

INVITED VIEWS IN BASIC AND APPLIED ECOLOGY

Cross-disciplinary approaches for better research: The case of birds and bats



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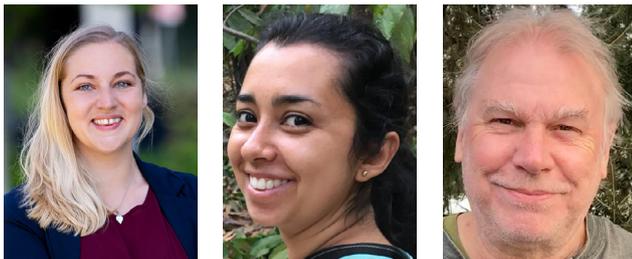
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Abstract

Across a wide range of disciplines, mounting evidence points to solutions for addressing the global biodiversity and climate crisis through sustainable land use development. Managing ecosystem services offers promising potential of combining environmental, economic, and social interests in this process. Achieving sustainability, however, requires collaboration across disciplines, or in short “cross-disciplinary” approaches. Multi-, inter- and transdisciplinary approaches are often used as synonyms, although they are defined by different levels of integrating results and perspectives. We highlight challenges and opportunities related to these cross-disciplinary approaches by using research on bird- and bat-mediated ecosystem services as a case - with a focus on sustainable agricultural development. Examples from transdisciplinary collaborations show how more integrative and inclusive approaches promote the implementation of basic and applied ecological research into land use practices. Realizing this opportunity requires strong partnerships between science, practice and policy, as well as integration of diverse skills and perspectives. If appropriately funded and guided, this effort is rewarded by improved data quality, more targeted concepts, as well as improvement implementation and impact of sustainability research and practice. We outline a stepwise approach for developing these processes and highlight case studies from bird and bat research to inspire cross-disciplinary approaches within and beyond ecology.

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Introduction

Ecosystem services are closely linked to human well-being, yet they are under acute threat. The 2005 Millennium Ecosystem Assessment found that 60 percent of the world's valued ecosystem services are either degraded or in decline (MA, 2005). The loss of biological predation and pollination services can cause dramatic increases of pest densities and impair at least a third of the global human food supply due to environmental degradation (Tschamtkke et al., 2012; Zhang, Ricketts, Kremen, Carney & Swinton, 2007). Sustainable land use transformations are needed to counteract this trend and achieve goals of combining agriculture, food production and biodiversity conservation (Aznar-Sánchez, Piquer-Rodríguez, Velasco-Muñoz & Manzano-Agugliaro, 2019). However, these cross-disciplinary goals are subject to diverse and sometimes conflicting interests that must be reconciled across different disciplines and perspectives shaping sustainable land use development. The 2030 Agenda for Sustainable Development seeks to address these social-ecological challenges by integrating social, economic, and environmental dimensions (UN, 2015).

Multi-, inter- and transdisciplinary research approaches are often used as synonyms although they describe different degrees of integrating results and perspectives across disciplines (Table 1; Evely et al., 2010). Collectively, these types of collaboration across different disciplines are referred to as

cross-disciplinary approaches. Their value to overcome the “mismatch between the ecological knowledge generated by researchers and that applied by practitioners” (Hulme et al., 2014) is increasingly recognized in the broad field of ecology, spanning disciplines such as ecosystem, evolution and conservation science. Research from these disciplines creates knowledge for sustainable development, but implementation of disciplinary knowledge into sustainable land use practices can only be achieved through its integration across different disciplines, perspectives and interests (Reyers & Selig, 2020; Schneider et al., 2019). However, research-based concepts to optimize sustainability are not put into action as often as they could be because many opportunities for uniting diverse interests across multiple disciplines have yet to be explored (Maas, Toomey & Loyola, 2019a; Toomey, Knight & Barlow, 2017).

In this article, we exemplify cross-disciplinary approaches by using the case of research on bird- and bat-mediated ecosystem services that are linked to sustainable agriculture and human well-being (Fig. 1). We highlight the mismatch between extensive scientific evidence on the contribution of birds and bats to ecosystem services, and their limited application to practice in conservation and agriculture (Donázar et al., 2016; Zhang et al., 2007).

Despite demonstrated direct links between bird- and bat-mediated ecosystem services and human well-being (e.g., Mahendiran & Azeez, 2018; Methorst et al., 2021), research

Table 1. Definitions of multiple disciplinary approaches. Take home messages for each approach are highlighted in bold.

Approach	Short definition
Disciplinary	Staying within a recognized and/or traditional research discipline without involving other disciplines or knowledge-assets in defining research agendas. <ul style="list-style-type: none"> • Answering specific research questions within one discipline.
Multidisciplinary	Drawing on knowledge and perspectives from different disciplines, but staying within traditional disciplinary boundaries. Theoretical perspectives and findings of other disciplines are compared but not integrated. <ul style="list-style-type: none"> • Comparing results to other disciplines without integrating them.
Interdisciplinary	Synthesizing and harmonizing links between disciplines into a coordinated and coherent theory, concept and/or method, crossing subject boundaries. <ul style="list-style-type: none"> • Creating results that integrate different research disciplines.
Transdisciplinary	Combining interdisciplinary research with a participatory approach by integrating academic and non-academic perspectives, transcending traditional disciplinary boundaries of a respective field. <ul style="list-style-type: none"> • Creating results that integrate academic and non-academic perspectives.
Cross-Disciplinary	Overarching term for multi- inter- and trans-disciplinary approaches outlined above, following definitions from Evely et al., 2010.

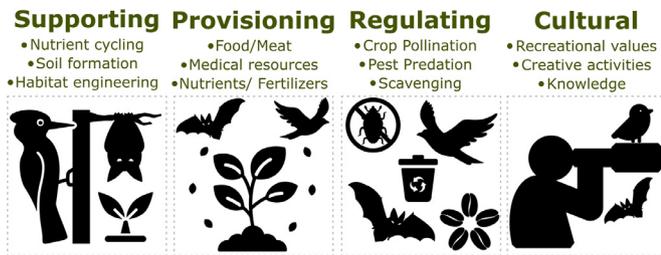


Fig. 1. Examples of bird- and bat-mediated ecosystem services linked to human well-being. All services present opportunities for the development of more sustainable agricultural management. Three examples were chosen per ecosystem service category, using information from the following reviews: Donázár et al., 2016; Fujita, Kameda, Şekercioğlu, Wenny & Whelan, 2016; Kunz et al., 2011; Maas et al., 2016; Whelan et al., 2008, 2015; Taylor et al., 2018; Gaston et al., 2018; Mahendiran et al., 2018; Balzan et al., 2020; Barbaro et al., 2019; Michel et al., 2020.

and communication gaps among disciplines of ecology, economics, and society limit sustainable land use practices (Balzan, Sadula & Scalvenzi, 2020). We argue that trans-disciplinary approaches in particular, hold much promise to enhance the integration and implementation of basic and applied ecological research into land use management approaches that are more inclusive and sustainable. Using cases from bird and bat research, we highlight untapped potentials in ecosystem service management (Díaz et al., 2018) and examples of cross-disciplinary approaches that illustrate their associated challenges and opportunities. In particular, our perspective highlights how integrated and inclusive communication and collaboration promote the implementation of ecological research and sustainable development.

Diverse perspectives and interests

Global challenges such as the climate and biodiversity crisis must be addressed across diverse sectors and perspectives (Maron et al., 2017; Pe'er et al., 2020; Toomey et al., 2017), but knowing-doing gaps impair the implementation of research into practice (Hulme et al., 2014; Kleijn et al., 2019; Maas et al., 2019a). For example, scientific publications and presentations are not accessible to many relevant stakeholder groups in practice and policy, inhibiting the incorporation of research results in decision-making processes (Fabian et al., 2019). While science communication can take many forms, from unilateral to inclusive, co-production of knowledge and participatory approaches such as citizen science require integrative collaboration between academics and non-academics (Wyborn et al., 2019; Norström et al., 2020; Saunders et al., 2021). Co-production of knowledge thereby goes beyond its communication by also addressing its creation, integration and implementation across diverse perspectives and interests (Wyborn et al., 2019). Linking common goals of diverse stakeholders is

both a key challenge and an opportunity to integrate and implement multiple knowledge assets into more inclusive and sustainable development of our society and environment. The chosen cross-disciplinary approach matters for the results.

Current examples from bird and bat research from land use systems emphasize the urgent need to improve communication and collaboration between science, practice, and policy to optimize implementation of global sustainability goals in agricultural research and practice (Balzan et al., 2020; Brescancin, Dobšinská, De Meo, Šálka & Paletto, 2018; Kross, Ingram, Long & Niles, 2018; Penvern et al., 2019). Specifically, this involves not only better informing farmers and policymakers, but also adapting research designs to enable more effective cooperation between different interest groups. For example, farmers from eight European countries revealed that they consider multiple wildlife species and services, country-specific farming practices, and their own interests and needs, when weighing whether to incorporate techniques that promote biodiversity (Penvern et al., 2019). Recent research from the US shows similarly that farmer perceptions of the benefits and costs associated with farmland biodiversity and wildlife-friendly practices differ depending upon used crop types and cultivation methods (Kross et al., 2018; Lindell, 2020). Addressing these relevant user interests in research requires trans-disciplinary approaches that integrate expertise and perspectives from other disciplines.

While the boundaries between different cross-disciplinary approaches are not sharp, trans-disciplinary, integrative and inclusive approaches show the greatest potential to promote the translation of scientific evidence into practice (Maas et al., 2018, 2021b). For example, stakeholder surveys on protected area management in Europe confirmed that effectively implementing bird and bat conservation plans requires inclusive communication and participation strategies, as well as continued engagement (Brescancin et al., 2018; Frick, Kingston & Flanders, 2019; Saunders et al., 2021). Integrating approaches from other disciplines such as social sciences into ecological research, enables the study and evaluation of different perspectives on biodiversity conservation and sustainability, with increased opportunities to strengthen collaborations across different fields and interests (Balzan et al., 2020; Maas, Fabian, Kross & Richter, 2021a).

Cross-disciplinary research

Examples of bird and bat research in an agricultural context show that proven concepts for promoting biodiversity and ecosystem services (e.g., nesting boxes and roosts) are not put into practice based on ecological research results alone (Lindell, 2020; Russo, Bosso & Ancillotto, 2018; Seibold, Cadotte, MacIvor, Thorn & Müller, 2018). While not all problems or questions need a cross-disciplinary



Fig. 2. Examples for multiple benefits resulting from cross-disciplinary research. Benefits are shown at individual, internal and external level of respective projects. Transparent circles represent examples of how individual components of a cross-disciplinary project can have varying degrees of anchoring in and overlap between these levels [adapted from Mallaband et al., 2017].

approach and science should not be limited to means of implementation, more comprehensive concepts invite numerous opportunities to increase the quality and impact of research focused on sustainable agricultural development and biodiversity conservation (Evely et al., 2010; Schneider et al., 2019). Considering the views of different disciplines and stakeholders enriches the design, quality, and scope of ecological research at different levels (Fig. 2). For example, integrating social science methods and results, including surveys or interviews that shed light on demographic and ethnographic perspectives, enhance the targeted identification of project partners and research questions (Penvern et al., 2019; Kross et al., 2017; Brescancin et al., 2018). Incorporating diverse knowledge assets from other disciplines promotes the quality and completeness of ecological data, for example when local and landscape data from agricultural experts or economic data are included (Maas et al., 2019b; Tschamtko et al., 2016). Emerging innovative technologies and statistical models stimulate new developments and opportunities in the collection and analysis of complex or big data filling knowledge gaps. For example, the integration of sound and camera technology, DNA barcoding, or software applications promote the development of cross-disciplinary and complex databases (Russo et al., 2018; Seibold et al., 2018). Moreover, promoting more inclusive scientific communities strengthens the relevance, impact and implementation of participatory research, science communication and trans-disciplinary outreach activities (Maas et al., 2018, 2021b).

While these opportunities bring different benefits to research and sustainable development, limitations must be considered. The main challenges of cross-disciplinary research approaches are associated with the complexity of translating research outputs to societal impact (Holzer et al., 2019; Maas et al., 2019a), and advancing academic training while simultaneously navigating discipline-oriented research and scholar evaluation (Maas et al., 2021b; MacFarlane & Rocha 2020; Saunders et al., 2021). Applying principles of inclusiveness and cross-disciplinary approaches throughout entire research projects is key to “responsible research and innovation” and is increasingly demanded by research funders (Holzer et al., 2019; Owen, Macnaghten & Stilgoe, 2012). Attaining these goals without overburdening individual partners from different disciplines requires overarching strategies that link long-term planning and funding (Holzer et al., 2019). The COVID-19 pandemic provides powerful examples both of the close interrelationship between science and society, and how significant but also fragile diverse and inclusive research and communication is in the face of complex challenges (Maas et al., 2020a; MacFarlane & Rocha 2020). Scientific fields such as ecology and conservation science were challenged by widespread interruption or loss of their work and simultaneous high and sometimes undifferentiated media attention (Corlett et al., 2020; MacFarlane & Rocha 2020). In times of complex challenges, the importance of diverse, inclusive, and cross-disciplinary approaches is particularly evident. Addressing global environmental issues requires diverse skills and

perspectives that make science more productive, innovative and impactful (Maas et al., 2020a). Effective conservation communication requires not only biological but also psychological expertise, for example to debunk misinformation about bats (MacFarlane & Rocha 2020) or facilitate bird conservation on farms (Saunders et al., 2021). Such inclusive communication and participation strategies require continued engagement to effectively implement conservation and management objectives across disciplines (Brescancin et al., 2018; Mallaband et al., 2017).

Stepwise approaches

Overcoming the barriers and limitations of cross-disciplinary research requires strong partnerships, targeted funding and guidance by experts from various fields to design action-oriented strategies, guidelines and frameworks for collaboration and implementation (MacFarlane & Rocha, 2020; Maron et al., 2017; Saunders et al., 2021). We suggest a stepwise preparation strategy to develop and implement cross-disciplinary projects. This approach should be integrated before the project starts and implemented throughout its course.

The first step should identify relevant disciplines, perspectives, and specific partners for the project, considering examples from related cross-disciplinary research (Holzer et al., 2019). Next, approaches to cross-disciplinary collaboration should be reviewed and adapted based on available concepts, guidelines, and interests from different disciplines relevant to the project goals (Maas et al., 2019a). Third, these steps should be used to align and agree on common goals and attainable expectations against which implementation of the project's success can be measured and evaluated (Maas et al., 2019a; Mallaband et al., 2017). While this process can take place within the framework of available funding, opportunities for additional support can and should also be identified or demanded by the project's partners (Holzer et al., 2019; Seibold et al., 2018; Garcia et al., 2020). These requirements highlight the many challenges and opportunities of cross-disciplinary research, and the need for targeted funding of specialists who guide and support the processes behind it (Saunders et al., 2021). Last but not least, science, society and politics are jointly called upon to advance the quality and scope of cross-disciplinary research through targeted support (Maas et al., 2020a).

The case of bird and bats

Birds and bats serve as an excellent model for sustainable land use development because of their relevant contributions to ecological and economic resilience of agroecosystems (Maas et al., 2016, 2019b; Williams-Guillén, Olimpi, Maas, Taylor & Arlettaz, 2016). For example, predatory species

play a key role for multitrophic interactions in complex food webs of different ecosystems, and provide economically important pest suppression services in a variety of crops and agroforestry systems (e.g., Barbaro et al., 2019; Maas et al., 2016; Maas, Clough, & Tschardtke, 2013). Through their high functional diversity and mobility, they contribute to provisioning, supporting, regulating, and cultural ecosystem services along large spatial scales (Fig. 1), demonstrating the importance of landscape-level perspectives for sustainability (Kunz, De Torre, Bauer, Lobova & Fleming, 2011; Whelan, Şekerciöglü & Wenny, 2015, 2008). As mobile links, they connect resources within and between ecosystems and contribute to their resilience against disturbances (Lundberg & Moberg, 2003). Further, birds and bats serve as valuable ecological indicators because they are fairly easy to identify and detect, and contain specialized species that are sensitive to landscape change in all terrestrial habitat types (Whelan et al., 2015; Williams-Guillén et al., 2016).

Experimental research on birds and bats provides powerful examples of the value of ecosystem services, as well as the mutual interdependence of ecosystems to sustain them. For example, results from exclusion experiments from cocoa agroforestry systems in Indonesia show that birds and bats support an average of one-third of the yield and that their services are enhanced by the proximity of natural habitats (Maas, Clough, & Tschardtke, 2013; Maas, Tschardtke, Saleh, Putra & Clough, 2015). Global reviews have shown that this potential of biological pest control is of economic relevance across all biogeographic realms (Fig. 3) and in a wide variety of ecosystems, from natural forests to different agroforestry systems such as cacao, coffee, mixed fruit, apple, citrus or olive orchards (Maas et al., 2016; Martínez-Sastre, García, Miñarro & Martín-López, 2020; Penvern et al., 2019; Russo et al., 2018).

However, although birds are among the best-studied groups of organisms worldwide, they continue to decline despite their demonstrated importance for ecosystem services, with insectivorous and specialized species in agricultural landscapes being particularly affected (Bowler, Heldbjerg, Fox, de Jong & Böhning-Gaese, 2019; Şekerciöglü et al., 2019). Bats provide similar or even superior contributions to ecosystem services in agriculture that are often underrepresented in research and underestimated in practice (Maas, Clough, & Tschardtke, 2013, 2016; Russo et al., 2018). Scientists provide many recommendations how to promote biodiversity and ecosystem services while ensuring food-security goals through local management and connectivity landscapes. Unfortunately, such measures often do not make it into agricultural practice and management (Kleijn et al., 2019; Penvern et al., 2019). This discrepancy between good disciplinary understanding and poor implementation of bird- and bat-mediated ecosystem services raises important questions and highlights many opportunities for sustainable development.

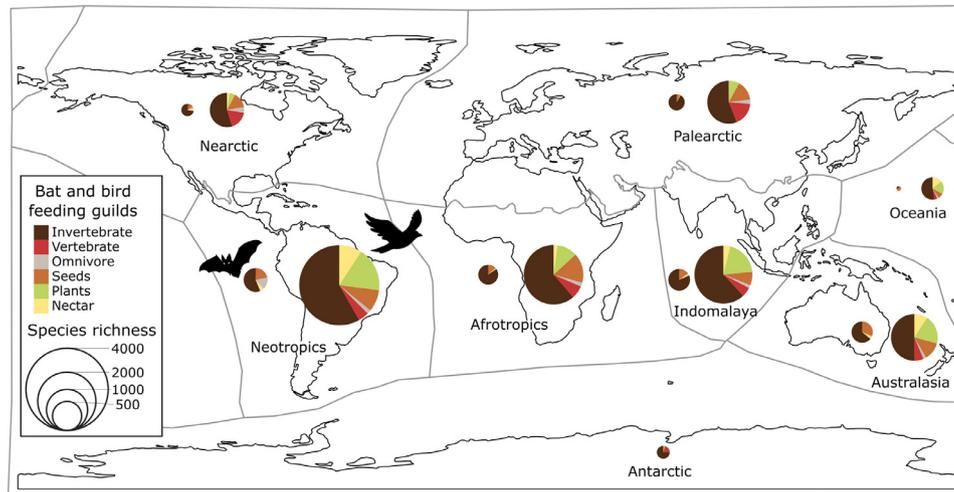


Fig. 3. Global distribution of feeding guilds of birds and bats. Pie charts presenting birds (right) and bats (left) are proportional to species richness in each biome, highlighting the global potential to manage pest suppression services provided by insectivorous species [adapted from Maas et al., 2016].

Lessons learned from birds and bats

Case studies from bird and bat research highlight both success stories and pitfalls of cross-disciplinary research. Research projects that have successfully implemented bird and bat conservation measures in different regions of the world draw similar conclusions:

- (1) Close cooperation with local farmers and consideration of their interests and reservations is essential for the development of effective measures (Balzan et al., 2020; Maas et al., 2018). For example, a study of bat ecosystem services and farmer perceptions in Costa Rica identified that the probability of bat hunting increased with decreasing knowledge about the animal's life history and experience with common vampire bat attacks on cattle (Reid, 2013). The results pointed to the relevance of conservation measures that provide farmers with information and tools to distinguish strategies to control pest species without harming beneficial bat species. Similarly, the successful implementation of a seven-year research project on pest control services and multitrophic interactions mediated by birds and bats in Indonesia was facilitated by close collaboration and communication with local cacao farmers and stakeholders (Maas et al., 2014). Monthly workshops were integrated into the project five months before the start of ecological field work and continued four years after the field work, resulting in a close collaboration between scientists and farmers throughout the project (Maas et al., 2018).
- (2) Practices should be designed in ways that allow clear communication, and feasible implementation and maintenance to ensure long-term success (Lindell, 2020). The successes of the transdisciplinary project of Maas et al. (2014), including the design and increase of more biodiversity-friendly farming practices in the study area even beyond the project, were only possible through inclusive and integrative communication (pers. comm., Maas). Similarly, such transdisciplinary approaches facilitated the successful implementation of conservation measures for the endangered partridge populations in Germany (Gottschalk & Beeke, 2014).
- (3) Implementation success of bird and bat conservation and management actions is facilitated by a focus on easily identifiable and abundant species (Maas et al., 2015; García et al., 2020). For example, relating insect control with the most common bird species in cacao agroforests from

Sulawesi (Maas et al., 2015) and apple orchards from Spain (García, Miñarro and Martínez-Sastre, 2021) enabled the identification of simple techniques, like the deployment of nest boxes, to enhance provision of pest control services. However, the success of these management strategies cannot be guaranteed and must be evaluated under local ecological conditions. For instance, providing roosting sites to induce seed dispersal by common frugivorous bats successfully accelerated the presence of early-successional plant species in northern Costa Rica (Kelm, Wiesner & HELVERSEN, 2008) but had no significant effects on forest succession in the south of the same country (Reid, 2013).

Further, links between ecosystem services and human well-being offer various opportunities to translate ecological functions and processes to economic or societal values (Díaz et al., 2018). For example, quantifying the value of ecosystem services to crop yields (e.g. Classen et al., 2014; Maas, Clough, & Tscharntke, 2013, 2016, 2019b; Tremlett, Moore, Chapman, Zamora-Gutierrez & Peh, 2020), human health (Gaston et al., 2018) and other facets of human well-being (Methorst et al., 2021), may enhance the impact of ecological research. Protecting common species is easy to implement and can provide a positive umbrella effect for the conservation of other species and associated ecosystem functions (Frick et al., 2019; Johnson, Ober & Adams, 2017). Participatory and creative research design additionally helps to communicate complex approaches and facilitate the engagement of non-academic stakeholders, which in turn promotes cross-disciplinary networks and the implementation of long-term projects and visions (Crewe et al., 2020; Rai et al., 2021).

Finding solutions to complex conservation challenges demands a trans-disciplinary approach. The catastrophic population declines of Old World vultures in Asia and Africa (Buechley & Şekerciöglu 2016; Ogada, Keesing & Virani, 2012) provide an exemplary illustration. Dramatic declines of vultures and associated scavenging services

(Donázar et al., 2016) across South Asia could only be understood and effectively counteracted through trans-disciplinary research and collaboration between international NGOs, academic institutions, and government agencies (Ogada et al., 2012). Similar efforts are needed to protect vultures in Africa, from threats such as ivory poaching, bushmeat consumption, and energy infrastructure (Ogada et al., 2012; Sanz-Aguilar et al., 2015). These threats span a diverse range of issues such as cultural traditions, economics, conservation, and veterinary practices. Halting and reversing the negative population trends of vultures around the world will require concerted cross-disciplinary research and coordinated actions that are of international scope (Sanz-Aguilar et al., 2015).

Pitfalls of trans-disciplinary research are primarily linked to the effort in preparing and setting-up studies and experiments that require or suggest collaboration with local stakeholders. Lack of collaboration with local and regional stakeholders may limit the alignment and coordination of implementation strategies, as well as resulting benefits on different project levels (Fig. 2). Drawing on the experience from previous research can help to optimize field experiments (Maas et al., 2019b), conservation measures (Frick et al., 2019), and cross-disciplinary collaborations (Maas et al., 2018). These examples from bird and bat research are transferable to many other fields in and outside of ecology (Evely et al., 2010).

Conclusions

Sustainable land-use transformations can be achieved only by fostering strong partnerships and collaborations across environmental, economic and societal disciplines and perspectives (Reyers & Selig, 2020; Schneider et al., 2019). The case of bird and bat research emerging from disciplinary and cross-disciplinary approaches demonstrates challenges and opportunities related to increasing socio-ecological standards in science and practice (Maas et al., 2020b).

Implementing scientific evidence in conservation and management actions requires integrative and inclusive collaboration between science and practice. This holds many opportunities for ecological research, especially if the increased effort is appropriately supported, guided by experts and implemented through stepwise approaches that allow regular evaluation (e.g., Balzan et al., 2020; Holzer et al., 2019; Maas et al., 2021a; Saunders et al., 2021).

The biodiversity and climate crisis, together with related environmental issues of our time such as the continuous degradation of ecosystem services, are truly international in scope (Bongaarts, 2019; Maron et al., 2017; Powers & Jetz, 2019), and require diverse perspectives and leadership to be solved (Maas et al., 2019a, 2021b). To address these complex challenges and optimize use of related

opportunities, we need to promote not only cross-disciplinary research, but also diversity and inclusion in science and society. This applies to basic and applied ecology, as well as to many intertwined areas and dimensions of sustainable land use development. While not every project needs to take this approach, and disciplinary research must also maintain its value and quality, any move toward cross-disciplinary approaches will be associated with benefits for sustainable development at individual, internal and external levels of science, policy and society (Evely et al., 2010.; Schneider et al., 2019). Attaining this potential requires courageous action of decision-makers and stakeholders across these levels to develop and implement overarching strategies that foster increased quality and impact of science at large spatial and temporal scales.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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