Land sharing versus land sparing—What outcomes are compared between which land uses?

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Abstract
Land sharing versus land sparing describes contrasting strategies to conserve biodiversity while maintaining agricultural production. We comprehensively reviewed empirical studies comparing land-sharing and land-sparing strategies to assess how these were conceptualized and how consequences for biodiversity, commodity production, and additional ecosystem services have been quantified. Out of 52 studies, a majority conceptualized land sharing as environmental-friendly agriculture or low-yielding agriculture, and land sparing as high-yielding agriculture combined with preserved natural habitats. However, the latter also represented land sharing in several studies, resulting in an overlap in how land sharing and land sparing were conceptualized. Studies focuses on a limited number of taxonomic groups, primarily birds, whereas ecosystem services (mainly carbon storage) and economic outcomes were rarely considered. To facilitate comparisons and on-the-ground implementation, we suggest to recognize the multitude of land-use combinations along a continuum from extreme land sharing to extreme land sparing. This includes being explicit about both the spatial scales of preserved habitats and the features in land sharing or intermediate strategies that are assumed to benefit biodiversity and hamper commodity production. We also suggest that taxonomic groups, ecosystem services, and welfare consequences should be analyzed based on conservation needs and impacts on social-ecological systems.

KEYWORDS
agriculture, biodiversity conservation, ecosystem services, forestry, land sharing, land sparing, land-use strategy, policy, wildlife-friendly farming

1 | INTRODUCTION

Land sharing versus land sparing has been one of the most debated concepts in conservation sciences the last decades (Fischer et al., 2014). Originally, land sharing and land sparing were introduced by Green, Cornell, Scharlemann, and Balmford (2005) as alternative land-use strategies to reconcile biodiversity conservation with agricultural production. They defined land sparing as a strategy where increased yields on farmland reduces the need of converting natural habitats to meet production targets, resulting in landscapes with high-yielding farmland and freed up natural habitats. They defined wildlife-friendly farming (later renamed as “land sharing”...
reached the same set agricultural production targets. Various studies have since used empirical data to compare the relative benefits of land sharing and sparing for biodiversity and commodity production, mainly considering trade-offs with agricultural production (e.g., Chandler et al., 2013; Dotta, Phalan, Silva, Green, & Balmford, 2016; Egan Franklin & Mortensen, 2012; Gilroy, Edwards, Uribe, Haugaasen, & Edwards, 2014), and to a lesser extent forestry production (i.e., harvest of timber; e.g., Edwards et al., 2014; Yoshii, Yamaura, Soga, Shibuya, & Nakamura, 2015).

It has been argued that contrasting land sharing against land sparing is too simplistic to guide real-world conservation decisions in a general sense (Fischer et al., 2017). A clear distinction between realized land-sharing and land-sparing strategies is complicated because none of the land-use strategies are tied to particular spatial scales and both can be represented by commodity production combined with preserved natural habitats. This may result in that a combination of agricultural production and similar-sized patches of natural habitats become labeled as either land sharing or sparing in different studies (Fischer et al., 2014), which could complicate their generic use and comparison of results across studies. However, to what extent land sharing and sparing have been represented by similar land uses has not been quantified, and thus the extent to which on-the-ground comparisons of the two strategies overlap is not known.

It has been debated how to best quantify the outcomes from land sharing and sparing to increase our understanding for how biodiversity, commodity production, and potentially other ecosystem services are affected (Grass et al., 2019; Kremen, 2015; Law & Wilson, 2015; Phalan, Balmford, Green, & Scharlemann, 2011; Tscharntke et al., 2012; von Wehrden et al., 2014). This includes which biodiversity proxies to use to convey the value of habitats for species. The most straightforward way to measure community-wide effects of land-use strategies is to compare species richness or the number of species that are most abundant under each of the strategies (which may vary depending on the production target). While species richness has the advantage of showing how many species each strategy supports, it is usually measured at a plot rather than landscape scale and does therefore not account for how environmental heterogeneity affects landscape-scale variance in species communities (Grau, Kuemmerle, & Macchi, 2013; von Wehrden et al., 2014). Therefore, differences in plot-scale species richness between land-use strategies may not reflect how they compare in species richness at the landscape scale, as there are likely differences in environmental heterogeneities and thus species turnover between plots. In addition, species richness may not reflect how land-use strategies affect species’ viability. Abundances, on the other hand, convey information about how land-use strategies affect species’ fitness and persistence, but effects need to be summarized over species to value the virtue of alternative strategies (Phalan, Balmford, et al., 2011).

In addition to using different proxies for biodiversity, studies also differ in what and how many taxonomic groups they have used to inform these proxies. Land-use strategies can affect taxonomic groups differently depending on how species respond to habitat loss and fragmentation, and to which extent they rely on processes such as meta-population dynamics, mass-effects, and landscape complementation (Smith et al., 2014). Because conclusions based on a single taxonomic group may not necessarily lend themselves to broader generalizations (Wolters, Bengtsson, & Zaitsev, 2006) it is important to study different taxonomic groups, and particularly species of conservation concern, to increase the ability to predict relative effects of land sharing and sparing on biodiversity (Ekroos et al., 2016; von Wehrden et al., 2014).

Beyond the choice of biodiversity indicators, it has been argued that the original focus on biodiversity–yield relationships is too narrow for real-world conservation decisions (e.g., Bennett, 2017; Grau et al., 2013), because agricultural landscapes are multifunctional (van Huylenbroeck, Vandermeulen, Mettepenningen, & Verspecht, 2007). While commodity production in the original framework was measured as yield (Green et al., 2005), it has been suggested to use units that are more comparable across crops, such as calories (Phalan, Balmford, et al., 2011), or economic values, such as farmers’ net income, which reflect how different strategies affect farmers and welfare (Salles, Teillard, Tichit, & Zanella, 2017). In addition, the value of landscapes with commodity production may not be simply expressed as the economic value of the produce. Therefore, it has been argued that studies evaluating relative benefits of land sharing versus land sparing should more broadly consider effects on ecosystem services and their consequences for welfare, non-monetary values, and sustainable commodity production (Bennett, 2017; Grass et al., 2019; Kremen & Miles, 2012; Tscharntke et al., 2012). The value of some ecosystem services can in principle be captured by estimates of yield, such as the impact of pollination on agricultural production. However, explicitly considering these services can increase the understanding for how the outcomes of land sharing and
sparing are dependent on contexts such as if crops are animal pollinated or not, and will therefore contribute to the general understanding of how biodiversity may benefit commodity production via ecosystem service feedbacks (see Ricketts et al., 2016). For instance, land-sharing strategies that integrate conservation with agricultural production will likely generate higher values in a context where insect pollination and biological control by natural enemies have a large impact on yield (Grass et al., 2019; Power, 2010). Other ecosystem services do not affect yield but need to be accounted for to estimate the value of alternative strategies for welfare. It is particularly important to consider ecosystem services that are expected to vary considerably between different land-use strategies, such as carbon storage, since they may alter the relative merits of land sharing and sparing (Grass et al., 2019).

In this study, we compiled and evaluated the literature on how empirical studies that explicitly compare land sharing and land sparing have represented these strategies with specific land uses, as well as how they have quantified biodiversity, commodity production, and other ecosystem services. We summarize how land sharing and land sparing have been conceptualized and show potential overlaps in definitions which can complicate distinction between the two strategies when making comparisons across studies, as well as highlight research gaps in terms of what taxonomic groups, production outcomes and ecosystem services have been studied. To this end we compiled data on (a) how empirical studies have reported that land has been used for biodiversity conservation and commodity production in land-sharing and land-sparing strategies and (b) which conservation and production outcomes these studies considered, including how studies quantified biodiversity, commodity production, and to which extent other ecosystem services were assessed.

2 METHODS

2.1 Article selection

We compiled and analyzed the empirical literature on land sharing versus land sparing, focusing on how studies that explicitly have compared land-use strategies defined as land sharing and land sparing have conceptualized these in terms of land uses involving nature conservation, commodity production or both. We also extracted information on how biodiversity, commodity production, and other ecosystem services (hereinafter, referred to as ecosystem services) have been measured in the studies. Our review procedure was based on table 1 in Luederitz et al. (2016), outlining specific sequential steps for a systematic literature review (definition of selection criteria, data gathering, data screening and cleaning, data scoping, and full-text review).

To gather the literature on land sharing versus land sparing, we searched for articles using Web of Science Core Collection, Scopus, and other relevant databases that together cover most publishers and journals relevant for the topic (list of databases in Supporting Information S1). The database search was based on titles, abstracts and keywords using a search string that contained land sharing and land sparing, as well as some alternative terms that have been used for the same purpose as land sharing: “wildlife friendly agri*” OR “wildlife friendly farm*” OR “land shar*” OR “land spar*” OR “environment* friendly farm*” OR “environment* friendly agri*” OR “biodiversity friendly farm*” OR “biodiversity friendly agri*.” We particularly deemed it important to include wildlife-friendly farming/agriculture in the search string to capture all relevant literature, because the term was used instead of land sharing in the original framework (Green et al., 2005).

The database search was done on August 11, 2020 and resulted in 1697 unique articles. Since we were only interested in reviewing empirical articles that had compared land-use strategies that they defined as land sharing (or any of the synonyms in the search string) and land sparing, we screened out articles that resulted from the database search but that were not relevant for the review using the following conditions:

(a) The study should have compared at least two land-use strategies that in the article were defined as land sharing (or the synonyms above) and land sparing, respectively, and (b) reported empirical results (based on field, modeled, or remotely sensed data) on how the defined land-sharing and land-sparing strategies compared in terms of biodiversity and/or ecosystem services. For the sake of completeness, and to assess to what extent ecosystem services have been considered, we included studies that measured ecosystem services even if they did not measure biodiversity as proposed in the original framework (Green et al., 2005).

We first read titles, abstracts, and keywords to screen out those articles that did not meet the above conditions. Thus, we excluded (a) articles that did not include the terms land sharing (or its synonyms) or land sparing, (b) articles that were stated or found to not report empirical results (e.g., reviews), and (c) articles that did not specify measures or types of taxonomic groups or ecosystem services. Following this procedure, we identified 152 potentially relevant articles, which were appraised in full text. During the full-text review, we identified another 100 articles that did not meet the above conditions. We finally included 52 articles from which we extracted and analyzed data (Supporting Information S2).
The only synonym used instead of land sharing in the final 52 articles was wildlife-friendly farming/agriculture.

2.2 Data extraction

We assessed how many of the included articles had conceptualized land sharing and sparing as the following land-use strategies:

1. High-yielding commodity production, defined by articles as land managed for producing commodities, such as agricultural crops or timber, combined with preserved natural habitats, defined by articles as natural or semi-natural habitats that were not used for commodity production, typically continuous or patches of forests or grasslands;

2. Environmental-friendly commodity production, defined by articles as agricultural/silvicultural land managed both for producing commodities and benefiting biodiversity/ecosystem services, including for instance organic farming and shaded agroforestry;

3. Low-yielding commodity production, defined by articles as land with a low productivity of commodities because of environmental-friendly commodity production and/or integrated patches of nature conservation (without separating between the two); and

4. Environmental-friendly commodity production combined with preserved natural habitats.

All land-sharing and land-sparing strategies were represented by one of these four conceptualizations. Regarding land-sharing and land-sparing strategies that were represented by high-yielding commodity production combined with preserved natural habitats, we investigated if there was an overlap in how land sharing and sparing had been represented in terms of patch size of the preserved natural habitats. We did this by comparing the reported mean patch size (km²) of the preserved natural habitats in each of these land-sharing and land-sparing strategies. In articles where the conserved nature was reported as continuous, and no mean patch size was given, we noted the patch size as continuous. In other cases, where no mean patch size was given, we noted the patch size as NA. [Correction added on 9 September 2021, after first online publication: The paragraph “All land-sharing and land-sparing strategies...” was removed from bullet list 4 in section 2.2 and set as a separate paragraph.]

Some studies had assessed a land-use strategy that combined features from the compared land-sharing and land-sparing strategies (or a continuum of strategies). We noted how many studies had included such “intermediate strategies.”

We collected information on how biodiversity was quantified, including which biodiversity proxies were used (e.g., abundance or species richness), what taxonomic groups were studied, if threatened species were analyzed separately (either individual species or as a group), and whether studies quantified habitat-specific resources used by focal taxonomic groups. These variables were used to analyze the representation of taxonomic groups in biodiversity data and how studies quantified resource availability to examine how land-use strategies benefit organisms (e.g., by providing food or nesting resources).

Finally, we noted if studies measured commodity production quantity (e.g., by tons or calories), ecosystem services (e.g., carbon storage and pollination), and producers’ net income. We also noted if studies measured how biodiversity affects ecosystem services and how ecosystem services affect commodity production, and if agriculture or forestry was the focal commodity production system of the study.

Based on this material (Supporting Information S2), we compiled a quantitative assessment on how individual studies conceptualized land sharing and sparing and quantified their outcomes.

3 RESULTS

3.1 Conceptualizations of land sharing and land sparing

Each of the 52 reviewed articles had specified and studied a land-sharing strategy and a land-sparing strategy (Table 1), which were each represented by one of the four land-use strategies (1—4) described above. In addition to the strategies presented in Table 1, 14 of the articles defined and studied an intermediate land-use strategy (or a continuum of strategies) that combined features from the land-sharing and land-sparing strategies that were studied in the article.

All studies represented land sparing with high-yielding commodity production combined with preserved natural habitats (Table 1). In contrast, studies represented land sharing in different ways. Most studies represented land sharing by environmental-friendly commodity production (54% of all studies), followed by low-yielding commodity production (25%), high-yielding commodity production combined with preserved natural habitats (17%) and environmental-friendly commodity production combined with preserved natural habitats (4%) (Table 1). In studies representing land sharing with low-yielding commodity production, it was not specified if the lower yield was caused by ex-field (preserved natural habitats) or in-field (environmental-friendly commodity production) effects. Among
the studies that represented both land sharing and sparing with high-yielding commodity production combined with preserved natural habitats (i.e., 17% of all studies), the average patch size of the sampled preserved natural habitats was, if specified, always larger in the land-sparing strategy than in the land-sharing strategy. However, across studies, there was no clear distinction between land sharing and sparing as the average patch size of the sampled preserved nature overlapped between land sharing and sparing (Figure 1). More specifically, the average patch size of the sampled preserved natural habitats ranged between 0.01 km² and 0.44 km² when part of a land-sharing strategy, and between 0.02 km² and 1,000 km² when part of a land-sparing strategy (Figure 1). Additionally, there were 13 studies that reported the preserved nature under land sparing as continuous and 9 studies that did not report any mean patch size of the conserved nature, nor specified it as continuous.

3.2 | Biodiversity, commodity production, and ecosystem services

Out of 52 studies, 45 measured biodiversity outcomes, whereas the remaining seven focused exclusively on ecosystem services. Out of the 45 studies that measured biodiversity, 15 reported results based on data on both species-specific abundances and species richness, 17 based exclusively on species-specific abundances, and 13 based exclusively on species richness. Three studies went beyond recording data on abundance or presence/absence by recording the habitats’ capacity to provide nesting resources for birds (two studies) and food supply to mammals (one study). There were 15 studies that separately analyzed species that were classified as threatened. Birds were the most studied taxonomic group, followed by plants, arthropods, and mammals (Figure 2). Most studies considered one taxonomic group (75%), while 18% considered two taxonomic groups, and less than 7% considered more than two taxonomic groups.

In three studies, the land-use strategies were set in forestry commodity production systems, whereas the other 49 studies were set in agricultural commodity production systems. Most studies (69%) measured quantity of produced commodities, whereas the remaining studies compared how land uses that they defined as land sharing and sparing affected biodiversity and/or ecosystem services, without quantifying commodity production (Figure 3). Of the 12 studies that measured ecosystem services apart from

| TABLE 1  Number of different land-use strategies representing land sharing and land sparing |
|---------------------------------------------------------------|
| Land-use strategies                                           | Land-sharing strategies | Land-sparing strategies |
| High-yielding commodity production combined with preserved natural habitats | 9 | 52 |
| Environmental-friendly commodity production                  | 28 | 0 |
| Low-yielding commodity production                             | 13 | 0 |
| Environmental-friendly commodity production combined with preserved natural habitats | 2 | 0 |

**FIGURE 1** Average patch size of sampled conserved nature when combined with conventional commodity production as part of land-sharing (n = 9) or land-sparing (n = 52) strategies

**FIGURE 2** Number of articles that studied different taxonomic groups (n = 45)
yield (Figure 3), four also measured biodiversity and the quantity of commodities produced, whereas one only measured biodiversity and five only measured quantity of commodities produced. Ecosystem services were only included in studies that were set in agricultural commodity production systems and not in those that focused on forestry commodities. Carbon storage was the most studied ecosystem service (included in nine studies), whereas biological pest control, disease regulation, water regulation, erosion control, and cultural values were each analyzed in one study. Only one study related yields to an underlying ecosystem service and analyzed the relationship between that ecosystem service and biodiversity (effects of biological pest control by birds on agricultural production). Less than a tenth of the studies measured farmers’ net income from commodity production (Figure 3), out of which three measured biodiversity and one ecosystem services.

4 | DISCUSSION

Our review showed that both land sharing and land sparing have been represented as high-yielding commodity production combined with preserved natural habitats, and in many cases with similarly sized patches of conserved nature, creating an overlap between what is defined as land sharing and land sparing across studies. Studies have typically had a narrow taxonomic focus and almost exclusively measured biodiversity and commodity production (or assumed differences in commodity production), but rarely considered net income or ecosystem services. Thus, and as is further discussed below, our current understanding of the possible benefits of land sharing versus land sparing on multifunctional (agricultural) systems is still limited.

4.1 | Conceptualizations of land sharing and land sparing

It has previously been discussed that it is not always clear how to separate between land sharing and sparing because none of the land-use strategies are tied to specific land uses or spatial scales (Fischer et al., 2014). Our review showed that studies have consistently conceptualized land sparing as high-yielding commodity production combined with preserved natural habitats. Land sharing on the other hand has been conceptualized less consistently, including as environmental-friendly commodity production (e.g., Lentini et al., 2012; Lusiana, van Noordwijk, & Cadisch, 2012), low-yielding commodity production without detailing the mechanism by which this benefits biodiversity (e.g., Hulme et al., 2013; Phalan, Onial, et al., 2011), environmental-friendly commodity production combined with preserved natural habitats (Quinn, Brandle, & Johnson, 2012; Quinn, Oden, & Brandle, 2013) and high-yielding commodity production combined with preserved natural habitats (e.g., Cannon et al., 2019; Edwards, Gilroy, Thomas, Uribe, & Haugaasen, 2015). Notably, in a fairly high fraction of all studies, around 17%, both land sharing and sparing have been represented by high-yielding commodity production combined with preserved natural habitats with overlapping patch size.

Because different conceptualizations of land sharing and sparing may affect biodiversity and other outcomes differently, it is important to account for how they have been conceptualized when drawing conclusions about their implications. As an example, species that are dependent on natural habitats (e.g., for nesting, feeding, and sheltering) may thrive from a land-sharing strategy that consists of a mosaic landscape with natural elements, but not from one that consists of environmental-friendly agriculture in landscapes devoid of natural habitats (Batáry, Matthiesen, & Tscharntke, 2010). Thus, without considering the heterogeneous conceptualizations, evaluations of land-sharing and land-sparing strategies across studies risk becoming biased by different interpretations about what is land sharing and sparing in different contexts. Although earlier research suggests that land sparing is often the most beneficial for overall biodiversity conservation (see Kremen, 2015; Luskin, Lee, Edwards, Gibson, & Potts, 2017; von Wehrden et al., 2014), under the condition that increased production translates into more protected land (Phalan et al., 2016), we argue that broad summaries on such effects may become misleading, because of (a) an overlap between land sharing and sparing (land uses may in many cases not differ between the strategies when comparing across studies), and because...
The outcome of land sharing can depend on the way it is conceptualized (Table 1).

Our review showed that almost a third of all studies evaluated intermediate strategies, that is, land-use strategies that combine features from the studied land-sharing and land-sparing strategies. It has been argued that intermediate strategies may be more beneficial for biodiversity than pure land-sharing or land-sparing strategies (e.g., Finch et al., 2019; Maskell et al., 2013). Because intermediate strategies can include land uses representing both land-sharing and land-sparing strategies, they likely have particularly high biodiversity when land sharing and sparing benefit different species, which is frequently the case (e.g., Butsic & Kuemmerle, 2015; Kamp et al., 2015; Law et al., 2015). However, there are usually more species with the largest population in land-sparing than in intermediate strategies, which is often the criteria for comparing relative merits of land-use strategies (Phalan, 2018). Yet, the objective may not be to maximize population sizes of as many species as possible, but to identify a strategy that results in an optimal compromise that preserves species benefitting from land sharing and sparing, respectively, which can be an intermediate strategy (Butsic & Kuemmerle, 2015). Intermediate strategies may also have a high potential to benefit multiple ecosystem services (Law et al., 2015) that each is best preserved by a pure land-sharing or land-sparing strategy (e.g., Williams, Phalan, Feniuk, Green, & Balmford, 2018), but where an optimal balance between services requires an intermediate strategy (cf. Maskell et al., 2013). Thus, by including an intermediate strategy (or a continuum of strategies) when comparing land sharing and sparing, studies have an increased potential to discover how to achieve an optimal balance between abundance and diversity of preserved species and ecosystem services, while maintaining commodity production (Grass et al., 2019).

What constitutes an intermediate strategy can differ between studies because of varying conceptualizations of land sharing and sparing, and because different elements of land sharing and sparing can be combined in an intermediate strategy. To recognize the multitude of existing land-use combinations that harmonize agricultural production and biodiversity conservation, we suggest that in the spirit of the original model by Green et al. (2005), comparisons should be done along a continuum between what can be regarded as the extremes land sharing and sparing. Thus, rather than being divided into the coarse categories land sharing, sparing, and intermediate strategies, land-use strategies can be recognized for having different degrees of land sharing and sparing, which can reveal more optimal land-use strategies (see Finch et al., 2019). Furthermore, because land sharing, sparing, and intermediate strategies can be conceptualized differently with regard to land uses and spatial scales, being explicit about the land uses that are assumed to benefit biodiversity and hamper production, and the patch sizes of preserved habitats, can better enable practitioners to match the land-use strategies to local conditions (see Jiren, Dorresteijn, Schultner, & Fischer, 2018).

4.2 Biodiversity

We show that studies comparing land sharing and sparing have focused on a few taxonomic groups, whereas different taxonomic groups often correlate poorly with each other (Wolters et al., 2006). In particular, functionally important species occurring in mosaic agricultural landscapes are frequently regulated by multi-habitat processes, including source-sink dynamics and landscape complementation, and these effects will differ depending on the degree of mobility and habitat specificity across and within taxonomic groups (Smith et al., 2014). Since our results showed that studies were biased to certain taxonomic groups, most notably birds, conclusions about the relative merits of land sharing and sparing may not be valid for taxonomic groups that have been less studied. We, therefore, believe that there is still a need to assess a wider range of taxonomic groups, in particular such that are of high conservation concern.

In accordance with what was recommended by Phalan, Balmford, et al. (2011), we show that most studies measured species-specific abundance to assess how land sharing and sparing affect biodiversity, while less than a third of the studies only measured species richness. There are virtues and issues with both approaches. While species richness may seem as the obvious choice as a conservation objective, it suffers from not considering population sizes and is scale dependent (see von Wehrden et al., 2014). Abundance metrics can be informative regarding the viability of populations and thus show which strategies benefit the largest number of species in terms of population sizes, as compared with estimates of species richness (Phalan, Balmford, et al., 2011). However, it is not straightforward to determine what is the conservation objective when considering the abundance of a range of species, since a strategy focusing on benefitting most populations can be detrimental to a minority of populations that may be of conservation concern. In particular, conservation effort may try to benefit species both for their intrinsic and functional value (Mace, Norris, & Fitter, 2012), which may require a mix of different land-use strategies (Ekroos et al., 2016). In terms of conservation benefits, slightly more than a third of the studies explicitly analyzed threatened species that are of conservation
concern, whereas only one study analyzed the contribution of species to ecosystem services.

A different issue with using abundance or species richness is that habitats of poor quality resulting in low survival and reproductive rates may still have large populations due to immigration from other habitats (Pulliam, 1988). This may particularly affect conclusions on habitat-specific effects for more mobile organisms such as birds (Esler, 2000), the most commonly studied taxonomic group in studies on land sharing versus land sparing. Measurements that better capture how habitats contribute to organisms' fitness, such as reproductive success and food availability, are often more difficult and expensive to study. Yet, these understudied aspects have a great potential to increase our understanding of the ecological mechanisms contributing to relative merits of different land-use strategies (see Lentini et al., 2012; Monroe, Chandler, Burger, & Martin, 2016; Quinn et al., 2013).

4.3 Commodity production and ecosystem services

While the land-sharing versus land-sparing framework was originally proposed to reconcile biodiversity and commodity production (Green et al., 2005), our review showed that almost a third of all studies only focused on how biodiversity responded to stated land-sharing and land-sparing strategies, without quantifying commodity production. Thus, a large share of all studies that have defined contrasted land-use strategies as land sharing and sparing do not actually provide information about biodiversity–production relationships in accordance with the original formulation of the land-sharing versus land-sparing concept.

Perhaps more importantly, our review showed that less than 8% of all studies measured the sales value of the produced commodities and associated costs to deduce the net income from the contrasted land-use strategies. As an example, Lusiana et al. (2012) showed that land-use strategies with higher yields do not necessarily generate higher net income, because of higher associated costs. Thus, a land-use strategy that optimizes the trade-off between biodiversity (or ecosystem services) and commodity production may not be optimal for net income. While the land-sharing versus land-sparing literature has focused on commodity quantity, net income may be a better metric to estimate the social value of commodity production as it also accounts for costs and not only benefits (Salles et al., 2017). Furthermore, it is useful to know how land-use strategies affect farmers' net income to evaluate the need for policy instruments, such as subsidies, to encourage farmers to implement assessed land uses in practice.

In addition to commodities and biodiversity, agricultural land use and conserved nature affect the provision of ecosystem services. Accordingly, several studies have previously suggested that studies on land sharing and sparing should account for ecosystem services, such as water purification, aesthetic landscapes and carbon storage, to enable more holistic evaluations of how human welfare is affected (Bennett, 2017; Grass et al., 2019; Kremen & Miles, 2012; Tscharntke et al., 2012). While different land-use strategies likely benefit different ecosystem services (Grass et al., 2019), we showed that carbon storage was the only ecosystem service that had been considered in several studies in a land-sharing versus land-sparing context. We also showed that only four of the studies measuring ecosystem services also measured biodiversity and commodity production. This is particularly concerning because the land-use strategy that is most beneficial for ecosystem services, such as carbon storage and water quality, may not be the one most beneficial for biodiversity (e.g., Maskell et al., 2013; Wade et al., 2010). Therefore, a joint consideration of multiple ecosystem services and biodiversity seems necessary in order to design land-use strategies to harmonize biodiversity, welfare, and policy goals such as climate change mitigation. More studies on how land sharing and sparing affect a wider range of ecosystem services could also be of use to inform policies that target specific ecosystem services and add to existing literature on how different land uses affect ecosystem services (see Ricketts et al., 2016).

Ecosystem services can contribute to commodity production and therefore affect the trade-off between biodiversity and commodity production. While the total impact of ecosystem services on commodity production can be reflected by the quantity or value of the produce, measuring the impact of individual ecosystem services can shed light on how commodity production depends on contexts such as climate or abundance of certain species. In our review, the only study that considered the impact of ecosystem services on commodity production showed that land sharing was preferable to land sparing because birds provided biological control that enabled a high commodity production (Railsback & Johnson, 2014). Thus, ecosystem services could affect context-dependent conclusions of optimal land-sharing versus land-sparing combinations (Ekroos et al., 2014).

Finally, it is important to remember that some species may, depending on context, have a negative impact on commodity production, other ecosystem services, or people directly. As with ecosystem services, such human–wildlife conflicts can impact the relative merits of land...
sharing and sparing, but are rarely considered (Crespin & Simonetti, 2019).

Our results suggest that research on relative benefits of land sharing versus land sparing has not been well integrated with disciplines such as agroecology and rural and agricultural economics. Thus, the limited interdisciplinary integration also limits the feasibility to inform conservation decisions beyond simplified biodiversity–commodity production trade-offs—an argument that has also been made in other contexts regarding farmland biodiversity conservation (Batáry et al., 2020; Kleijn et al., 2019). However, it is important to note that we restricted our review to include studies that explicitly define compared land-use strategies as land sharing and sparing. Other empirical studies that have assessed the trade-offs among commodity production, biodiversity, and ecosystem services, but not explicitly compared land sharing and sparing, may provide valuable insights to inform conservation decisions. Thus, to comprehensively assess the research on the impact of different land-use strategies, there is a need to broaden the scope beyond land sharing and sparing.

5 CONCLUSION

Although land sharing and sparing are generally conceptualized by different and contrasting land uses in empirical studies, our review shows that there is considerable variation in conceptualizations across studies. Importantly, high-yielding commodity production combined with relatively small preserved natural habitats has been considered as both land sharing and sparing. This causes a conceptual overlap that compromises generalizing relative effects of the two land-use strategies across studies. Therefore, when study results are used as reference material for specific policy- and decision-making processes, their conceptualization of land sharing and sparing must be carefully assessed to fit a specific context and ensure that predictions about outcomes are as accurate as possible. For future studies, we suggest that the heterogeneity of analyzed land-use strategies can be better recognized by describing in what way (regarding land uses and spatial scales), and to what degree, they resemble land sharing and sparing, rather than strictly categorizing them as one or the other. This may be particularly important to understand the effectiveness of contrasting conservation interventions in areas where biodiversity is primarily threatened by increasing pressure to convert land to agriculture or increasing land-use intensity (Shackelford, Steward, German, Sait, & Benton, 2015), or by land abandonment (Sutcliffe et al., 2015). In these contexts, we highlight the need for joint evaluations of biodiversity, ecosystem services, and economic values, which are based on conservation needs and the dynamics of the social–ecological systems affecting land-use decisions.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

All authors were involved in conceiving the ideas presented in this article. William Sidemo-Holm collected and analyzed the data. William Sidemo-Holm led the writing with support from Johan Ekroos and Henrik G. Smith.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this article are available in the Supporting Information.

ETHICS STATEMENT

No original data were collected for this article. Institutional ethics review was not required.

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