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Short Communication

Identifying the optimal landscape configuration for landscape multifunctionality

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ABSTRACT

Increased pressure on land resources to provide multiple benefits calls for landscape strategies that optimize the supply of multiple ecosystem services (ES). Previous research into the drivers of landscape multifunctionality have focused on land use composition changes, but the spatial configuration of different land use types also drives ES supply. While the impact of landscape configuration on individual ES is well understood, the net outcome of these influences when considering many ES is not. Here we present the *net-balance spatial interactions hypothesis,* which posits that the strength and direction of local and surrounding landscape influences on the local supply of an individual ES will drive its optimal landscape configuration. Accordingly, the net balance of these influences across multiple prioritized ES will determine the optimal configuration for landscape multifunctionality. Further, ES that share the same optimal configuration strategy form a bundle that can be managed together. Using data from German grasslands we demonstrate that the net-balance spatial interactions hypothesis is applicable to land-use planning scenarios that aim to maximize multiple ES. It allows general rules to be applied when local, detailed ES data is not available, and can help identify the best option to minimize trade-offs in the face of multiple competing land-use objectives.

1. Introduction

Despite the need to manage for landscape-scale ecosystem service multifunctionality (defined here as the co-supply of multiple ecosystem services (ES) relative to their human demand; Manning et al., 2018), identifying multifunctional landscape strategies is often challenging due to trade-offs between the supply of different ES (Bennett et al., 2009; Stürck & Verburg, 2017; Linders et al., 2021; Neyret et al., 2023). These occur because of inherent biophysical constraints between different ES, but also because differing priorities between stakeholders lead to management activities that may favor one service at the expense of others (Vallet et al., 2020; Lavorel et al., 2022). Such trade-offs can result in 'winners', 'losers' and inequities (Neyret et al., 2023), leading to conflicts between stakeholder groups (Vallet et al., 2020). There is thus a need to identify strategies that minimize trade-offs between ES and thus create and foster multifunctional landscapes.

Different land use types deliver different levels of ES, and so the relative abundance of different land use types in a landscape, i.e. landscape composition, is likely to be the main driver of ES supply at the landscape-level (Arroyo-Rodríguez et al., 2020; Neyret et al., 2023). In addition, the supply of ES at any given point in the landscape can be strongly influenced by its surroundings, meaning that both landscape composition and landscape configuration (i.e. how these land use types are arranged in the landscape) matters for multifunctionality (Lamy

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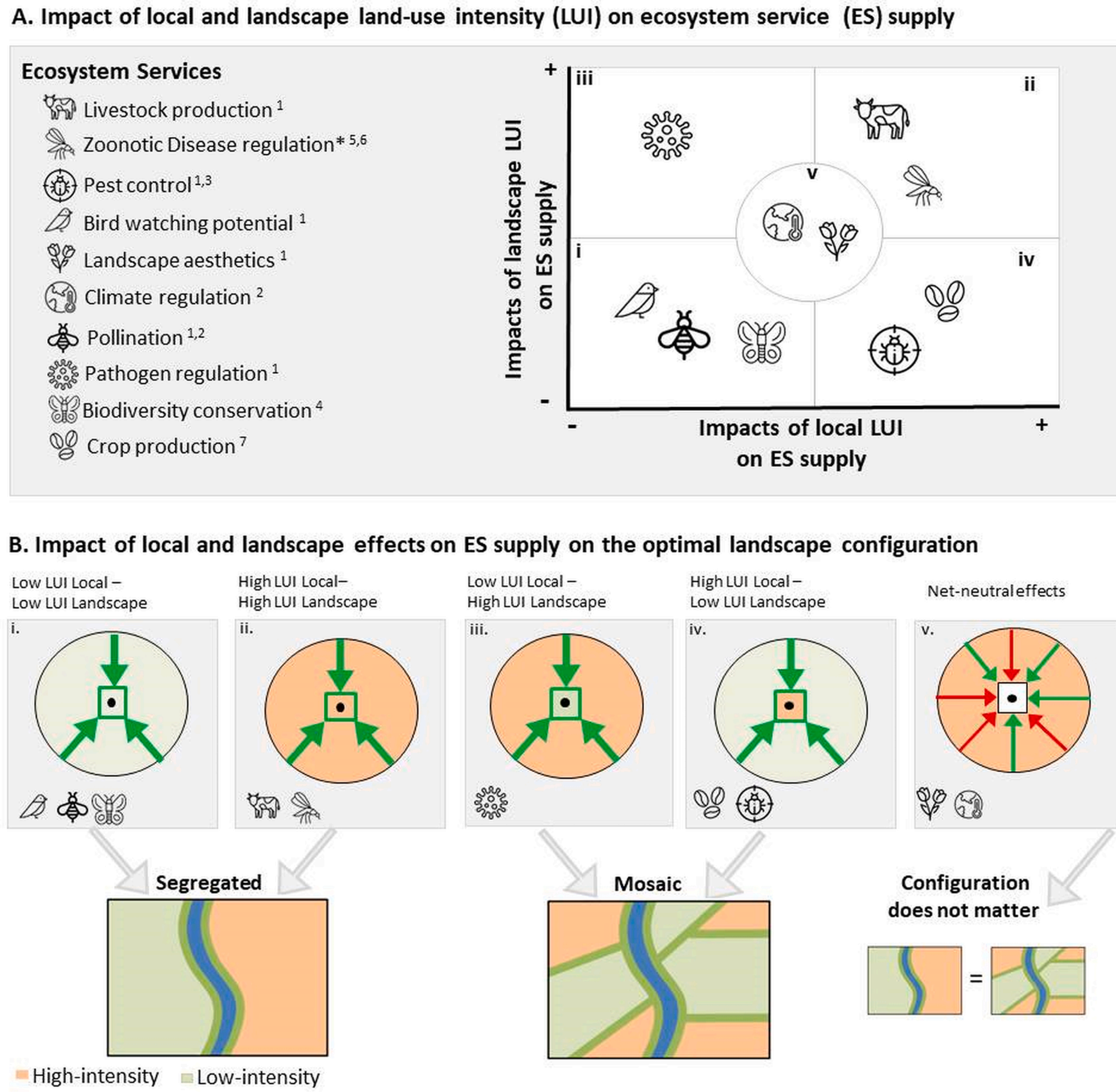

Fig. 1. Hypothesized relationships, showing the impact of high and low land-use intensity at local- and landscape-levels on individual ecosystem service (ES) supply and the optimal configuration of land use types. In A., we present the range of potential responses of individual ES to local- and landscape- land-use intensity, with empirical evidence for each case being presented in the references (noted as reference numbers after the ES). In B., we present the overall effect of landscape properties (positive effects as green arrows, negative as red) and local-level characteristics on plot-level service supply, and how this determines the optimal configuration strategy for these services. References: [1] Le Provost et al. (2023), [2] Kremen et al. (2002), [3] Larsen & Noack (2021), [4] Le Provost et al. (2021), [5] Muylaert et al. (2019), [6] Prist et al. (2022), [7] González-Chaves et al. (2022). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

et al., 2016; Duarte et al., 2018). Surrounding context and spatial interactions between landscape units (hereafter *spatial interactions*) are particularly important for ES whose underlying functions rely on the spatial exchange of matter and organisms, including spillover and dispersal processes (Blitzer et al., 2012). In contrast, spatial interactions might be less important for ES which are driven primarily by sessile organisms and immobile abiotic properties, such as soil carbon storage or biomass production (Le Provost et al., 2023).

Studies investigating the effects of spatial interactions on ES tend to focus on individual ecological properties (Duarte et al., 2018). These studies show that local ES are influenced by different landscape configuration features, have different forms of relationships with these drivers, and that these relationships operate over contrasting ranges of influence (Lamy et al., 2016; Le Provost et al., 2023). For example, flower strips surrounding an agricultural field positively impact pollination and pest control within the crop (Tschumi et al., 2020). However, they have little impact on other ES, such as carbon storage, in adjacent land (Harbo et al., 2023), and can even negatively affect some ES, for example by acting as a reservoir of diseases and pests or a corridor for invasive species spread (Roos et al., 2019; Fischer et al., 2018). If the effects of the surrounding landscape on ES are overall positive, a site may have far higher levels of multiple ES than expected from its local conditions, and vice versa for ES that are negatively affected by surrounding land (Le Provost et al., 2023). This situation is complicated by the fact that many landscape management actions that alter configuration to enhance a specific service (e.g. planting of flower strips along field margins) could have unforeseen impacts on other ES, and multifunctionality. The balance of surrounding landscape influences on multiple ES is, to our knowledge, not quantified in any system and so the net impact of configurational changes on landscape multifunctionality remains unknown.

While studies of configuration effects rarely consider multiple ES, landscape multifunctionality studies typically do not quantitatively incorporate spatial interactions between landscape features (Stürck &

Verburg, 2017; Pinillos et al., 2020; Neyret et al., 2023; Pitman, 2022), but see Mitchell et al., 2015 and Lavorel et al., 2022. The non-spatial nature of previous studies leaves the open question as to where land-use changes should be applied, and in what pattern, if we are to maximize ES-multifunctionality. Thus, to identify management actions that promote landscape multifunctionality, we need to understand how diverse spatial interactions accumulate to drive multiple ES.

Here, we hypothesize that the optimal configuration for achieving landscape multifunctionality can be estimated from the net balance of positive, neutral, and negative impacts of surrounding land use on local 'plot-level' supply of multiple ES. We term this framework *the net-balance spatial interactions hypothesis*. In this hypothesis, the strength and direction of impacts of local and surrounding conditions (i.e. landscape) on local-scale service supply determines the optimal landscape configuration for individual ES. We base our argument on the foundational assumption that ES supply at any given point in the landscape is driven by a combination of local and surrounding conditions.

Local conditions refer to the abiotic, biotic, and management conditions at any given point in a landscape. These factors can have both positive and negative effects on local ES supply, e.g. intensive land use promotes higher grass fodder production, but lowers cultural ES provision (Allan et al., 2015). Surrounding conditions refer to the abiotic, biotic, land use, and management conditions outside of the local patch (plot) and may act at multiple spatial scales. Likewise, these surrounding conditions can have both positive and negative impacts on the ES: for instance, the spillover of pollinators from non-intensive land uses into more intensive ones, or the drift of pollutants from intensively managed land into non-intensive land uses (Blitzer et al., 2012).

The combination of factors operating at different spatial scales (i.e. local and landscape), drives the optimal configuration for each individual ES (Fig. 1A). We present this concept for the case of low vs. high land-use intensity, where intensity is defined broadly as the level of human input to the land, e.g. in terms of energy, labor, and chemical inputs. However, it can be applied and generalized for a wide range of binary ecosystem condition cases e.g., intensive agriculture/human-dominated vs. semi-natural habitats, organic vs. conventional farming, forest vs. grassland.

An ES that is promoted by low land-use intensity at both local and landscape level will be highest in landscapes where land uses are spatially segregated, with large contiguous units specializing in this ES. An example of this is biodiversity related ES in European grasslands. Biodiversity is highest when local management conditions are low intensity (infrequent mowing and low fertilization, Blüthgen et al., 2012) and surroundings are also low intensity (here represented by higher land use diversity), as this allows for dispersal and re-colonization processes (Le Provost et al., 2021) (Fig. 1Bi). We also expect that the opposite is true: when both local and surrounding conditions are high intensity and positively affect local ES supply, the optimal configuration is also spatial segregation of low and high intensity land (Fig. 1Bii).

In contrast, where ES supply is boosted by high land-use intensity at the local level but by low land-use intensity in the surrounding landscape (Fig. 1Biv), then this ES will be maximized in a fine-grain mosaic of high and low land-use intensity areas. For example, crop production of insect pollinated crops can benefit from locally high land-use intensity in the form of fertilizer and pesticide inputs (Tudi et al., 2021), but also from the spillover of pollinators and pest-controlling organisms from surrounding lands, which are most abundant in low-intensity landscapes (e.g. González-Chaves et al., 2022) (Fig. 1Biv).

If the strength of positive and negative effects of high and low intensity landscape features on local ES supply are equal and cancel out, or are unimportant, then differences in spatial arrangement will have little effect on ES supply (Fig. 1Bv). This may occur for ES that are not strongly driven by surrounding factors, such as soil carbon storage or erosion control, which are primarily driven by local abiotic processes (Grünzweig et al., 2022).

This hyphotesis advances on previous approaches (e.g. Hersperger, 2006; Martin de Agar et al., 2016) to assess the drivers of landscape multifunctionality by estimating how local and landscape influences alter the optimal configuration of multiple services and by weighting the relative importance of these services by stakeholder's demand, to ensure that the identified configuration generally promotes the most important services. Here, we used empirical data on the plot and landscape drivers of ecosystem services supply (Le Provost et al., 2023) and their prioritization by multiple stakeholders (Peter et al., 2022) to provide an initial demonstration of how the net-balance spatial interactions hypothesis can be applied.

2. Methods

Study design: The studied grasslands are part of the large-scale and long-term Biodiversity Exploratories project (www.biodiversity-exploratories.de) and are located in three regions in Germany varying in geology, topography, climate, and landscape aspects: Schwäbische Alb, Hainich-Dün and Schorfheide-Chorin. In each region, 50 survey plots were established in grasslands varying in local land-use intensity and monitored for multiple ecological properties since 2006 (see Fischer et al., 2010). While the surveyed plots in Schwäbische Alb are dominated by both forests and grasslands in a patchy and disaggregated configuration, the surveyed plots in the other regions are surrounded by a higher proportion of crop area, often distributed in larger and more aggregated patches (details in Table S2).

Ecosystem services: We selected four ES provided by grasslands and highly-prioritized by stakeholders in the regions (Peter et al., 2022). Aesthetic value (indicator: acoustic diversity used as experience of nature sounds); livestock production (indicator: forage quality); climate regulation (soil carbon stocks < 10 cm), and biodiversity as a cultural service (indicator: bird species richness). Biodiversity is used here as an indicator of cultural services, related to the enjoyment of nature, rather than as an indicator of the supporting services it underpins. This reflects the initial survey from which demand data was collected (Peter et al., 2022). Details on the data collection of the services can be found in Le Provost et al., 2023.

Stakeholder priorities: We focused on stakeholder groups in the study regions that highly prioritize grassland-based services: local residents, nature conservation associations, agriculture sector and tourism sector. The relative prioritization of the services by these groups was quantified using survey data of 126 correspondents, who distributed a maximum of 20 points across all services (Peter et al., 2022). Priority scores for each ES were then normalized by the total number of points attributed to grassland ES by each correspondent (see Le Provost et al., 2023 for details). Since the prioritization did not vary significantly across regions, we used overall scores for each group.

Data analysis: for each ES we examined the statistical models of Le Provost et al. (2023). These described the relative impact of multiple landscape and plot-level drivers on each ES. Plot level land-use intensity is defined at the scale that relates to the 50 x 50 m plot and was determined by combining the levels of fertilization, the mowing frequency, and intensity of livestock (see Blüthgen et al., 2012 for details). Landscape land-use intensity was determined in a 1000 m radius surrounding the plots and defined by land-use diversity (a low land-use diversity being associated to higher intensity; Table S2 for an overview of land-use cover across regions). Diversity of land-uses in our study tends to be associated with a range of semi-natural habitat types being present within the surrounding landscapes, and thus reflects intensity in this system.While the overall concept of local and landscape influences, and their impact on the optimal configuration should hold true for a range of contexts, the scale of local vs. landscape must be defined on a case basis, based upon the scale at which ecological processes involved operate, the scales for which data is available, as also the land use intensity indicator.

From each model we determined the strength of local vs landscape effects of land-use intensity based on the total standardized effects of structural equation models (Le Provost et al., 2023). If both local and

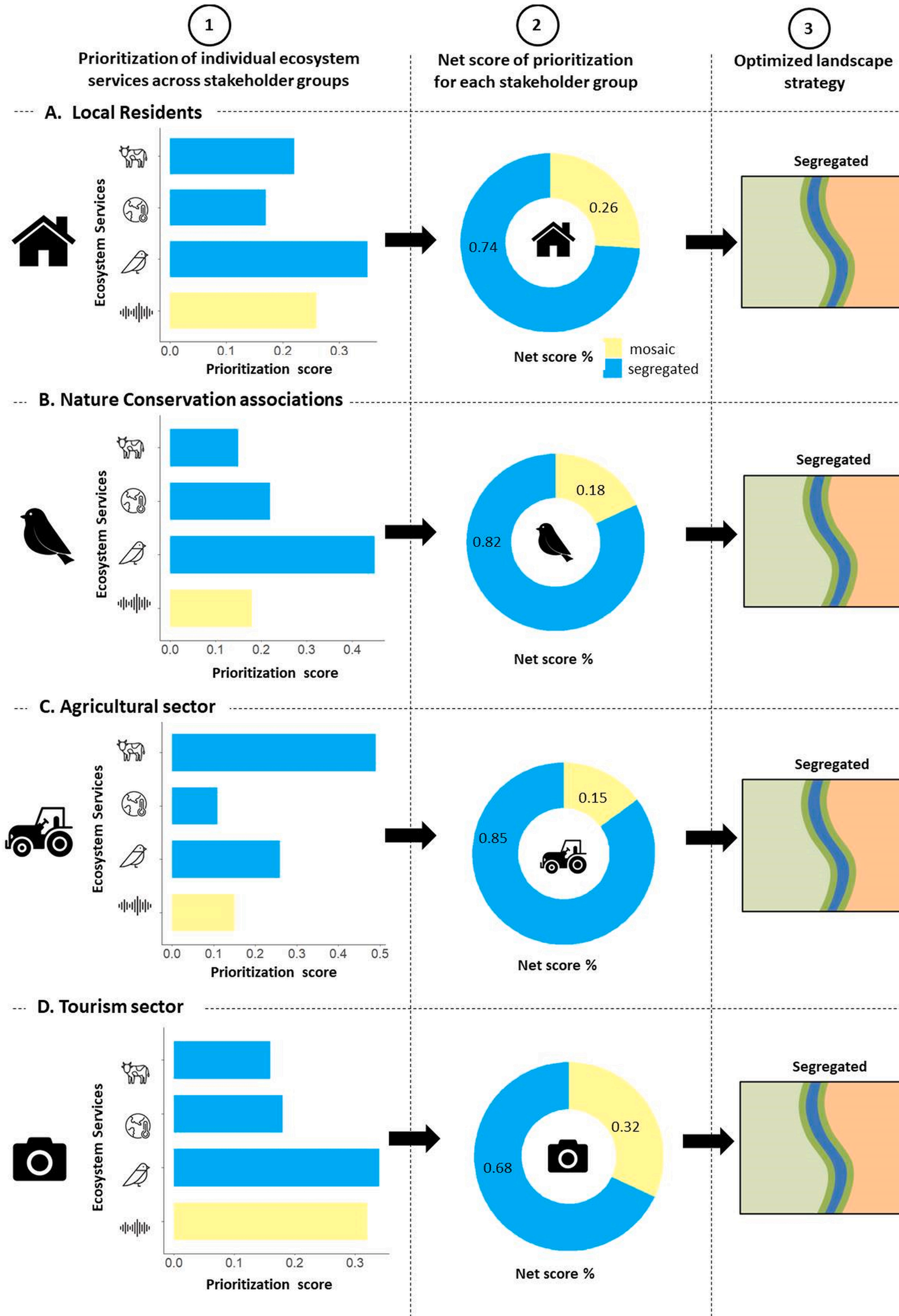

Fig. 2. Ecosystem service (ES) prioritization of stakeholder groups determines their optimal landscape configuration for multifunctionality. In 1, each panel a-d shows the relative prioritization (as a proportion) of individual ES by each stakeholder group: A (local residents), B (nature conservation associations), C (agricultural sector), D (tourism sector), and yellow or blue color indicates which configuration promotes plot level supply of that service (mosaic and segregation respectively). Ecosystem services are represented by the following icons: livestock production (cow); climate regulation (earth), biodiversity conservation (bird), and aesthetics (sonogram). In 2, the priority scores are multiplied landscape each strategy, (i.e. segregated or mosaic, when 1 is for the more beneficial strategy) across stakeholder groups to identify the strategy that gives the highest multifunctionality; and in 3. the respective landscape strategy (mosaic or segregation) which maximizes the supply of ES for each stakeholder group. Example is based on data from Le Provost et al. (2023). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

landscape LUI affected the service in the same direction, we assign the service to be better provided by a segregated type of management, following our hypothesis. If local and landscape effects differed in the direction of effect, we assigned the service to be maximized in a mosaic pattern of field management. We then calculated relative merit of each landscape strategy (i.e. segregated or mosaic) to different stakeholders by weighting each ES by its relative priority to each stakeholder, defined as the proportion of points allocated to each service. This provides an approximate indication of the strategy that gives the highest multi-functionality for each stakeholder group.

3. Results and discussion

Using information extracted from ES provision models (Le Provost et al., 2023; SM 1), we show that different services benefit from different strategies. Climate regulation and livestock production were highest at high intensity, at both local and landscape scales, thus indicating they would benefit from a segregated strategy. Biodiversity (bird species richness) was enhanced by low intensity at both local and landscape level, thus also indicating it would be highest under segregated management. Acoustic diversity was highest at high intensity at local conditions but low intensity landscape conditions, thus indicating that it would benefit most from a mosaic configuration.

When these patterns are combined with stakeholder priority data our demonstration shows the optimal strategy, in this case, is similar across stakeholder groups, despite differences in priorities; application of our framework predicts that all groups would benefit from the segregation of intense grasslands from low intensity grasslands, but at a cost to one ES (Fig. 2). Clearly, more advanced work is required to fully test these predictions. If most of the ES demanded by a stakeholder group are optimized by a segregated landscape, then this will be the best strategy for multifunctionality, as seen here (Fig. 2a,b,c,d). Conversely, mosaic land uses will maximize multifunctionality when the most demanded ES are optimized by a mosaic configuration. Following this logic, ES that share the same optimal configuration strategy may be managed together as a bundle (e.g. all the ES found in a and b of Fig. 1).

Difficulties in identifying an optimal configuration strategy may arise where highly prioritized ES have contrasting optimization patterns. When such complexities arise, identifying and achieving the optimal landscape configuration is non-trivial. In such cases, 'optimal' landscapes are unlikely to deliver big gains to everyone (Neyret et al., 2023). While this framework does not provide a clear solution to deal with such conflicting results, it at least demonstrates the absence of a win–win solution, which is still useful knowledge for managers.

4. Application and conclusion

The net-balance spatial interactions hypothesis is a general framework applicable to a wide range of land planning scenarios. It is also, to our knowledge, the first framework to formally assess the impacts of landscape configuration on the simultaneous supply of multiple ES that acknowledges both positive and negative spatial interactions between landscape components. Until now, most studies investigating optimal landscape configuration strategies to promote different ES have been framed around the land-sharing and land-sparing debate, which focuses primarily on biodiversity conservation and food production (Kremen, 2015; Loconto et al., 2020). Studies aiming to identify optimal landscape configurations for other objectives also usually consider only one or two ES, and thus identify the best configuration for a small subset of the many ES that are delivered by ecosystems and demanded by stakeholders (e.g. Rieb & Bennett, 2020; Karimi et al., 2024). This best outcome change if additional ES with contrasting responses are considered, revealing additional trade-offs and synergies, and complexities in their management.

The simple 'rules of thumb' presented here require elaboration if we are to provide more precise and quantitative conclusions. In real ecosystems, different ES respond to a wide range of landscape factors over different scales, and these drivers include multiple land use types and continuous gradients of ecosystem condition. This additional complexity will likely affect the optimal size and arrangement of units in clusters and mosaics, and requires us to go beyond the simple binary cases and single scales presented here. Identifying the optimum in such cases requires more extensive simulation and empirical modeling of how variation in these factors would alter outcomes. Moreover, the extension of segregation patterns will likely depend on the scale defined. Thus it is important to consider how best to define local and landscape within the context of each specific study. The framework also currently assumes equilibrium conditions based on current patterns and so needs extension if it is to accommodate the temporal dynamics underpinning issues of sustainability and resilience to environmental change. This could include the weighting of the supporting functions that underpin ES within the measure as a first step (see e.g. Allan et al., 2015). Nevertheless, even in its simple form, the framework further emphasizes the point that considering only a few ES objectives when devising landscape strategies, rather than the full array of ES demanded by stakeholders, can lead to detrimental outcomes for multifunctionality (Neyret et al., 2023).

The framework presented here can also help structure debates over landscape optimization strategies for multiple objectives and inform policies that aim to increase the multifunctionality of landscapes, such as the spatial arrangement of agri-environment scheme actions (Whittingham, 2011). By providing a general 'rule-of-thumb' on how multifunctionality responds to landscape configuration, it has the potential to inform decisions, even when detailed local information is missing.

Data availability statement

The data associated with this paper is linked to another publication and may be made available upon request.

Author contributions

A.L.B. and P.M. conceived the hypothesis and led writing of the manuscript. G.P. and S.P. provided data to build the workable example. All the authors contributed critically to the drafts and gave final approval for publication.

CRediT authorship contribution statement

Andrea Larissa Boesing: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Valentin H. Klaus:** Writing – review & editing. **Margot Neyret:** Writing – review & editing. **Gaëtane Le Provost:** Writing – review & editing, Data curation. **Sophie Peter:** Writing – review & editing, Data curation. **Markus Fischer:** Writing – review & editing. **Peter Manning:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization.

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.

Data availability

Data will be made available on request.
Supplementary material (Reference data)

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Appendix A. Supplementary data

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References

Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N., et al., 2015. Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. Ecol. Lett. 18, 834–843.
Arroyo-Rodríguez, V., Fahrig, L., Tabarelli, M., Watling, J.I., Tischendorf, L., Benchimol, M., et al., 2020. Designing optimal human-modified landscapes for forest biodiversity conservation. Ecol. Lett. 23, 1404–1420.
Bennett, E.M., Peterson, G.D., Gordon, L.J., 2009. Understanding relationships among multiple ecosystem services. Ecol. Lett. 12, 1394–1404.
Blitzer, E.J., Dormann, C.F., Holzschuh, A., Klein, A.M., Rand, T.A., Tscharntke, T., 2012. Spillover of functionally important organisms between managed and natural habitats. Agric. Ecosyst. Environ. 146, 34–43.
Blüthgen, N., Dormann, C.F., Prati, D., Klaus, V.H., Kleinebecker, T., Hölzel, N., et al., 2012. A quantitative index of land-use intensity in grasslands: Integrating mowing, grazing and fertilization. Basic Appl. Ecol. 13, 207–220.
Duarte, G.T., Santos, P.M., Cornelissen, T.G., Ribeiro, M.C., Paglia, A.P., 2018. The effects of landscape patterns on ecosystem services: meta-analyses of landscape services. Landsc. Ecol. 33, 1247–1257.
Fischer, M., Bossdorf, O., Gockel, S., Hänsel, F., Hemp, A., Hessenmöller, D., et al., 2010. Implementing large-scale and long-term functional biodiversity research: The Biodiversity Exploratories. Basic Appl. Ecol. 11, 473–485.
Fischer, C., Gayer, C., Kurucz, K., Riesch, F., Tscharntke, T., Batáry, P., 2018. Ecosystem services and disservices provided by small rodents in arable fields: Effects of local and landscape management. J. Appl. Ecol. 55, 548–558.
González-Chaves, A.G., Carvalheiro, L.G., Garibaldi, L.A., Metzger, J.P., 2022. Positive forest cover effects on coffee yields are consistent across regions. J. Appl. Ecol. 59, 330–341.
Grünzweig, J.M., De Boeck, H.J., Rey, A., Santos, M.J., Adam, O., Bahn, M., et al., 2022. Dryland mechanisms could widely control ecosystem functioning in a drier and warmer world. Nat. Ecol. Evol. 6, 1064–1076.
Harbo, L.S., Schulz, G., Heinemann, H., Dechow, R., Poeplau, C., 2023. Flower strips as a carbon sequestration measure in temperate croplands. Plant Soil 482, 647–663.
Hersperger, A.M., 2006. Spatial adjacencies and interactions: Neighborhood mosaics for landscape ecological planning. Lands. Urb. Plan. 77, 227–239.
Karimi, J.D., Corstanje, R., Harris, J.A., 2024. Understanding the importance of landscape configuration on ecosystem service bundles at a high resolution in urban landscapes in the UK. Landsc. Ecol. 36, 2007–2024.
Kremen, C., 2015. Reframing the land-sparing / land-sharing debate for biodiversity conservation. Ann. n. y. Acad. Sci. 1355, 52–76.
Kremen, C., Williams, N.M., Thorp, R.W., 2002. Crop pollination from native bees at risk from agricultural intensification. PNAS 99, 16812–16816.
Lamy, T., Liss, K.N., Gonzalez, A., Bennett, E.M., 2016. Landscape structure affects the provision of multiple ecosystem services. Environ, Res. Lett., p. 11
Larsen, A.E., Noack, F., 2021. Impact of local and landscape complexity on the stability of field-level pest control. Nat. Sustain. 4, 120–128.
Lavorel, S., Grigulis, K., Richards, D.R., Etherington, T.R., Law, R.M., Herzig, A., 2022. Templates for multifunctional landscape design. Landsc. Ecol. 37, 913–934.
Le Provost, G., Thiele, J., Westphal, C., Penone, C., Allan, E., Neyret, M., et al., 2021. Contrasting impacts of multiple components of land-use intensity on above- and belowground diversity. Nat. Commun. 12, 3918.
Le Provost, G., Schenk, N.V., Penone, C., Thiele, J., Westphal, C., Allan, E., et al., 2023. The supply of multiple ecosystem services requires biodiversity across spatial scales. Nat. Ecol. Evol. 7, 236–249.
Linders, T.E.W., Schaffner, U., Alamirew, T., Allan, E., Choge, S.K., Eschen, R., et al., 2021. Stakeholder priorities determine the impact of an alien tree invasion on ecosystem multifunctionality. People Nat. 3, 658–672.
Loconto, A., Desquilbet, M., Moreau, T., Couvet, D., Dorin, B., 2020. Land Use Policy The land sparing – land sharing controversy: Tracing the politics of knowledge. Land Use Policy 96, 103610.
Manning, P., Van Der Plas, F., Soliveres, S., Allan, E., Maestre, F.T., Mace, G., et al., 2018. Redefining Ecosystem Multifunctionality. *Nat. Ecol. Evol.* 2, 427–436.
Martin de Agar, P., Ortega, M., de Pablo, C.L., 2016. A procedure of landscape services assessment based on mosaics of patches and boundaries. Journal of Environ. Manag. 180, 214–227.
Mitchell, M.G.E., Bennett, E.M., Gonzalez, A., 2015. Strong and nonlinear effects of fragmentation on ecosystem service provision at multiple scales. Environ. Res. Lett. 10, 094014.
Muylaert, R.L., Sabino-Santos, G., Prist, P.R., Oshima, J.E.F., Niebuhr, B.B., Sobral-Souza, T., et al., 2019. Spatiotemporal dynamics of hantavirus cardiopulmonary syndrome transmission risk in Brazil. Viruses 11, 1–15.
Neyret, M., Peter, S., Le Provost, G., Boch, S., Boesing, A.L., Bullock, J., et al., 2023. Landscape management strategies for multifunctionality and social equity. Nat. Sustain. 6, 391–403.
Peter, S., Le Provost, G., Mehring, M., Müller, T., Manning, P., 2022. Cultural worldviews consistently explain bundles of ecosystem service prioritisation across rural Germany. People Nat. 4, 218–230.
Pinillos, D., Bianchi, F.J.J.A., Poccard-Chapuis, R., Corbeels, M., Tittonell, P., Schulte, R. P.O., 2020. Understanding Landscape Multifunctionality in a Post-forest Frontier: Supply and Demand of Ecosystem Services in Eastern Amazonia. Front. Environ. Sci. 7, 1–16.
Pitman, W.D., 2022. Multifunctional landscapes for enhanced ecosystem benefits and productive agriculture in the southeastern US. Landsc. Ecol. 37, 1957–1971.
Prist, P.R., Tambosi, L.R., Mucci, L.F., Pinter, A., Pereira de Souza, R., Muylaert, R., et al., 2022. Roads and forest edges facilitate yellow fever virus dispersion. J. Appl. Ecol. 59, 4–17.
Rieb, J.T., Bennett, E.M., 2020. Landscape structure as a mediator of ecosystem service interactions. Landsc. Ecol. 35, 2863–2880.
Roos, D., Caminero Saldaña, C., Arroyo, B., Mougeot, F., Luque-Larena, J.J., Lambin, X., 2019. Unintentional effects of environmentally-friendly farming practices: Arising conflicts between zero-tillage and a crop pest, the common vole (Microtus arvalis). Agric. Ecosyst. Environ. 272, 105–113.
Stürck, J., Verburg, P.H., 2017. Multifunctionality at what scale? A landscape multifunctionality assessment for the European Union under conditions of land use change. Landsc. Ecol. 32, 481–500.
Tschumi, M., Brett, R., Williams, N.M., Dainese, M., Isaacs, R. & Jacot, K. (2020). The effectiveness of flower strips and hedgerows on pest control, pollination services and crop yield: a quantitative synthesis, 1488–1498.
Tudi, M., Ruan, H.D., Wang, L., Lyu, J., Sadler, R., Connell, D., et al., 2021. Agriculture Development, Pesticide Application and Its Impact on the Environment. Int. J. Environ. Res. Public Health 18, 1–23.
Vallet, A., Locatelli, B., Pramova, E., 2020. Ecosystem services and social equity: Who controls, who benefits and who loses? CIFOR 1–8.
Whittingham, M.J., 2011. The future of agri-environment schemes biodiversity gains and ecosystem.pdf. J. Appl. Ecol. 48, 509–513.