From trade-offs to synergies in food security and biodiversity conservation

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Providing universal food security and conserving biodiversity are prominent challenges facing humanity in the 21st century. Typically, these challenges are believed to involve a trade-off, especially in farming landscapes of the Global South. We conducted a multivariate analysis of social–ecological data from 110 landscapes in the Global South, and found that different system characteristics lead to partly predictable outcomes, resulting either in trade-offs or, unexpectedly, in synergies (mutual benefits) between food security and biodiversity. Specifically, these synergies are fostered by social equity, by reliable access to local land, and by increasing social capital (eg maintenance of traditions) and human capital (eg health). In contrast, we also found high degrees of food security in landscapes with adequate infrastructure, market access, and financial capital, but this increased security came at the expense of biodiversity. Our findings demonstrate that a social–ecological systems perspective can help to identify previously unrecognized synergies between food security and biodiversity conservation.

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Global sustainability goals recognize that achieving food security and conserving biodiversity are among the most critical challenges of our time (Foley *et al.* 2011; UN 2015). Despite ongoing increases in global food production, approximately 800 million people remain undernourished (FAO *et al.* 2015), and the expansion and intensification of agriculture continue to be major causes of biodiversity loss (Foley *et al.* 2005; Tilman *et al.* 2011).

Linking these two challenges has created a narrative that is dominated by the notion of an inevitable trade-off between food production and biodiversity conservation. Accordingly, the discourse on possible solutions has followed a similar path (Foley *et al.* 2005). Well-known examples of frameworks that attempt to reduce such trade-offs include the concept of land sparing versus land sharing (Green *et al.* 2005), and the increasingly popular notion of sustainable intensification (Tilman *et al.* 2011). Despite their broad appeal, these approaches provide incomplete solutions to the complex problem at hand for several reasons, including their narrow focus on food production instead of food security, and an insufficient consideration of broader societal issues such as justice or governance (Fischer *et al.* 2011; Loos *et al.* 2014).

Building on the theoretical framework by Wittman *et al.* (2017), we used a social–ecological perspective, thereby taking into account a more comprehensive suite of factors influencing the food–biodiversity nexus. By comparing many landscapes from around the world, our overarching goal was to explore typical relationships between social–ecological system characteristics and outcomes with respect to food security and biodiversity conservation.

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A social–ecological systems perspective recognizes interdependencies and feedbacks between social and ecological characteristics (Liu *et al.* 2007). In the context of food security and biodiversity conservation, key themes considered in a social–ecological approach (but largely glossed over in other frameworks) include food flows, livelihood strategies, governance, and endowments with various capital assets (ie the means to achieve a certain outcome; including social, human, infrastructure, financial, and natural capital; for example, food production depends on natural capital, requires health and knowledge and often benefits from good social relations with others; Wittman *et al.* 2017).

We focused on farming landscapes of the Global South, which cover a large part of the habitable terrestrial surface (Foley *et al.* 2005) and harbor a considerable share of Earth's biodiversity (Perfecto and Vandermeer 2010). Moreover, both the need to provide food to local people and the pressure on biodiversity are particularly acute in the Global South (eg Figure 1).

We concentrated on the landscape scale, because the landscape is a meaningful unit for managing both social and ecological outcomes (Wu 2013), including in the context of food security and biodiversity conservation (Wittman *et al.* 2017). However, no global systematic assessments of food security or biodiversity are available at the landscape scale. National-level data (eg from the Food and Agriculture Organization of the United Nations) are inadequate for this purpose because they would mask critical differences by aggregating across very different ecological and sociopolitical contexts within a given nation. We therefore elicited case-specific expert knowledge via an innovative, theoretically grounded survey instrument on food security, biodiversity conservation, and social–ecological systems characteristics of

Figure 1. *Farming landscapes of the Global South are often characterized by small-scale farming, and food security and biodiversity outcomes result from a complex interaction between different social–ecological drivers. The image shows a farming landscape in southwestern Ethiopia where smallholder farmers grow maize, teff (*Eragrostis tef*; annual bunch grass with edible grains), sorghum, and other grains for their own consumption, as well as coffee and khat (*Catha edulis*; perennial shrub whose leaves can be chewed as a stimulant), which are primarily sold at markets. Improvement of the road network has led to improved access to medical care. However, unabated population growth leads to land scarcity, which in turn increases food insecurity, and the exploitation and destruction of highly biodiverse afromontane forest ecosystems.*

farming landscapes throughout the Global South. Drawing on the resulting data, we investigated the nature of possible trade-offs between food security and biodiversity conservation and, where possible, identified mechanisms to foster synergies between these two societal goals.

Methods

Using an online survey, we obtained data for farming landscapes throughout the Global South. We defined a landscape as an area measuring tens to thousands of square kilometers, which can be characterized by certain unifying features such as, for example, similar biophysical and sociopolitical characteristics. Suitable landscapes were primarily used for farming, and at least some people in the landscape were required to be at a realistic risk of food insecurity. The survey contained 85 detailed questions grouped into four main sections: general information (eg respondent's background and expertise), food security (eg access, availability, stability through time), biodiversity conservation (eg wild and agrobiodiversity, stability through time), and social–ecological system characteristics (eg biophysical properties, farming practices, capital assets) (Wittman *et al.* 2017). Most questions used Likert scales, thus generating ordinal data (see WebPanel 1 for full questionnaire).

We distributed the survey widely through mailing lists (Social Science Working Group of the Society for Conservation Biology; Food and Climate Research Network), as well as via Twitter (@ideas4sust), blogs (ideas4sustainability.wordpress.com; foodandbiodiversity.wordpress.com; agroecopeople.wordpress.com), and academic and practitioner networks (eg Bioversity International, CGIAR, Programme on Ecosystem Change and Society). We also directly emailed scientists who had conducted relevant empirical case studies as identified in a previous review (Glamann *et al.* 2017). Data collection occurred between November 2015 and February 2016.

Although our invitation to participate in the survey was open, we specified clearly who it was directed at. The survey addressed self-identified experts in food security and biodiversity conservation who were willing to share their expertise on a particular, potentially food-insecure farming landscape of their choice. From a total of 223 responses, we used 110 cases (WebFigure 1) that passed a set of stringent quality-control criteria (eg minimum expertise, completeness of data) and fulfilled all requirements for our analysis (eg representing farming landscapes with at least potential food insecurity; for details, see WebPanel 2).

Most respondents were scientists (n = 84), and their experience within a given landscape ranged from half a year to 40 years (median 5 years) (WebFigure 2, a and b). Disciplinary backgrounds varied widely but ecology, biodiversity conservation, and resource management were mentioned most frequently (WebFigure 2c). Overall, the self-assessed expertise was balanced between food security (70 participants responding "high" or "very high") and biodiversity conservation (83 participants responding "high" or "very high") (WebFigure 3).

For the analysis, we first extracted the main gradients in food security and biodiversity conservation using nonlinear principal component analysis (NLPCA), a method that is particularly suited to ordinal data (De Leeuw and Mair 2009). The derived first principal component of food security explained 40% of the variance in answers related to food security, and correlated with food availability, accessibility, adequacy, acceptability, stability, and utilization (WebFigure 4a). Likewise, the derived first principal component of biodiversity explained 51% of the variance in answers related to biodiversity, and correlated with native biodiversity, farmland biodiversity, protected species, rare species, functional groups, and planned biodiversity (see WebPanel 2 for details; WebFigure 4b). The two variables derived in this way provided meaningful, data-driven indices of food security and biodiversity conservation, and were used as response variables in subsequent analyses.

Second, we summarized information on the social–ecological characteristics of a given landscape separately for seven different themes: biophysical characteristics, sociodemographics, farming practices and livelihood strategies, food flows, governance, justice, and capital assets. With regard to food security and biodiversity, the characteristics for each theme were elicited by drawing on a number of separate questions. For instance, biophysical characteristics were related to biome, topography, rainfall variability, soil degradation, water pollution, and the prevalence of invasive species (see WebPanels 1 and 2 for details and input data to all seven themes). To reduce complexity, we extracted key gradients within each theme via NLPCA (WebFigures 5–11). The first two axes of each of the seven ordinations were extracted and rotated using varimax rotation in order to improve interpretability of the axes. The fourteen variables thus derived constituted meaningful descriptions of the social–ecological characteristics of a given landscape, and we considered them appropriate explanatory variables in later analyses.

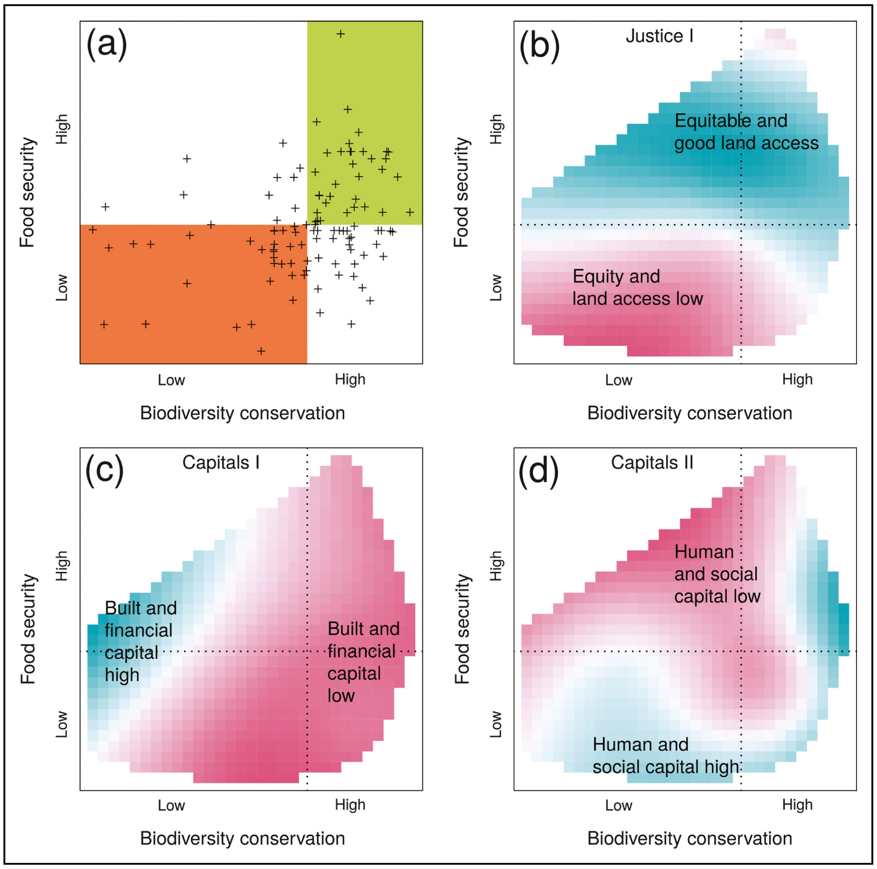

Figure 2. *(a) State of food security and biodiversity conservation in 110 focal landscapes. (b–d) Relationships between food security and biodiversity conservation in response to social–ecological system characteristics describing justice ([b]; 20% explained deviance), built and financial capital assets ([c]; 21% explained deviance), and human and social capital assets ([d]; 23% explained deviance). The global distribution of focal landscapes is shown in WebFigure 1; additional details on social–ecological system characteristics and how they were derived are provided in WebPanels 1 and 2.*

Third, we related the rotated axes of each of the seven NLPCAs to the previously calculated indices of food security and biodiversity conservation using generalized additive models. We used this procedure because it enabled us to simultaneously model the response of both food security and biodiversity to any given set of social–ecological characteristics. We present only the results for statistically significant models (Holm adjusted $P < 0.05$) with an explained deviance of more than 10%.

Finally, respondents were asked whether they anticipated the state of food security and biodiversity conservation to improve or deteriorate over the next 10 years. We summarized these responses by counting how often respondents agreed or strongly agreed that conditions would either improve or deteriorate. All methods are described in detail in WebPanel 2.

Results and discussion

As expected, some landscapes exhibited a trade-off between food security and biodiversity conservation. However, across all 110 landscapes, "win–win" outcomes and "lose–lose" outcomes were also common (Figure 2a). Overall, food security and biodiversity outcomes showed a weak positive correlation (Spearman $\tau = 0.31$, $P = 0.001$).

This finding contradicts the dominant discourse around trade-offs between food and biodiversity (Glamann *et al.* 2017). Food security and biodiversity trade-offs are possible – common, in fact – but as this analysis shows, not inevitable or universal. Given this finding, we were interested in further understanding key drivers underpinning the food security–biodiversity relationship. Are there specific sets of system characteristics that are generally associated with "lose–lose" or "win–win" outcomes, or with classically assumed food–biodiversity trade-offs ("win–lose", "lose–win")?

Drawing on our generalized additive models, we uncovered significant associations between system characteristics and combined outcomes for food security and biodiversity conservation (Figure 2, b–d). First, food security was reported to be low in landscapes with high levels of social inequity and poor access to land for local people

(Figure 2b). Social inequity has been argued to be an obstacle to poverty reduction in general (Haddad 2015), and has been empirically shown to negatively relate to food security in Asian countries (Friel and Baker 2009). Adequate access to land for smallholder farmers (ie subsistence farmers who support a household from often <2 ha of land), in turn, is a crucial component of such equity, with important implications for food security (Lipton and Saghai 2017).

Second, we found significant associations in food–biodiversity outcomes in relation to built and financial capital assets. Good infrastructure, easy access to markets, and high levels of financial resources were related to high food security but low biodiversity (Figure 2c). Infrastructure modernization and improvements in market access are often seen as efficient tools to fuel economic development and thus reduce poverty (World Bank 2007). However, our findings show that increasing these capital assets increased food security only in situations where biodiversity conservation was limited. This, in turn, suggests that a conventional strategy focusing on markets and infrastructure may inadvertently foster a trade-off between food security and biodiversity conservation. Road infrastructure, for example, provides access to markets and agricultural inputs, but can facilitate both the expansion and intensification of agriculture (Laurance *et al.* 2014), which are key drivers of biodiversity loss (Matson *et al.* 1997).

Third, human and social capital assets were related to food and biodiversity outcomes in a non-linear way. Health, knowledge, maintenance of traditions, and a high awareness of natural capital were related to high biodiversity but also to low food security (Figure 2d). Other authors have noted that a "win–win" situation, where biodiversity is maintained in farming systems that provide sufficient food and other benefits to people, may stem from the maintenance of traditional management and knowledge systems (Barthel *et al.* 2013). In contrast to that narrative, our findings suggest that high food insecurity in combination with poverty might cause an involuntary dependency of people on their natural environment – keeping awareness of natural capital and traditional ecological knowledge high, not by choice but by necessity.

Our findings on capital assets have possible implications for global and national policies targeting the Global South. Many such policies focus on strengthening the agricultural sector by increasing export-oriented production, focusing especially on commodity crops, including fibers (eg cotton), food (eg wheat, maize, soybean, rice, barley), luxury goods (eg coffee, cocoa), oils (eg palm oil, rapeseed), or pulp and paper. These initiatives often neglect immediate local needs, instead focusing on indirect benefits from ecosystems (as defined by Daw *et al.* 2011) and often inadvertently causing environmental deterioration. Our findings on capital assets show that these and other "big push" strategies that focus on infrastructure modernization may be short sighted (Mikulcak *et al.* 2015), and need to be balanced with conscious efforts to also improve other capital assets, for instance via education (Lutz and Samir 2011) and the support of grassroots-level smallholder initiatives (Altieri and Toledo 2011).

In summary, in the landscapes we studied, "win–win" outcomes for food security and biodiversity were associated with high equity, ready access to land for local people, and high human and social capital. In contrast, a trade-off between food security and biodiversity conservation was related to a singular focus on built and financial capital in a given landscape. These findings suggest that justice and the types and diversity of capital assets are key factors influencing food security and biodiversity conservation across a wide range of landscapes worldwide. Avoiding a narrow focus solely on infrastructure development, commercialization, and built capital – and instead also strengthening human capital, social capital, and equity – therefore seems critical for fostering synergies between food security and biodiversity conservation. Suitable strategies for specific rural areas such as those identified here need to be complemented with strategies tailored to urban areas, as well as to possible interactions among multiple landscapes. For example, in many developing countries, rapid urbanization draws on resources generated in rural and peri-urban areas (Lerner and Eakin 2011), thereby creating links between different landscapes. Long-distance links between landscapes can also be important. Our findings on the role of infrastructure and market access indicate the relevance of interactions with places outside of a given landscape through teleconnections (Seto *et al.* 2012) or social–ecological telecoupling (Liu *et al.* 2013). How to best address cross-scale connections remains a key challenge for future research; our work indicates that the landscape scale is clearly useful, but how landscape-scale analyses can be best integrated with insights generated at other scales remains an open question.

We did not find significant relationships between either food security or biodiversity and a range of governance-related variables. We had included questions on whether the government listened to local concerns, and whether it was generally believed to be reliable and effective (see WebPanel 1 for details). Given the growing discourses on food sovereignty (Wittman *et al.* 2010) and the need for locally appropriate governance mechanisms (Phalan *et al.* 2016), we were surprised that no consistent benefits of governance variables were found for either food security or biodiversity conservation. However, we caution that the fact that we did not discover a statistically significant effect does not necessarily mean that there is no such effect. Given evidence presented elsewhere, we believe that the lack of statistical significance in our dataset may be an artifact of our data, or of the specific questions we asked. For example, our questions did not specifically differentiate between different levels of government, and we did not ask separately about

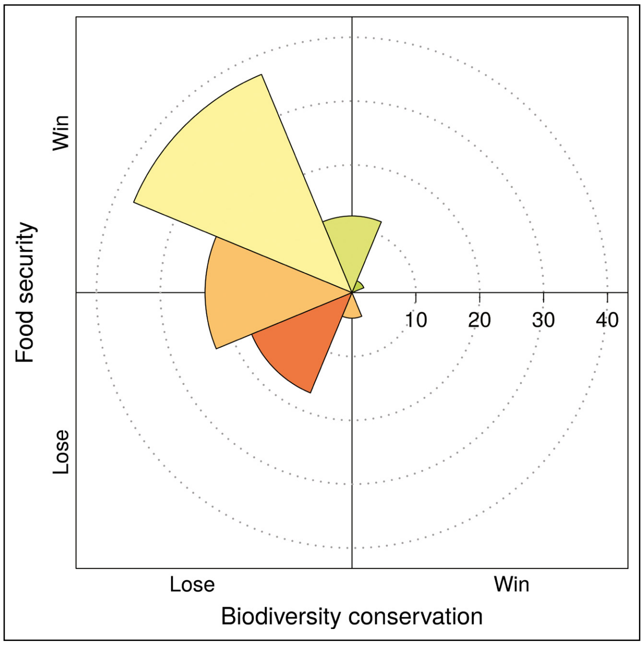

Figure 3. *Anticipated future trends for food security and biodiversity conservation in the focal landscapes within the next decade. Wedge length indicates the number of respondents considering a win, no change, or a loss in food security and biodiversity conservation, respectively. For example, most respondents anticipated a gain in food security and a loss in biodiversity (n = 37; yellow wedge, top-left).*

conservation measures for flora and fauna. Our broad-brush approach was probably appropriate for this particular questionnaire (which was the first of its kind), but future research may need to explore governance issues in more detail in order to generate a better understanding of how it influences food and biodiversity outcomes.

In a final step of analysis, we asked experts about their perception regarding future trends in their focal landscapes. Troublingly, most experts anticipated a trade-off looming on the horizon, namely that food security will increase while biodiversity will decline (n = 37; Figure 3). A large proportion of experts also expected a decline in biodiversity with no change in food security (n = 23), or even a decrease in both (n = 17). Despite the previous findings indicating that synergies are possible, positive trends for both food security and biodiversity conservation were anticipated in only two of the 110 landscapes analyzed.

Conclusions

Our findings suggest that the prevailing view of a trade-off between food security and biodiversity may fuel a self-fulfilling prophecy. At present, it appears that humanity primarily pursues strategies that lead to trade-offs (eg through agricultural commercialization and infrastructure development), while strategies that might lead to a "win–win" outcome exist but are neglected (Chappell and LaValle 2011). We see an urgent need to more routinely bring social system characteristics back into existing discourses on food security and biodiversity conservation – including issues related to justice, as well as social and human capital (Sunderland 2011; Zimmerer 2013). To this end, a social–ecological systems perspective can provide a useful way forward.

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References

Altieri MA and Toledo VM. 2011. The agroecological revolution in Latin America: rescuing nature, ensuring food sovereignty and empowering peasants. *J Peasant Stud* **38**: 587–612.

Barthel S, Crumley CL, and Svedin U. 2013. Biocultural refugia: combating the erosion of diversity in landscapes of food production. *Ecol Soc* **18**: art71.

Chappell MJ and LaValle LA. 2011. Food security and biodiversity: can we have both? An agroecological analysis. *Agr Hum Values* **28**: 3–26.

Daw T, Brown K, Rosendo S, and Pomeroy R. 2011. Applying the ecosystem services concept to poverty alleviation: the need to disaggregate human well-being. *Environ Conserv* **38**: 370–79.

De Leeuw J and Mair P. 2009. Gifi methods for optimal scaling in R: the package homals. *J Statistical Softw* **31**: 1–20.

FAO, IFAD, and WFP (Food and Agriculture Organization of the United Nations, International Fund for Agricultural Development, and World Food Programme). 2015. The state of food insecurity in the world 2015. Meeting the 2015 international hunger targets: taking stock of uneven progress. Rome, Italy: FAO.

Fischer J, Batary P, Bawa KS, *et al.* 2011. Conservation: limits of land sparing. *Science* **334**: 593.

Foley JA, DeFries R, Asner GP, *et al.* 2005. Global consequences of land use. *Science* **309**: 570–74.

Foley JA, Ramankutty N, Brauman KA, *et al.* 2011. Solutions for a cultivated planet. *Nature* **478**: 337–42.

Friel S and Baker PI. 2009. Equity, food security and health equity in the Asia Pacific region. *Asia Pac J Clin Nutr* **18**: 620–32.

Glamann J, Hanspach J, Abson DJ, *et al.* 2017. The intersection of food security and biodiversity conservation: a review. *Reg Environ Change* **17**: 1303–13.

Green RE, Cornell SJ, Scharlemann JPW, and Balmford A. 2005. Farming and the fate of wild nature. *Science* **307**: 550–55.

Haddad L. 2015. Equity: not only for idealists. *Dev Policy Rev* **33**: 5–13.

Laurance WF, Sayer J, and Cassman KG. 2014. Agricultural expansion and its impacts on tropical nature. *Trends Ecol Evol* **29**: 107–16.

Lerner AM and Eakin H. 2011. An obsolete dichotomy? Rethinking the rural–urban interface in terms of food security and production in the Global South. *Geogr J* **177**: 311–20.

Lipton M and Saghai Y. 2017. Food security, farmland access ethics, and land reform. *Global Food Security* **12**: 59–66.

Liu JG, Dietz T, Carpenter SR, *et al.* 2007. Complexity of coupled human and natural systems. *Science* **317**: 1513–16.

Liu JG, Hull V, Batistella M, *et al.* 2013. Framing sustainability in a telecoupled world. *Ecol Soc* **18**: art26.
Loos J, Abson DJ, Chappell MJ, *et al.* 2014. Putting meaning back into "sustainable intensification". *Front Ecol Environ* **12**: 347–55.
Lutz W and Samir KC. 2011. Global human capital: integrating education and population. *Science* **333**: 587–92.
Matson PA, Parton WJ, Power AG, and Swift MJ. 1997. Agricultural intensification and ecosystem properties. *Science* **277**: 504–09.
Mikulcak F, Haider JL, Abson DJ, *et al.* 2015. Applying a capitals approach to understand rural development traps: a case study from post-socialist Romania. *Land Use Policy* **43**: 248–58.
Perfecto I and Vandermeer J. 2010. The agroecological matrix as alternative to the land-sparing/agriculture intensification model. *P Natl Acad Sci USA* **107**: 5786–91.
Phalan B, Green RE, Dicks LV, *et al.* 2016. How can higher-yield farming help to spare nature? *Science* **351**: 450–51.
Seto KC, Reenberg A, Boone CG, *et al.* 2012. Urban land teleconnections and sustainability. *P Natl Acad Sci USA* **109**: 7687–92.
Sunderland TCH. 2011. Food security: why is biodiversity important? *Int Forest Rev* **13**: 265–74.
Tilman D, Balzer C, Hill J, and Befort BL. 2011. Global food demand and the sustainable intensification of agriculture. *P Natl Acad Sci USA* **108**: 20260–64.
UN (United Nations). 2015. Transforming our world: the 2030 Agenda for Sustainable Development. United Nations, The General Assembly. http://bit.ly/1OTd4Sr. Viewed 28 Aug 2017.
Wittman H, Abson DJ, Kerr RB, *et al.* 2017. A social–ecological perspective on harmonizing food security and biodiversity conservation. *Reg Environ Change* **17**: 1291–301.
Wittman H, Desmarais AA, and Wiebe N (Eds). 2010. Food sovereignty: reconnecting food, nature and community. Oakland, CA: Food First Books.
World Bank. 2007. World development report 2008: agriculture for development. Washington, DC: World Bank.
Wu JG. 2013. Landscape sustainability science: ecosystem services and human well-being in changing landscapes. *Landscape Ecol* **28**: 999–1023.
Zimmerer KS. 2013. The compatibility of agricultural intensification in a global hotspot of smallholder agrobiodiversity (Bolivia). *P Natl Acad Sci USA* **110**: 2769–74.

Supporting Information

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