are able to identify even in diverse settings the exact species they prefer to visit. Reported declines in bees have raised an alarm over their conservation (Biesmeijer et al. 2006; Goulson et al. 2008; Potts et al. 2010). The decline seems to be multi-causal and driven by human activities such as deforestation and land-use change, pesticide use in agricultural lands, pathogens and parasites, bee keeping practices, and—more recently—climatic change (Roubik 1995; Le Conte and Navajas 2008; Oldroyd and Nanork 2009; González-Varo et al. 2013). Initially the focus has been primarily on managed honeybees as they were regarded as the economically more important pollinators (Southwick and Southwick 1992; Morse and Calderone 2000; Allsopp et al. 2008 as quoted in Jaffé et al. 2009; Garibaldi et al. 2013). Feral and wild bees, however, are important because they are reservoirs of local adaptations, which are said to ultimately determine the survival of honeybees in the wild (Matheson et al. 1996 as quoted in Jaffé et al. 2009). Despite the impact of human activities on wild bee decline, the majority of research comprise ecological studies (e.g. Patiny et al. 2009; Winfree 2010). Human–insect connections garner relatively little attention and a comprehensive review on wild bees interaction with humans is yet to be conducted (Watson and Stallins 2016).

In this review paper, we aimed to understand how research is framing the role that wild bees play in social–ecological systems (SES). SES are linked natural and social systems. The involvement of people in biophysical structures or processes demonstrates how SES are formed. Because of the extent of environmental impacts caused by anthropogenic activities, it is disadvantageous to ignore social systems when studying the functioning of the natural environment (Bodin and Tengö 2012). Hence an in-depth understanding of both social and natural systems is pivotal

Electronic supplementary material The online version of this article (doi:10.1007/s13280-016-0844-z) contains supplementary material, which is available to authorized users.

for improving stewardship of natural resources and ecosystem services for human well-being and sustainability (Boyd and Folke 2012). One way of doing so is to link social and ecological components in a common framework of a systems approach (Westley et al. 2002). A systems approach allows for scrutiny of the way in which humans and nature, i.e. in our context wild bees, interact and the impacts that they have on each other. This would provide information on the different types of environment where wild bees occur as well as the influence humans have on them and their habitat.

We conducted a mixed quantitative and qualitative literature review targeting publications that explicitly deal with bee–human systems. It is important to establish the current state of knowledge on wild bees in social contexts in order to identify gaps and leverage points where intervention for conservation is possible and promising, and to highlight key gaps in our understanding that should be addressed by future research.

In order to examine the way in which the social dimensions of wild bees are being researched, we have four objectives in this paper. Objective one (1) is to identify trends in research around wild bees and human interactions; objective two (2) is to examine the frameworks being used to understand wild bee and human interactions; objective three (3) seeks to characterise the interactions between humans and wild bees; and objective four (4) identifies drivers of change in wild bee and human interactions.

Our review draws on literature that make elements of a SES explicit. We examined the direct benefits that wild bees provide to people, which the 2005 Millennium Ecosystem Assessment (MEA) defines as ecosystem services. Ecosystem services are derived from biophysical structures or processes through several steps of transformation in a cascade (Haines-Young and Potschin 2010). By attributing value to a biophysical structure or process, people become involved in the transformation of biophysical structures or processes to ecosystem services (Spangenberg 2014). As these services are co-produced by both humans and nature, it therefore has an intrinsically social–ecological character (Andersson et al. 2007; Reyers et al. 2013; Queiroz et al. 2015). The ecosystem cascade framework of Haines-Young and Potschin (2010) is useful in analysing the ecosystem services wild bees mediate. In the ecosystem cascade framework, a function of a landscape structure or process cannot be regarded as a service unless people consider the function as a benefit (Haines-Young and Potschin 2010). The ecosystem cascade framework highlights that services go hand-in-hand with the needs of the people (Haines-Young and Potschin 2010).

We also consider the role of wild bees in livelihoods, particularly as defined by the sustainable livelihoods

framework of Scoones (1998). The sustainable livelihoods framework looks at the combination of livelihood resources (natural, economic, financial, human, or social capital) that result in certain livelihood strategies, given particular contexts and institutional processes. Sustainable livelihoods outcomes, such as poverty reduction or improvement of well-being and capabilities, are the envisaged endpoints of the framework (Scoones 1998).

In the following methodology, we outline our approach for identifying and analysing literature. We further present our quantitative and qualitative approaches to answering our four research objectives. The results section addresses each objective in turn. In the discussion section, we argue that our results indicate that there is an increasing recognition of the interlinked nature of wild bees and humans. We conclude this review by highlighting challenges in researching bee–human systems and providing recommendations for further development of the field.

METHODOLOGY

Following the review framework of Newig and Fritsch (2009), we conducted a thorough search of full articles through Scopus using search terms that exclude managed honeybees and studies of bees with no human interaction. This included articles published as early as 1916 until July 2015. The search string that was used can be found in Appendix S1.

The resulting number of bibliographies was 8368. We narrowed down this number by further excluding journal articles from the basic research fields, which do not investigate interactions with humans. These are the fields of astronomy, biochemistry, chemistry, engineering, genetics, molecular biology, and physics. We then reviewed the abstracts of the remaining journal articles and thereafter selected publications that contain information on wild bees and humans, leaving 71 publications that were then studied in detail. A further assessment was conducted using close reading of the articles. Only articles written in English showing wild bee–human interaction were considered, resulting in a final count of 46 publications (listed in Appendix S2) for review and coding. Most of the excluded articles treated wild bees and humans as separate entities.

Each publication was reviewed and coded based on several criteria (Table 1). In order to understand trends in wild bee research (objective 1), we identified basic information about the paper. This included year of publication, disciplinary focus, country of origin of first authors and co-authors, and country of study. We performed descriptive statistics on each of these metrics, and generated tables and figures through R software version 3.0.2 and its packages

Table 1 Criteria for review of publications

Journal information	Information on bees	Methodological information	Analytical information
Year of publication	Genus or species of bees	Methods of identifying benefits	Role of bees in social context
Type of paper (e.g. case study, review, etc.)	Type of bee habitat	Methods of quantifying benefits	Place in the ecosystem cascade framework
Discipline	Type of human interaction or activity	Framework used	Place in the livelihoods framework
Thematic focus	Services identified		Gainer of direct benefit
Country of institution of first author	Benefits identified		Drivers of change
Country of study			
Scale of the study			

bipartite, ggplot2, and sjPlot. Additionally, we performed inferential statistics using STATA 14.0 and MATLAB R2016b on the number of publications per year and the association of wild bee services and benefits with either the livelihood or ecosystem frameworks. For objective 2 (the frameworks for understanding interactions), we distinguished whether the research was examining human and wild bee interactions through the livelihoods framework (Scoones 1998) or the ecosystem cascade framework (Haines-Young and Potschin 2010). If no information was available the answer provided was N/A or not applicable. Descriptive statistics as well as figures and tables were generated as in objective 1.

In order to characterise the interactions between humans and wild bees (objective 3), we focused on both the way in which humans benefitted from wild bees, and the way in which human activities impacted upon the bees. Therefore, each publication was analysed based on its scale of study, wild bee–human interaction and its corresponding services or benefits, its use of livelihood, the social context where bees are found, and the direct gainer of benefits from the wild bees. Drivers of change to wild bee–human interaction were also identified from each publication (objective 4).

RESULTS

Trends in wild bee–human interaction research

The number of publications dealing with wild bees in social contexts increased between 1982 and 2015 (Fig. 1). We see from the figure that there were deviations in some years but, in general, there were more publications that dealt with both wild bees and humans during the last decade as compared with the previous years. We conducted a Mann–Kendall test to determine the statistical significance ($\alpha = 0.05$) of the increasing number of publications per year. The tests resulted in a Kendall's tau-*b* of 0.589

with significance probability (p) = 0.000 (rounded to three significant digits) indicating that there is a strong positive correlation between the year of publication and the number of publications. To corroborate this result, we also ran a Spearman's rank correlation, which resulted in a Spearman's rho of 0.732 with $p = 0.000$ (rounded to three significant digits). These results show that there is a clear monotonic increase in publications throughout the years, but the relevant question at this point is whether this increase is compatible with an exponential law. Through a nonlinear regression test, we see that the doubling time for the amount of publications is 5.9 years with a confidence interval (95%) of 3.3–8.4 years. If this trend is sustained, thereby confirming the exponential law, this means that we are now witnessing the onset of a rapidly increasing field.

Most of the publications reviewed had their research conducted in Africa, Asia, and Latin America. Authors based in Europe conducted research only in these regions; conversely, authors from Asia, Africa, Latin America, and the Middle East conducted studies only in their own region (Fig. 2). Authors based in North America conducted research in all other regions except Australia and the Middle East. Two publications had first authors with dual affiliations: one with Asia and Europe and another with Africa and Asia. These show that one-third of the publications had its research conducted in countries outside of the first author's region. In addition, the majority of these publications had co-authors from the country where the research was conducted. When these publications were grouped according to discipline, the majority of the publications came from the fields of ecology followed by anthropology (Fig. 3). There were also several medical publications and one each from the fields of economics and archaeology. Most of the benefits were identified through qualitative methodologies such as interviews, participant observation, focus group discussions, or literature review. Quantitative methodologies such as economic valuation or retrospective panel approach were also used to a limited

Fig. 1 Increase in publications. There is a general trend of increase in publications on wild bees in social contexts during the last decade. The shaded area is the 95% confidence region of the nonlinear regression

Fig. 2 Research mobility of the Northern Hemisphere. Most of the (first) authors from the Northern Hemisphere conducted their studies outside of their own region. European first authors conducted research in Asia, Africa, and Latin America while North American first authors conducted research in all regions except Australia and the Middle East. First authors from Africa (with the exception of one author with dual affiliation with Asia), Asia, Latin America, and the Middle East conducted research only in their own regions

Fig. 3 Domination of ecology and anthropology. Most of the publications on wild bees fall within the fields of ecology, followed by anthropology

extent. Where quantitative methodologies were used, benefits were quantified through volume or monetary value of hive products. The majority of the publications were focused on a community scale, with several publications also working on a provincial scale. Most of the studies found wild bees in forested areas, while some studies also found wild bees in agricultural land and urban areas.

Frameworks for understanding wild bee–human interactions

The livelihoods framework has been the most popular framework for understanding human interactions with wild bees. The majority (57%) of the publications reviewed used the livelihoods framework while a minority (39%) used an ecosystem cascade framework. Two of the publications did not use any framework. Despite only a small number of publications using an ecosystem cascade framework, the framework has been increasingly used in the more recent years. In fact, all of the reviewed publications in 2015 used the ecosystem cascade framework.

The livelihoods framework publications mostly focused on services and benefits from wild bees as both natural and economic capital. Most of the livelihoods framework publications identified wild bees and their products such as beeswax, cerumen, honey, propolis, and royal jelly as services, which provide material benefits that can be sold in order to obtain cash income. All publications, except for two, using the livelihoods framework were case studies. Almost all (93%) of the countries of study were located in developing countries in Africa, Latin America, and Asia, except two publications that conducted studies in Australia and the Mediterranean region.

The ecosystem cascade framework publications, on the other hand, mostly dealt with service (flows) in the

cascade. Wild bees and their products were the services that provided benefits in the form of food, medicine, pollination, and religious and social life. Majority (67%) of the studies were conducted in Asia and Latin America while studies conducted in the Middle East, Africa, and North America were only a minority (33%). Most of the countries of study (67%) using the ecosystem cascade framework also belong to the Group of Twenty major economies.

We conducted Fisher's exact tests to see whether there was a statistically significant relationship between services or benefits and the analytical frameworks. The Fisher's exact test for services resulted in $p = 0.067$ (Table 2), while for benefits it resulted in $p = 0.000$ (rounded to three significant digits) (Table 3). The results show a statistically significant relationship at $\alpha = 0.10$ between the frameworks used and the services from wild bees, but not at $\alpha = 0.05$ which is the case for the benefits.

We also conducted a Pearson's Chi-squared (χ^2) test to supplement the Fisher's exact tests, and the results for services from wild bees returned $\chi^2 = 6.85$ with three degrees of freedom and $p = 0.077$. The resulting contingency tables show that bees, pollen, and products were the services that contributed greatly to the χ^2 (Table 2). For benefits from wild bees, $\chi^2 = 19.8$ with four degrees of freedom and $p = 0.001$ (Table 3). Material, medicine, and food were the biggest contributors to the χ^2 , which rendered the relationship with the analytical frameworks highly significant.

Characteristics of interactions between humans and wild bees

All in all, services derived from wild bees were identified as the wild bees themselves, beeswax, cerumen, honey, pollen, propolis, and royal jelly. These services provided benefits in the form of culture (religious and social life), food, material, medicine, and pollination. The livelihoods framework publications focused on honey and other bee products as services and these have provided people with food and material, which they can sell in order to have cash income (Figs. 4, 5). Conversely, the ecosystem cascade framework publications focused on pollen and bees as services, with medicine, pollination, and culture as benefits (Figs. 4, 5).

The majority of the publications also identified bees as central to the way of life of the people or communities involved in the studies. This assessment was based on the interaction of bees with humans. Human interaction with bees is mostly via bee product harvesting and beekeeping. Bee product harvesting mostly occurred in Africa (42%) and Asia (42%) and, to a certain extent, in Latin America (13%) and Australia (3%). Beekeeping was mostly

Table 2 Results of Pearson χ^2 and Fischer's exact tests for services from wild honey bees

Framework	Key	Honey	Pollen	Bees	Products	Total
Ecosystem cascade	Frequency	13	2	5	3	23
	Expected frequency	13.0	1.1	2.7	6.1	23.0
	χ^2 contribution	0.0	0.6	2.0	1.6	4.2
	Row percentage	56.52	8.70	21.74	13.04	100.00
Livelihoods	Frequency	21	1	2	13	37
	Expected frequency	21.0	Eco 1.9	4.3	9.9.	37.0
	χ^2 contribution	0.0	0.4	1.2	1.0	2.6
	Row percentage	56.76	2.70	5.41	35.14	100.00
Total	Frequency	34	3	7	16	60
	Expected frequency	34.0	3.0	7.0	16.0	60
	χ^2 contribution	0.0	1.0	3.2	2.6	6.9
	Row percentage	56.67	5.00	11.67	26.67	100.00

Pearson $\chi^2(3) = 6.8581$ $Pr = 0.077$

Fisher's exact = 0.067

Table 3 Results of Pearson χ^2 and Fischer's exact tests for benefits from wild honey bees

Framework	Key	Food	Medicine	Material	Pollination	Culture	Total
Ecosystem cascade	Frequency	4	10	4	6	2	26
	Expected frequency	4.0	5.8	11.7	3.1	1.3	26.0
	χ^2 contribution	0.0	3.0	5.0	2.6	0.3	10.9
	Row percentage	15.38	38.46	15.38	23.08	7.69	100.00
Livelihoods	Frequency	5	3	22	1	1	32
	Expected frequency	5.0	7.2	14.3	3.9	1.7	32.0
	χ^2 contribution	0.0	2.4	4.1	2.1	0.3	8.9
	Row percentage	15.63	9.38	68.75	3.13	3.13	100.00
Total	Frequency	9	13	26	7	3	58
	Expected frequency	9.0	13.0	26.0	7.0	3.0	58.0
	χ^2 contribution	0.0	5.4	9.1	4.7	0.6	19.8
	Row percentage	15.52	22.41	44.83	12.07	5.17	100.00

Pearson $\chi^2(4) = 19.8383$ $Pr = 0.001$

Fisher's exact = 0.000

identified in the studies conducted in Africa, Asia, and Latin America. In addition, two studies in the Mediterranean and the United States also focused on beekeeping. A few publications also identify bee product use, bee hunting, and honey trading as types of human interaction with bees (Fig. 6). Bee product use and bee hunting were both identified in studies conducted in India and in Argentina and Brazil, respectively.

Sources of changes to the bee–human interaction

Drivers of change to wild bee–human interaction in the publications were also identified and these were mostly

socio-cultural (36%) and environmental (32%) in nature. Governance systems (24%) also drive changes to wild bee–human interaction, while economic activities (8%) have minimal influence. These drivers of change have geographical trends. Most of the socio-cultural drivers are prevalent in developing countries in Africa and Latin America. The environmental drivers of change are predominantly found in developing countries in Africa and Asia. Governance systems drive changes solely in Asia-Pacific. Some of the drivers of change also have clear association with either the livelihoods or ecosystem cascade frameworks. The governance systems and economic drivers of change are all associated with the livelihoods

Fig. 4 Comparison of wild bee services identified in publications that used either an ecosystem cascade (pink) or livelihoods (green) framework. Publications that used a livelihoods framework identified honey and bee products as the main services that wild bees provide. Publications that used an ecosystem cascade framework identified pollen and the bees themselves as main services

framework. The socio-cultural and environmental drivers of change, on the other hand, are associated on equal terms with both livelihoods and ecosystem cascade frameworks.

DISCUSSION

Our results show that research is framing the role of wild bees in SES as essential not only from an ecological point of view but also from a social point of view. Wild bees play a central role in social contexts in most regions of the world (Table 4). Whether it is through bee product harvesting or beekeeping or honey trading, humans greatly benefit from interacting with wild bees especially on the level of livelihoods. This interaction, however, drives changes in the wild bee–human system. Most of the changes are driven by socio-environmental causes, which are quite apparent in Africa and Asia. In the following subsections, we discuss our results in detail and suggest how an ecosystem services perspective can support efforts for wild bee conservation.

Geographical trends of research involving wild bees and humans

Our results show that wild bee research in social contexts was mostly conducted in the regions of Africa, Asia, and Latin America. This is almost consistent with the biogeographic distribution of bees, with most taxa found in Latin America, followed by Africa and Asia (Michener 2007). For us, this trend also shows that direct interaction with wild bees is still prevalent in communities in Africa and Asia and, to a certain extent, in Latin America. It is, therefore, not surprising that most of the drivers of change to wild bee–human systems are mostly found in Africa, Asia, and Latin America. Some of our findings on the drivers of change have much in common with the synthesis by Brown and Paxton (2009), Potts et al. (2010), and González-Varo et al. (2013) of the factors affecting bees and animal pollinators, albeit differing on the level of importance. For example, Brown and Paxton (2009) and Potts et al. (2010) found that habitat loss, fragmentation, and degradation have a strong effect on bee or pollinator decline worldwide while in our findings, these only come second to socio-cultural drivers. A socio-ecological approach enabled us to see how socio-cultural processes drive ecological changes by taking into consideration biophysical interactions between societies and ecosystems (Gingrich et al. 2016).

All of the reviewed publications showed wild bees in a positive light, i.e. they bring services and benefits to humans. On the contrary, most of the changes to the wild bee–human systems were caused by human activities (Vanbergen and IPI 2013). High-quality habitats with increased plant diversity enhance wild bee communities not just in rural but also urban areas (Le Féon et al. 2010; Banaszak-Cibicka and Żmihorski 2012; Kennedy et al. 2013). If wild bee habitat loss continues to be induced by human activity, then an apparent imbalance between what wild bees provide and what humans give in return occurs.

Wild bees provide multiple ecosystem services

Analysing the publications through the lens of the livelihoods and ecosystem cascade frameworks yielded a holistic picture of the interactions between humans and wild bees. Wild bees provide a broad spectrum of ecosystem services that range from provisioning to regulating to cultural. Provisioning ecosystem services were the focus of majority of the publications reviewed, especially those that used a livelihoods framework but regulating ecosystem services were also often cited, especially in publications that used the ecosystem cascade framework. This is consistent with the Millennium Ecosystem Assessment (MEA 2005) report showing a strong linkage

Fig. 5 Comparison of benefits derived from wild bee services identified in publications that used either an ecosystem cascade (pink) or livelihoods (green) framework. Material and food benefits are mostly identified in publications that used a livelihoods framework. Medicine, pollination, and cultural benefits dominate in publications that used an ecosystem cascade framework

Fig. 6 Wild bees in social contexts. Humans interact directly with bees during bee product harvest, beekeeping, or bee hunting. Indirectly, bees become involved in social contexts when their products are used or traded

between provisioning as well as regulating ecosystem services and human well-being in the form of health and basic material for good life as well as security. Cultural ecosystem services may only have a medium linkage to

constituents of well-being in the MEA (2005) but they were also mentioned in some of the reviewed publications.

The livelihood and ecosystem cascade frameworks associate with different ecosystem services, but both are similar in addressing the needs of people (Scoones 1998; Haines-Young and Potschin 2010). As our results show, the difference lies on the services and benefits identified in the ecosystem cascade framework publications not having mainstream market value, unlike those of the livelihoods framework publications. Cash income and employment play important roles in allowing ecosystem services to contribute to poverty alleviation, which is needed in the developing countries associated with the publications using the livelihoods framework (Daw et al. 2011). Despite identifying mostly nonmarket services, ecosystem cascade framework publications were conducted in countries belonging to the 20 major economies in the world. It is in the best interest of these G-20 countries to include non-market services in policy decisions in order for their societies to stay within the economically optimal point for human welfare; this would require incentivising or investing in the provision of nonmarket ecosystem services (Fischer et al. 2008).

Table 4 Summary of results from coding analysis of publications

Region	Dominant role of bees in social context 1: Central, 2: marginal	Dominant framework 1: Livelihood, 2: ecosystem cascade	Type of wild bee–human interaction 1: bee product harvesting, 2: beekeeping, 3: honey trading, 4: bee hunting, 5: bee product use	Dominant drivers of change 1: Socio-environmental, 2: socio-cultural, 3: governance
Africa	1	1	1, 2, (3)	1, 2
Asia	1	1	1, 2, (4), (5)	1, 3
Australia	1	1	2	(3)
Europe	^a	1	(2)	^a
Latin America	1	2	1, 2, (4), (5)	2
Middle East	2	2	(3)	^a
North America	^a	2	(2)	(2)

(): minor extent

^a no data

Beyond provisioning ecosystem services

Recognising multiple ecosystem services from wild bees to humans may prove useful in engaging actors with different interests and goals to contribute to wild bee conservation efforts (Milcu et al. 2013). However, most of the reviewed publications only focused on provisioning ecosystem services of wild bees. In ecosystem management, if only one ecosystem service is focused on, considerable declines in the provision of other ecosystem services may occur (Bennett et al. 2009). One of the reviewed publications (de Carvalho et al. 2014) showed how a focus on provisioning ecosystem services led to the decline of cultural ecosystem services. Trade-offs often occur between provisioning ecosystem services and regulating or cultural ecosystem services (Meacham et al. 2016).

Trade-offs also occur between different ecosystem services and between the present and future supply of services especially when managing ecosystems for multiple ecosystem services and balancing the well-being of different stakeholders (Carpenter et al. 2006; Daw et al. 2015). An example in Southeast Nigeria shows how outright felling of trees could provide honey (Okoye and Agwu 2008). However, prioritising this provisioning ecosystem service may lead to declines in biodiversity, water purification, and climate regulation if a forest is cleared (Carpenter et al. 2006).

There is much room for recognition of other ecosystem services such as cultural or regulating ecosystem services. Carpenter et al. (2006) point out that in trade-off decisions, people often prefer to prioritise provisioning ecosystem services over cultural and regulating ecosystem services. Daniel et al. (2012) highlight the importance of cultural ecosystem services and their potential to motivate and mobilise public support for the protection of ecosystems.

Carpenter et al. (2006) additionally mention that by paying attention to regulating ecosystem services, impact of extreme events can be moderated. For wild bees, increased attention to their cultural and regulating ecosystem services may further promote their conservation, especially with the reported declines over the past years (Biesmeijer et al. 2006; Cameron et al. 2011).

Wild bees in social contexts as a socio-ecological system

The drivers of change in wild bees–human systems show that resource management and sustainability problems are usually system problems where social and ecological systems are almost impossible to consider as separate entities (Berkes and Folke 2002; Rissman and Gillon 2016). While humans depend on bees for ecosystem services, the bees also depend on humans for survival since most of the drivers of change in wild bees–human systems are mediated by anthropogenic activities. This apparent interdependence between bees and humans show that the wild bees–human system is an SES, which is characterised by connectedness, context, and feedback (von Bertalanffy 1968 as quoted in Berkes et al. 2003; Keune et al. 2014).

In order to find ways of implementing sustainable practices, an understanding of what really drives the dynamics of societies in response to the ecosystems they depend on is needed (Scheffer et al. 2002). Most drivers of change caused by anthropogenic activities cause wild bees to be marginalised within the SES. Callo-Concha et al. (2014) discussed marginality (sic) in SES; however, it mostly focused on how social marginalisation occurs due to ecological variables or ecosystem settings such as degraded soils inhibiting the well-being of people. We suggest that human-induced marginalisation may also happen to ecosystems and its components.

In this review, human-induced marginalisation of wild bees is not just a product of overexploitation of wild bees and their hive products, but also of disregard for them and the conditions they thrive in. Marginalisation of wild bees may, therefore, be a product of human activity on the one hand and lack of human action on the other hand.

CONCLUSION

Our review establishes the current state of knowledge on wild bee–human interaction. We have chanced upon gaps in both research and praxis and we deem it important to address these. References to systems of governance (regulations or institutions) for wild bee–human systems are lacking in the publications we have reviewed. The International Pollinators Initiative (IPI), formally established in 2002 by the Convention of Biological Diversity, mostly focuses on bee interaction with agricultural landscapes and on one ecosystem service (regulating) in Africa, North America, and Oceania. Asia and Latin America, where most drivers of change also occur, should also be included in the IPI. Commitment is needed from governments and society to support the development of a stronger collaboration among researchers, policy makers, practitioners, and citizen stakeholders in order to advance sustainability (Fischer et al. 2015). In the field of research, our results show that wild bee publications in social contexts are still mostly confined within the fields of ecology or anthropology. Interdisciplinary and transdisciplinary approaches are still needed to make studies integrative and to promote co-production of knowledge with stakeholders. If studies are to help the wild bee–human system, the drivers of change especially in developing countries should be addressed in a manner that minimises trade-offs between ecosystem services and maintains or improves well-being.

Acknowledgments We thank Andrea Alberti, Guido Lüchters, and Heike Zimmermann for their assistance in data analysis and two anonymous reviewers for their constructive comments. Denise Margaret S. Matias is grateful to the German Academic Exchange Service (DAAD) for financial support.

REFERENCES

- Allsopp, M.H., W.J. de Lange, and R. Veldtman. 2008. Valuing insect pollination services with cost of replacement. *PLoS ONE* 3: e3128. doi:[10.1371/journal.pone.0003128](https://doi.org/10.1371/journal.pone.0003128).
- Andersson, E., S. Barthel, and K. Ahrné. 2007. Measuring social–ecological dynamics behind the generation of ecosystem services. *Ecological Applications* 17: 1267–1278.
- Banaszak-Cibicka, W., and M. Żmihorski. 2012. Wild bees along an urban gradient: Winners and losers. *Journal of Insect Conservation* 16: 331–343. doi:[10.1007/s10841-011-9419-2](https://doi.org/10.1007/s10841-011-9419-2).
- Bennett, E.M., G.D. Peterson, and L.J. Gordon. 2009. Understanding relationships among multiple ecosystem services. *Ecology Letters* 12: 1394–1404. doi:[10.1111/j.1461-0248.2009.01387.x](https://doi.org/10.1111/j.1461-0248.2009.01387.x).
- Berkes, F., and C. Folke. 2002. Back to the future: Ecosystem dynamics and local knowledge. In *Panarchy: Understanding transformations in human and natural systems*, ed. L.H. Gunderson, and C.S. Holling, 121–146. Washington, DC: Island Press.
- Berkes, F., J. Colding, and C. Folke. 2003. Introduction. In *Navigating social–ecological systems: Building resilience for complexity*, ed. F. Berkes, J. Colding, and C. Folke, 1–30. Cambridge: Cambridge University Press.
- Biesmeijer, J.C., S.P.M. Roberts, M. Reemer, R. Ohlemüller, M. Edwards, T. Peeters, A.P. Schaffers, S.G. Potts, et al. 2006. Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313: 351–354. doi:[10.1126/science.1127863](https://doi.org/10.1126/science.1127863).
- Bodin, O., and M. Tengö. 2012. Disentangling intangible social–ecological systems. *Global Environmental Change* 22: 430–439. doi:[10.1016/j.gloenvcha.2012.01.005](https://doi.org/10.1016/j.gloenvcha.2012.01.005).
- Boyd, E., and C. Folke. 2012. Conclusions: Adapting institutions and resilience. In *Adapting institutions: Governance, complexity and social–ecological resilience*, ed. E. Boyd, and C. Folke, 264–280. Cambridge: Cambridge University Press.
- Brown, M.J.F., and R.J. Paxton. 2009. The conservation of bees: A global perspective. *Apidologie* 40: 410–416. doi:[10.1051/apido/2009019](https://doi.org/10.1051/apido/2009019).
- Callo-Concha, D., J.H. Sommer, J. Kleemann, F.W. Gatzweiler, and M. Denich. 2014. Marginality from a socio-ecological perspective. In *Marginality: addressing the nexus of poverty, exclusion and ecology*, ed. J. von Braun, and F.W. Gatzweiler, 56–65. Dordrecht: Springer. doi:[10.1007/978-94-007-7061-4](https://doi.org/10.1007/978-94-007-7061-4).
- Cameron, S.A., J.D. Lozier, J.P. Strange, J.B. Koch, N. Cordes, L.F. Solter, and T.L. Griswold. 2011. Patterns of widespread decline in North American bumble bees. *Proceedings of the National Academy of Sciences of the United States of America* 108: 662–667. doi:[10.1073/pnas.1014743108](https://doi.org/10.1073/pnas.1014743108).
- Carpenter, S.R., E.M. Bennett, and G.D. Peterson. 2006. Scenarios for ecosystem services: An overview. *Ecology and Society* 11: 29.
- Daniel, T.C., A. Muhar, A. Arnberger, O. Aznar, J.W. Boyd, K.M.A. Chan, R. Costanza, T. Elmqvist, et al. 2012. Contributions of cultural services to the ecosystem services agenda. *Proceedings of the National Academy of Sciences of the United States of America* 109: 8812–8819. doi:[10.1073/pnas.1114773109](https://doi.org/10.1073/pnas.1114773109).
- Daw, T.M., K. Brown, S. Rosendo, and R. Pomeroy. 2011. Applying the ecosystem services concept to poverty alleviation: The need to disaggregate human well-being. *Environmental Conservation* 38: 370–379. doi:[10.1017/S0376892911000506](https://doi.org/10.1017/S0376892911000506).
- Daw, T.M., S. Coulthard, W.W.L. Cheung, K. Brown, C. Abunge, D. Galafassi, G.D. Peterson, T.R. McClanahan, et al. 2015. Evaluating taboo trade-offs in ecosystems services and human well-being. *Proceedings of the National Academy of Sciences of the United States of America* 112: 6949–6954. doi:[10.1073/pnas.1414900112](https://doi.org/10.1073/pnas.1414900112).
- de Carvalho, R.M.A., C.F. Martins, and J. da Silva Mourão. 2014. Meliponiculture in Quilombola communities of Ipiranga and Gurugi, Paraíba state, Brazil: An ethnoecological approach. *Journal of Ethnobiology and Ethnomedicine* 10: 1–12. doi:[10.1186/1746-4269-10-3](https://doi.org/10.1186/1746-4269-10-3).
- Fischer, B., K. Turner, M. Zylstra, R. Brouwer, R. de Groot, S. Farber, P. Ferraro, R. Green, et al. 2008. Ecosystem services and economic theory: Integration for policy-relevant research. *Ecological Applications* 18: 2050–2067.
- Fischer, J., T.A. Gardner, E.M. Bennett, P. Balvanera, R. Biggs, S. Carpenter, T. Daw, C. Folke, et al. 2015. Advancing sustainability through mainstreaming a social–ecological systems

- perspective. *Current Opinion on Environmental Sustainability* 14: 149. doi:[10.1016/j.cosust.2015.06.002](https://doi.org/10.1016/j.cosust.2015.06.002).
- Garibaldi, L.A., I. Steffan-Dewenter, R. Winfree, M.A. Aizen, R. Bommarco, S.A. Cunningham, C. Kremen, L.G. Carvalheiro, et al. 2013. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Science* 339: 1608–1611. doi:[10.1126/science.1230200](https://doi.org/10.1126/science.1230200).
- Gingrich, S., M. Schmid, T. Dirnböck, I. Dullinger, R. Garstenauer, V. Gaube, H. Haberl, M. Kainz, et al. 2016. Long-term socio-ecological research in practice: Lessons from inter- and trans-disciplinary research in the Austrian Eisenwurzen. *Sustainability* 8: 743. doi:[10.3390/su8080743](https://doi.org/10.3390/su8080743).
- González-Varo, J.P., J.C. Biesmeijer, R. Bommarco, S.G. Potts, O. Schweiger, H.G. Smith, I. Steffan-Dewenter, H. Szentgyörgyi, M. Woyciechowski, and M. Vilà. 2013. Combined effects of global change pressures on animal-mediated pollination. *Trends in Ecology & Evolution* 28: 524–530. doi:[10.1016/j.tree.2013.05.008](https://doi.org/10.1016/j.tree.2013.05.008).
- Goulson, D., G.C. Lye, and B. Darvill. 2008. Decline and conservation of bumble bees. *Annual Review of Entomology* 53: 191–208. doi:[10.1146/annurev.ento.53.103106.093454](https://doi.org/10.1146/annurev.ento.53.103106.093454).
- Haines-Young, R., and M. Potschin. 2010. The links between biodiversity, ecosystem services and human well-being. In *Ecosystem ecology: A new synthesis*, ed. D.G. Raffaelli, and C.L.J. Frid, 110–139. Cambridge: Cambridge University Press and British Ecological Society.
- Jaffé, R., V. Dietmann, M.H. Allsopp, C. Costa, R.M. Crewe, R. Dall'olio, P.D.E. LA Rúa, M.A. El-Niweiri, et al. 2009. Estimating the density of honeybee colonies across their natural range to fill the gap in pollinator decline censuses. *Conservation Biology* 24: 583–593. doi:[10.1111/j.1523-1739.2009.01331.x](https://doi.org/10.1111/j.1523-1739.2009.01331.x).
- Kennedy, C.M., E. Lonsdorf, M.C. Neel, N.M. Williams, T.H. Ricketts, R. Winfree, R. Bommarco, C. Brittain, et al. 2013. A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. *Ecology Letters* 16: 584–599. doi:[10.1111/ele.12082](https://doi.org/10.1111/ele.12082).
- Keune, H., N. Dendoncker, and S. Jacobs. 2014. Ecosystem service practices. In *Ecosystem services: Global issues, local practices*, ed. S. Jacobs, N. Dendoncker, and H. Keune, 91–95. Amsterdam: Elsevier.
- Kremen, C., N.M. Williams, M.A. Aizen, B. Gemmill-Herren, G. LeBuhn, R. Minckley, L. Packer, S.G. Potts, et al. 2007. Pollination and other ecosystem services produced by mobile organisms: A conceptual framework for the effects of land-use change. *Ecology Letters* 10: 299–314. doi:[10.1111/j.1461-0248.2007.01018.x](https://doi.org/10.1111/j.1461-0248.2007.01018.x).
- Le Conte, Y., and M. Navajas. 2008. Climate change: Impact on honey bee populations and diseases. *Revue Scientifique Et Technique (International Office of Epizootics)* 27: 499–510.
- Le Féon, V., A. Schermann-Legionnet, Y. Delettre, S. Aviron, R. Billeter, R. Bugter, F. Hendrickx, and F. Burel. 2010. Intensification of agriculture, landscape composition and wild bee communities: A large scale study in four European countries. *Agriculture, Ecosystems & Environment* 137: 143–150. doi:[10.1016/j.agee.2010.01.015](https://doi.org/10.1016/j.agee.2010.01.015).
- Matheson, A., S.L. Buchmann, C. O'Toole, P. Westrich, and I.H. Williams. 1996. *The conservation of bees*. London: Academic Press.
- Meacham, M., C. Queiroz, A.V. Norström, and G.D. Peterson. 2016. Social-ecological drivers of multiple ecosystem services: What variables explain patterns of ecosystem services across the Norrström drainage basin? *Ecology and Society* 21: 14. doi:[10.5751/ES-08077-210114](https://doi.org/10.5751/ES-08077-210114).
- Michener, C. 2007. *The bees of the world*. Baltimore, MD: The Johns Hopkins University Press.
- Milcu, I.A., J. Hanspach, D. Abson, and J. Fischer. 2013. Cultural ecosystem services: A literature review and prospects for future research. *Ecology and Society* 18: 44. doi:[10.5751/ES-05790-180344](https://doi.org/10.5751/ES-05790-180344).
- Millennium Ecosystem Assessment (MEA). 2005. *Ecosystems and human well-being: Synthesis*. Washington, DC: Island Press.
- Morse, R.A. and N.W. Calderone. 2000. The value of honey bees as pollinators of U.S. Crops in 2000. *Bee Culture* 128: 15 pp insert.
- Newig, J. and O. Fritsch. 2009. The case survey method and applications in political science—meeting paper. American Political Science Association, Toronto, Canada. Retrieved June 27, 2016 from <http://ssrn.com/abstract=1451643>.
- Okoye, C.U., and A.U. Agwu. 2008. Factors affecting agroforestry sustainability in bee endemic parts of Southeastern Nigeria. *Journal of Sustainable Forestry* 26: 132–154. doi:[10.1080/10549810701879685](https://doi.org/10.1080/10549810701879685).
- Oldroyd, B.P., and P. Nanork. 2009. Conservation of Asian honey bees. *Apidologie* 40: 296–312. doi:[10.1051/apido/2009021](https://doi.org/10.1051/apido/2009021).
- Patiny, S., D. Michez, and P. Rasmont. 2009. A survey and review of the status of wild bees in the West-Palaearctic region. *Apidologie* 40: 313–331.
- Potts, S.G., J.C. Biesmeijer, C. Kremen, P. Neumann, O. Schweiger, and W.E. Kunin. 2010. Global pollinator declines: Trends, impacts and drivers. *Trends in Ecology & Evolution* 25: 345–353. doi:[10.1016/j.tree.2010.01.007](https://doi.org/10.1016/j.tree.2010.01.007).
- Queiroz, C., M. Meacham, K. Richter, A.V. Norström, E. Andersson, J. Norberg, and G. Peterson. 2015. Mapping bundles of ecosystem services reveals distinct types of multifunctionality within a Swedish landscape. *Ambio* 44: 89–101. doi:[10.1007/s13280-014-0601-0](https://doi.org/10.1007/s13280-014-0601-0).
- Rader, R., I. Bartomeus, L. Garibaldi, M.P.D. Garratt, B.G. Howlett, R. Winfree, S.A. Cunningham, M.M. Mayfield, et al. 2016. Non-bee insects are important contributors to global crop pollination. *Proceedings of the National Academy of Sciences of the United States of America* 113: 146–151. doi:[10.1073/pnas.1517092112](https://doi.org/10.1073/pnas.1517092112).
- Reyers, B., R. Biggs, G.S. Cumming, T. Elmqvist, A.P. Hejnovicz, and S. Polasky. 2013. Getting the measure of ecosystem services: A social-ecological approach. *Frontiers in Ecology and the Environment* 11: 268–273.
- Rissman, A.R., and S. Gillon. 2016. Where are ecology and biodiversity in social-ecological systems research? A review of research methods and applied recommendations. *Conservation Letters*. doi:[10.1111/conl.12250](https://doi.org/10.1111/conl.12250).
- Roubik, D.W. 1995. Pollination of cultivated plants in the tropics. FAO Agricultural Services Bulletin No. 118. Rome: FAO.
- Scheffer, M., F. Westley, W.A. Brock, and M. Holmgren. 2002. Dynamic interactions of societies and ecosystems: Linking theories from ecology, economy, and sociology. In *Panarchy: Understanding transformations in human and natural systems*, ed. L.H. Gunderson, and C.S. Holling, 195–239. Washington, DC: Island Press.
- Scoones, I. 1998. Sustainable rural livelihoods: A framework for analysis. Working Paper 72. Institute of Development Studies, Brighton, United Kingdom.
- Southwick, E.E., and L. Southwick Jr. 1992. Estimating the economic value of honey bees (Hymenoptera: Apidae) as agricultural pollinators in the United States. *Journal of Economic Entomology* 85: 621–633. doi:[10.1093/jee/85.3.621](https://doi.org/10.1093/jee/85.3.621).
- Spangenberg, J.H. 2014. Ecosystem services in a societal context. In *Ecosystem services: Global issues, local practices*, ed. S. Jacobs, N. Dendoncker, and H. Keune, 91–95. Amsterdam: Elsevier.
- Vanbergen, J., and The Insect Pollinators Initiative (IPI). 2013. Threats to an ecosystem service: Pressures on pollinators. *Frontiers in Ecology and the Environment* 11: 251–259. doi:[10.1890/120126](https://doi.org/10.1890/120126).

- von Bertalanffy, L. 1968. *General system theory: Foundations, development, applications*. New York: George Braziller Inc.
- Watson, K., and J.A. Stallins. 2016. Honey bees and colony collapse disorder: A pluralistic reframing. *Geography Compass* 10: 222–236. doi:[10.1111/gec3.12266](https://doi.org/10.1111/gec3.12266).
- Westley, F., S. Carpenter, W.A. Brock, C.S. Holling, and L.H. Gunderson. 2002. Why systems of people and nature are not just social and ecological systems. In *Panarchy: Understanding transformations in human and natural systems*, ed. L.H. Gunderson, and C.S. Holling, 121–146. Washington, D.C.: Island Press.
- Winfree, R. 2010. The conservation and restoration of wild bees. *Annals of the New York Academy of Sciences* 1195: 169–197. doi:[10.1111/j.1749-6632.2010.05449](https://doi.org/10.1111/j.1749-6632.2010.05449).

AUTHOR BIOGRAPHIES

Denise Margaret S. Matias (✉) is a Junior Researcher at the Center for Development Research (Zentrum für Entwicklungsforschung) in Bonn, Germany. Her research interests are indigenous community forests, karst conservation, and climate change and development issues.

Address: Department of Ecology and Natural Resources Management, Center for Development Research, University of Bonn, Walter-Flex-Str. 3, 53113 Bonn, Germany.
e-mail: denise.matias@uni-bonn.de

Julia Leventon is a Junior Professor in sustainable development at the Faculty of Sustainability of Leuphana University in Lüneburg, Germany. She has particular interest in multi-level sustainability governance from community management to multi-national development policies and programmes.

Address: Faculty of Sustainability, Institute of Ethics and

Transdisciplinary Sustainability Research, Leuphana University, Scharnhorstr. 1, 21335 Lüneburg, Germany.
e-mail: leventon@leuphana.de

Anna-Lena Rau is a Doctoral Student at the Leuphana University in Lüneburg, Germany. Her research interests include patterns of ecosystem services in agriculture.

Address: Faculty of Sustainability, Center for Methods, Leuphana University, Scharnhorstr. 1, 21335 Lüneburg, Germany.
e-mail: annrau@leuphana.de

Christian Borgemeister is a Professor and Director of the Department of Ecology and Natural Resources Management at the Center for Development Research (Zentrum für Entwicklungsforschung) in Bonn, Germany. His research interests are biological control and integrated pest management in the tropics and vector control of infectious diseases.

Address: Department of Ecology and Natural Resources Management, Center for Development Research, University of Bonn, Walter-Flex-Str. 3, 53113 Bonn, Germany.
e-mail: cb@uni-bonn.de

Henrik von Wehrden is a Professor of quantitative methods in sustainability science at the Faculty of Sustainability and Center of Methods of Leuphana University in Lüneburg, Germany. His research interests include community ecology, biodiversity, conservation biology, and combining different fields through quantitative methods.

Address: Faculty of Sustainability, Center for Methods, Institute of Ecology, Leuphana University, Scharnhorstr. 1, 21335 Lüneburg, Germany.

e-mail: henrik.von_wehrden@leuphana.de