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ORIGINAL ARTICLE

The intersection of food security and biodiversity conservation: a review

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Abstract Food security and biodiversity conservation are key challenges of the twenty-first century. While traditionally these two challenges were addressed separately, recently, papers have begun to specifically address the nexus of food security and biodiversity conservation. We conducted a structured literature review of 91 papers addressing this nexus. To ascertain how a given paper approached the topic, we assessed to what extent it covered 68 potentially relevant issues. The resulting dataset was analyzed using cluster analysis. Two main branches of literature, containing a total of six clusters of papers, were identified. The "biophysical-technical" branch (clusters: "sustainable intensification" and "production focus") was dominated by the natural sciences, focused strongly on the production aspect of food security, and sought general solutions. In contrast, the "social-political" branch (clusters: "social-ecological development"; "empowerment for food security"; "agroecology and food sovereignty"; and "social-ecological systems") often drew on the social sciences and emphasized social relations and governance, alongside broader considerations of sustainability and human well-being. While the biophysical-technical branch was often global in focus, much of the social-political branch focused on specific localities. Two clusters of papers, one from each branch, stood out as being particularly broad in scope—namely the clusters on "sustainable intensification" and "agroecology and food sovereignty." Despite major differences in their conceptual basis, we argue that exchange between these two research clusters could be particularly helpful in generating insights on the food–biodiversity nexus that are both generally applicable and sufficiently nuanced to capture key system-specific variables.

Keywords Agroecology · Biodiversity conservation · Cluster analysis · Food sovereignty · Food security · Sustainable intensification

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Introduction

Food security is typically defined as "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life" (FAO 2002), and biodiversity refers to the variety of genes, species, and ecosystems. Increasing global food security and conserving biodiversity are two of the world's most pressing challenges. Although food production has increased rapidly since the green revolution following the Second World War, approximately 880 million to 1.3 billion people are chronically food insecure, and up to 2 billion people remain undernourished (FAO 2014). Many food-insecure regions of the world also contain regions of rich biodiversity such as the tropical forests of Africa, Southeast Asia, and South America.

Historically, food security and biodiversity conservation have been dealt with as separate issues, each with their own scholarly approaches, debates, and understandings. However, recently there is increased awareness that conserving biodiversity and ensuring the food security of a growing human population are inextricably interrelated issues (Brussaard et al. 2010; Chappell and LaValle 2011; Garnett et al. 2013; Tscharntke et al. 2012). Arable land and land under permanent crops cover approximately 11 % or 1.5 billion hectares of Earth's land surface, and there are approximately 2.7 billion hectares of land under some form of agricultural use, whether crop production, livestock grazing, or agroforestry (FAO 2014). Within the next few decades, developing countries as a whole could increase cultivated land by approximately 110 million hectares (Alexandratos and Bruinsma 2012). Such an expansion of agricultural land, in turn, would pose a major threat to biodiversity (Foley et al. 2005; Gaston et al. 2003), especially because most of this expansion is expected to take place in areas with high conservation value. For example, Pouzols et al. (2014) found that "if projected landuse change by 2040 takes place… over 1000 threatened [vertebrate] species would lose more than 50 % of their present effective ranges worldwide" (p. 383). In addition to such global losses of biodiversity, local and regional extinctions are likely. For example, in the past decade, large swathes of lowland tropical forest in Southeast Asia have been cleared for oil palm and timber plantations, causing catastrophic declines in many species (Koh and Wilcove 2008; Sodhi et al. 2004).

Despite close connections between food security and biodiversity conservation, there is no coherent body of academic literature specifically addressing the nexus of food security and biodiversity conservation. Different approaches and perspectives are driven, in part, by the assumptions and traditions of the scientific disciplines that engage in this topic (Fischer et al. 2008). Some existing approaches emphasize single issues such as increasing food production while minimizing impacts on biodiversity (e.g., Foley et al. 2011; Tilman et al. 2011). Other approaches strive to address the food–biodiversity nexus more holistically, for example through social-ecological system analysis that considers the connection between issues such as poverty, equity, and corruption in addition to food supply (e.g., Altieri et al. 2012; Chappell and LaValle 2011; Fischer et al. 2014).

Given the limitations of "one size fits all solutions" (Beddington 2010), pluralistic approaches to studying and managing the nexus of food and biodiversity conservation are to be welcomed. However, we need to better understand the broad types of approaches found in this emerging field, and how these approaches relate to one another. For this reason, we undertook a quantitative review of recent academic literature on the food–biodiversity nexus. Our aims were to (1) identify and characterize the suite of different approaches being used to study the food security–biodiversity nexus; (2) identify similarities and differences between these approaches; and (3) highlight potential synergies that might facilitate a more holistic approach to conceptualizing and researching the nexus of food security and biodiversity conservation in the future.

Although we tried not to judge the different approaches and perspectives that we identify, we caution that any such analysis and its interpretation are inevitably somewhat subjective. Nevertheless, we believe that a broad scoping of this research topic is important at this point of its development, while the different strands of research are still relatively new and amenable to the incorporation of new ideas and approaches drawn from outside their own research communities.

Methods

Literature selection

We undertook a literature search of Scopus and Web of Science on October 1, 2014 using the keywords "food security" and "biodiv*," and "conserv*" in TITLE–ABS–KEY (Scopus), or in TOPIC (Web of Science). We decided against using more specific keywords such as "sustainable intensification" or "food sovereignty" because they may have biased the subsequent analysis. We considered "food security" the oldest and broadest definition that includes more specific subfields. The search was limited to the years 2010–2014 in order to analyze the most recent developments in research on food security and biodiversity conservation. Our search was limited to English language journal articles. Conference papers, book chapters, and books were excluded from the Scopus search; meetings and books were excluded from the Web of Science search.

Every article returned from the search was assessed for relevance (based on a reading of the Abstract) and included in the analysis if it met all the following criteria. *Criteria one*: The article obviously focused on food security and biodiversity conservation. This intersection had to be evident, so papers with partial foci were excluded. For example, Nghiem (2013) ("Biodiversity conservation attitudes and policy tools for promoting biodiversity in tropical planted forests") focused on the conservation of tropical planted forests, but apart from a single mention in the Abstract had no strong link to food security. *Criteria two*: The article dealt with the food security–biodiversity nexus as a topic in general terms. We excluded papers that focused specifically on a very narrow set of issues. For example, Kibblewhite et al. (2012) ("Legal frameworks in soil protection: Current development and technical information requirements") focused too specifically on monitoring soils, and Jones et al. (2013) ("Identification of pro–vitamin A carotenoid–rich cultivars of breadfruit (Artocarpus, Moraceae)") focused too specifically on the underutilized breadfruit containing many provitamin A carotenoids. *Criteria three*: The article focused on terrestrial systems. Although we acknowledge the importance of aquatic systems, we chose not to include papers that dealt with marine, coastal, and aquatic ecosystems or aquaculture, such as Brander (2010) "Reconciling biodiversity conservation and marine capture fisheries production." The full text of an article was read if it was unclear whether the article met these three criteria.

Identification of key issues

The aim of the analysis was to evaluate the framings and perspectives regarding the nexus of food security and biodiversity conservation covered by each article. To that end, a scheme with 68 questions was developed to allow us to consistently assess these issues across the analyzed articles (Table S1). While it was inevitable that this analysis could not capture all potentially relevant issues, the questions were designed to broadly address seven themes repeatedly discussed in the recent literature: (1) general approach to investigating the food security–biodiversity nexus: economic, ecological, political/institutional; (2) conceptual basis and farming practices, such as sustainable intensification, food sovereignty, land sparing–land sharing; (3) food security: We included the well-known criteria of availability, accessibility, and utilization (FAO 2014), as well as three additional As proposed by Rocha (2007, 2008). These are acceptability (culturally suitable food produced in a way not compromising human rights or dignity), adequacy (ecological sustainability and safety of produced food), and agency (sociopolitical requirements and systems enabling food security); (4) measurement of biodiversity, such as single species/taxon, genetic diversity, species richness and abundance, apparent or associated biodiversity; (5) social structures, government, and policy; (6) economic aspects and consumption patterns; and (7) other aspects such as cultural ecosystem services and spatial scales.

All articles were scored on each question using a scale from zero to two. An article scored zero if it did not consider a given issue at all, or rejected the importance of that issue for understanding or managing the biodiversity–food security nexus. An article scored one for a given issue if it agreed with or considered it to some extent, and an article scored two for a question if it agreed with or considered it to a great extent. For example, Garnett et al. (2013) scored two for the question "Paper discusses arguments for sustainable intensification," because such arguments were central to this paper (see Table S1 for the full set of issues considered).

Data analysis

After coding each paper on each of the 68 questions, we used agglomerative hierarchical cluster analysis, a method widely used to find grouping structures in multivariate data. Agglomerative clustering starts with the single elements and successively groups these elements together. We used Ward's clustering method as a grouping method and Gower dissimilarities as the measure of association. Gower dissimilarity is a symmetrical index for quantitative data, and we square-transformed the dissimilarity matrix to obtain Euclidean characteristics (Legendre and Legendre 2003). Ward's clustering was chosen because it usually produces clear group structures (no problems with chaining), and the resulting clusters were readily interpretable. This method finds clusters by minimizing the variance to the geometric centroids of the groups. Based on the cluster analysis, we derived a dendrogram to visualize broad patterns within the perspectives discussed in the papers and visually identified a conveniently small set of clusters. Analyses were performed using R version 3.0.1 (R Development Core Team 2012).

In addition, we assessed the scientific "impact" of each cluster using the 5-year impact factors of the journals in which the articles were published. For each cluster, we calculated the mean as well as the standard derivation (SD) of these journal impact factors. To highlight the most important topics and issues of a given cluster, a representative quote was selected to characterize papers in each cluster (see Table S2 for additional characteristic quotes for each cluster). These subjectively selected quotes were intended to provide a tangible glimpse into each cluster—the purpose of the quotes was not to depict the whole range of issues addressed in a given paper or cluster.

Results

The initial search returned a total of 228 unique articles. Using our defined selection criteria, we excluded 137 articles, leaving 91 for the analysis (Table S3). These articles were published in 58 different journals. The most frequently addressed issue was the availability of food (88 articles), followed by consideration of spatial scale (79 articles). On average, a given issue was addressed only in 33 % of papers (SD = 22 %).

Cluster analysis

A visual inspection of the dendrogram suggested the papers could be meaningfully grouped into six distinct clusters. These occurred in two large branches, one comprising two and the other comprising four clusters (Fig. 1). Articles in the first branch of the dendrogram generally conceptualized the challenge of achieving food security and biodiversity conservation as primarily a "technical" task, based on the application of, largely natural, sciences in order to ascertain the most efficient allocation of resources. Papers in this branch typically had a strong focus on biophysical measures and relatively little focus on the broader socioeconomic or sociopolitical contexts within which the systems studied were situated. In contrast, the second major branch of the dendrogram primarily focused on social relations and how humans relate to and interact with their environments. This branch had a stronger focus on the (often local) sociopolitical context and often had a more multifacetted perspective on the food security–biodiversity conservation nexus.

Within these two major branches, we named the clusters according to the themes they predominantly addressed. Biophysical-technical branch—(1) sustainable intensification ($n = 12$); (2) production focus ($n = 21$); social-political branch—(3) social-ecological development ($n = 22$); (4) empowerment for food security ($n = 15$); (5) agroecology and food sovereignty ($n = 14$); and (6) social-ecological systems ($n = 16$). Full citations for the papers in each cluster can be found in Table S3 in the supplementary material. It is important to note that not all papers falling into a particular branch, or cluster, necessarily advocated the approaches being discussed in that cluster (e.g., Bos et al. (2013) in the cluster on sustainable intensification discussed the concept at length, but was relatively ambivalent toward it).

The biophysical-technical branch ($n = 33$)

Sustainable intensification ($n = 12$)

> *"Defining better targets for more environmentally sustainable intensification of production must address the whole food production and distribution system. Although we focus primarily on the production sector, it is also critical to recognise that other efficiencies in the global food system could boost food availability […]. For example, significant amounts of food are lost in storage or distribution"* (Cunningham et al. 2013, p. 23).

This cluster focused on producing more food while minimizing impacts on biodiversity via "sustainable intensification"(e.g., Garnett et al. 2013; Heaton et al. 2013), that is, "the process of enhancing agricultural yields with minimal environmental impact and without expanding the existing agricultural land base" (Loos et al. 2014, p. 356). Papers in this cluster did not typically focus on a specific type of farming system (e.g., conventional or organic), and biotechnological approaches were addressed by different papers (including genetically modified organisms). Social problems such as unequal distribution, poverty, or consumption patterns (meat, dairy, waste) were regularly recognized by articles in this cluster (e.g., Acevedo 2011; Cunningham et al. 2013), but received relatively less emphasis than production issues. Despite sustainable intensification being partly motivated by a desire for biodiversity conservation, specific discussions of biodiversity management were uncommon. In terms of food security, the cluster emphasized food availability (all papers), and to a lesser extent accessibility (8 papers) and utilization of food (4 papers). All but one of the publications in this cluster were conceptual or review papers.

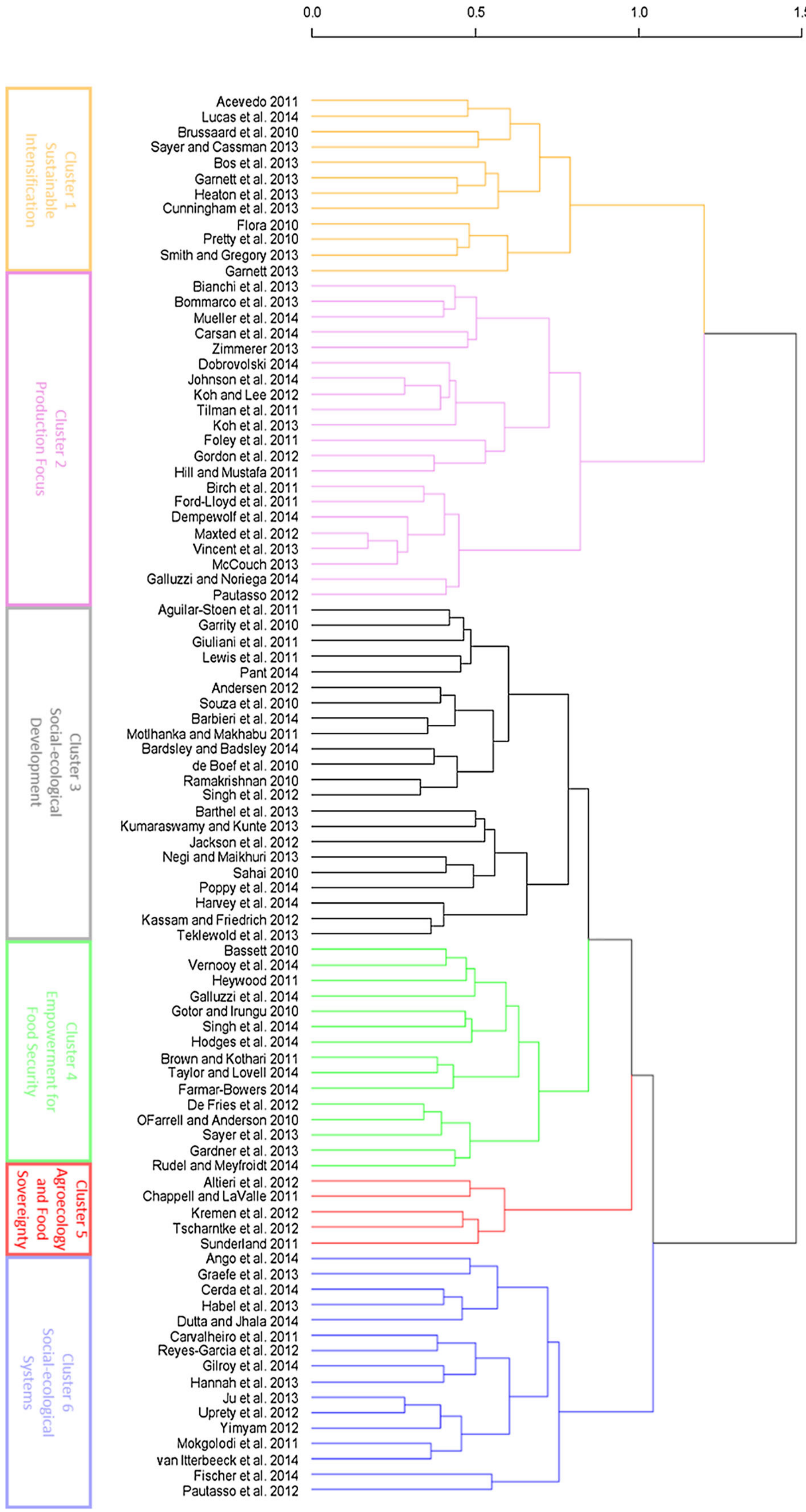
Production focus ($n = 21$)

> *"First, the transformation of agriculture must deliver sufficient food and nutrition to the world. To meet the projected demands of population growth and increasing consumption, we must roughly double food supplies in the next few decades"* (Foley et al. 2011, p. 338).

This cluster focused strongly on increasing agricultural production while minimizing negative impacts on biodiversity. Food production was seen as a meaningful end in its own right, with little or no explicit regard for accessibility (4 papers) or the sociopolitical context in which such yield increases might occur. In terms of biodiversity, many papers focused on genetic diversity (11 papers) and discussed issues related to spatial scales (15 papers). Regarding food security, the main focus was on the availability of food (all papers) and the ecological appropriateness of food production (16 papers). This cluster had the strongest link to (non-crop related) biodiversity assessment of any of the clusters in the analysis (e.g., Dutta and Jhala 2014; Gilroy et al. 2014). However, papers in this cluster often lacked a precise definition of the conservation concerns or empirical measurement of biodiversity.

Three subclusters were identifiable within the "production focus" cluster. "Food Production via Agrobiodiversity" ($n = 5$) favoured an ecological approach to increasing agricultural yields (e.g., Bommarco et al. 2013). "More Food for More People" ($n = 8$) emphasized the assumed need to produce more food to successfully feed a growing world population, generally taking a global

Fig. 1 Dendrogram illustrating how the analyzed papers addressed the intersection of food security and biodiversity conservation. Two main branches could be distinguished, consisting of two and four clusters, respectively—a biophysical-technical branch (clusters 1, 2) versus a social-political branch (clusters 3, 4, 5, 6)



perspective and often considering potential production opportunities, such as closing yield gaps (6 papers, e.g., Foley et al. 2011; Koh et al. 2013). "Production via Genetic Resources" ($n = 8$) particularly emphasized the importance of particular crops or crop wild relatives (e.g., Dempewolf et al. 2014; Pautasso 2012), emphasizing genetic diversity (7 papers), usually within the agricultural crops themselves.

The social-political branch ($n = 58$)

Social-ecological development ($n = 22$)

> *"Technological innovation is necessary but not sufficient to achieve food security. This article uses interlinked social, ecological and technical systems theory to investigate why agricultural biodiversity-rich developing countries fail to utilize 'agroecological competence'"* (Pant 2014 p. 336).

This cluster focused strongly on the sociopolitical contexts in which food security and conservation are to be achieved, with a particular focus on marginalized communities and the developing world (e.g., Andersen 2012; Lewis et al. 2011). Papers in this cluster tended to take a landscape to regional perspective with an emphasis on social issues (e.g., Barbieri et al. 2014; Bardsley and Bardsley 2014). Rural livelihoods (all papers), the importance of policy (18 papers), and cultural ecosystem services (15 papers) were emphasized. Many papers considered food security and biodiversity conservation as complementary (rather than conflicting) goals, whose harmonization could provide pathways for sustainable development (e.g., Pant 2014). In terms of biodiversity, single species (6 papers) and genetic diversity (7 papers) were most represented. In terms of food security, all papers considered availability, but many also considered accessibility (17 papers), appropriateness (19 papers), and acceptability (14 papers). Unlike the cluster "More Food for More People," crop wild relatives here were not considered in terms of their production potential, but as important for protecting the valuable knowledge of "wise" indigenous farmers who were using crop wild relatives as safeguards for securing food (e.g., Barbieri et al. 2014; Ju et al. 2013). As with the cluster "production focus," biodiversity was considered valuable primarily because it directly contributed to food security—with a food security perspective focused on more local scales and specific communities (e.g., Aguilar-Støen et al. 2011).

Within this cluster, there were two distinct subclusters: "Development Focus" ($n = 13$) typically focused on understanding how local social-ecological understandings could aid in sustainable development (e.g., Aguilar-Støen et al. 2011; Motlhanka and Makhabu 2011). These papers tended to take a case study approach. In contrast, papers using "social-agroecological approaches" ($n = 9$) often had a more global or conceptual lens to address the food security–biodiversity nexus (e.g., Jackson et al. 2012; Kassam and Friedrich 2012), while maintaining a strong focus on smallholder farmers (all papers), political approaches (7 papers), and traditional knowledge (all papers).

Empowerment for food security ($n = 15$)

> *"Top-down solutions for reducing tropical deforestation [ref.] or for enhancing food security [ref.] do not assure success without bottom-up efforts to identify solutions appropriate to particular places. Research to identify effective modes of engagement between scientists and decision-makers working at different scales of governance (e.g., international, national, state, and community) and analyses (e.g., global, watershed, patch) is an important frontier"* (DeFries et al. 2012, p. 604).

This cluster focused on the role of the economy, policy, and government. Most articles (12 papers) argued that social aspects in rural areas, such as poverty and injustice, were the main reasons for food insecurity (e.g., Bassett 2010; Lewis et al. 2011). Agency and food sovereignty were emphasized (e.g., Brown and Kothari 2011)—rural areas needed to be empowered to produce and consume their own food because they harbored practices and knowledge essential for food security. Papers in this cluster often suggested that by maintaining power over food production and resisting the adoption of unsustainable practices, biodiversity would also benefit (e.g., Sayer et al. 2013). This cluster had the strongest focus on gender inequality (9 papers) and called for explicit involvement of stakeholders (14 papers). Biodiversity was rarely conceptualized in detail, with the majority of papers not dealing with any concrete aspects of biodiversity conservation.

Agroecology and food sovereignty ($n = 5$)

> *"Agroecology-based production systems are biodiverse, resilient, energetically efficient, socially just, and comprise the basis of an energy, productive and food sovereignty strategy"* (Altieri et al. 2012, p. 2).

This cluster focused on multiple aspects of food security and biodiversity. The agroecological approach applies ecological theory to the management of agricultural systems and considers the interactions of important biophysical and socioeconomic components of farming systems (e.g., Altieri et al. 2012; Chappell and LaValle 2011).

Papers in this cluster studied the role of smallholders applying agroecology practices such as crop rotations, intercropping, or no-till agriculture in providing both food security and biodiversity conservation (Chappell and LaValle 2011). The articles in this cluster, on the one hand, addressed food availability and adequacy of production and, on the other hand, addressed accessibility and agency through the concept of food sovereignty (e.g., Altieri et al. 2012)—which values people's rights to decide without undue outside pressure which foods they would like to market and consume (Wittman 2010). Papers in this cluster typically argued that global food production was already sufficient to feed the world, and that further intensification of agriculture would have unnecessary, negative impacts on biodiversity. It was often argued that agroecological approaches supported greater biodiversity than conventional agriculture. Regarding food insecurity, emphasis was placed on social aspects, such as unequal distribution (4 papers), injustice, or lack of education (4 papers). Explicit concern for temporal scales when considering the food security–biodiversity conservation nexus was emphasized (all papers).

Social-ecological systems (n = 16)

> *"More diverse (agro-)ecosystems tend to show higher socioecological resilience to disturbances and unforeseen events [ref.]. Multispecies cropping systems can enhance soil fertility, diminish losses due to pathogens and pests, and help farmers adapt to changing environmental, socio-cultural, and market conditions"* (Pautasso et al. 2013, p. 153).

The final cluster in the social-political branch was the most difficult to characterize, in part because the papers in this cluster took a broad systems approach to the food security–biodiversity conservation nexus. As with other clusters in this branch, there was a strong focus on rural livelihoods (13 papers) and local/traditional knowledge (11 papers). In terms of food security, the papers dealt with availability (10 papers), accessibility (10 papers), and appropriateness (15 papers). In terms of biodiversity, single species (10 papers), species richness (9 papers), and genetic diversity (6 papers) were all addressed. A unifying factor for papers in this cluster was a "systematic" approach to the food security–biodiversity conservation nexus addressing a range of both social and biophysical issues. This included different analytical frameworks, including ecosystems services (e.g., Ango et al. 2014; Ju et al. 2013), land sharing–land sparing (e.g., Gilroy et al. 2014; Habel et al. 2013), or general systems thinking (e.g., Fischer et al. 2014). There was a strong focus on spatial scales, with all papers in the cluster addressing this issue.

Impact factor analysis

The mean impact factors of the publications within the biophysical-technical branch (5-year impact factors: 8.03) were approximately two and a half times as high as those in the social-political branch (Table 1). Journals publishing papers in the cluster "production focus" had the highest mean impact (8.93; SD = 11.65), while journals publishing papers in the "social-ecological systems" cluster had the lowest mean impact (2.76; SD = 1.93).

Discussion

While discussions about food security and biodiversity conservation provide space for multiple perspectives and worldviews (e.g., Ericksen 2008), our research strongly suggests that there are two major and quite distinct approaches to conceptualizing the nexus of food security and biodiversity conservation. This difference is important because the two most prevalent approaches—biophysical-technical approaches and social-political approaches—imply rather different potential policy interventions.

The biophysical-technical approach is focused primarily on the, generally justified, assumption (e.g., Gaston et al. 2003) of an inherent trade-off between food production and biodiversity conservation. Addressing this trade-off is conceptualized as a largely technical challenge where the provision of two socially valued "goods" (food and biodiversity) can be optimized via the efficient allocation and use of land (Fischer et al. 2014). This approach focuses heavily on biophysical measurements and interventions and comes largely from a more quantitative, natural science tradition, where generalizability and empirical hypothesis testing of simplified model systems are highly valued.

Although papers in the biophysical-technical branch often acknowledge that food security is determined not only by production levels, production typically remains the primary focus of most papers. The focus on one particular aspect of the food security–biodiversity nexus (such as agricultural production) is driven by what might be termed a classical reductionist approach to studying complex systems—where it is assumed that food production, consumptive demand, governance, and other issues can be meaningfully studied in isolation from one another (Loos et al. 2014). While there is obvious value in understanding how different land uses and technical interventions influence levels of food production and biodiversity, a biophysical-technical understanding on its own does not explain how the proposed (technical) solutions could or should be implemented. In fact, it appears that in this approach, individual human or societal values, preferences,

Table 1 Impact factor analysis of each cluster in the dendrogram

Cluster	Branch	Cluster name	*n*	Mean	SD
1	Biophysical-technical	Sustainable intensification	12	6.46	9.41
2	Biophysical-technical	Production focus	21	8.93	11.65
3	Social-political	Social-ecological development	22	3.30	3.06
4	Social-political	Empowerment for food security	15	3.71	3.51
5	Social-political	Agroecology and food sovereignty	5	3.47	1.37
6	Social-political	Social-ecological systems	16	2.76	1.9

Only papers in journals that had an ISI-listed impact factor were included in the analysis

or agency are seen as playing relatively minor roles in tackling the trade-offs between biodiversity conservation and food production. Similarly, there is typically no disaggregated assessment of the actual benefits of the suggested technical interventions (e.g., to whom the increased food production flows, and whether such flows are socially desirable). Despite criticism of the highly simplified conceptual frameworks underpinning the biophysical-technical approach (Kremen 2015), the relatively high impact of many papers applying this approach suggests that it clearly has considerable appeal within the scientific community.

In contrast, papers in the social-political branch do not necessarily assume that there is an inherent trade-off between food production and biodiversity conservation (Chappell and LaValle 2011). Instead, it is argued that the maintenance of biodiversity may be essential for ensuring food security (Frison et al. 2011). Moreover, there is a greater emphasis on issues of equity, justice, and distribution than on aggregate food production levels, and generally greater interest in the role of values, governance, and human agency in determining biodiversity and food security outcomes. Context-specific approaches that explicitly address not only ecological conditions, but aspects of political economy and social relations, are favoured by papers in this branch over generalizable quantitative models.

The social-political branch takes a more holistic, but often more local perspective, leading to more nuanced but less generalizable models of the food–biodiversity nexus. A highly contextualized approach, together with a greater emphasis of the social sciences, may explain the lower scientific impact of journals typically publishing this branch of research. Nevertheless, there is considerable merit in acknowledging that both food security and biodiversity conservation outcomes are often context dependent and result from complex interactions of multiple drivers across temporal and spatial scales (e.g., DeFries et al. 2012), even if this limits the possibility for individual studies to provide global analyses or "globally relevant solutions."

At first glance, the conceptual distance between the two broad approaches identified here may suggest two competing (or even mutually exclusive) discourses. Yet, drilling down to the specific research clusters within these two discourses offers hope that the gap between the two branches of research may be usefully bridged. Bridging the divide between the biophysical-technical and social-political approaches may help to provide a more nuanced and holistic approach that is still broadly applicable across different systems, spatial and temporal scales. The clusters on "sustainable intensification" and "agroecology and food sovereignty" appear to have great conceptual distance between them (Fig. 1) and are based on rather different foundational assumptions and analytical framings—generalizable, quantitative models premised on efficient allocation versus context-specific, often qualitative models premised on human agency and localized solutions. Nevertheless, we argue that there are potentially useful ways to bridging these two clusters and therefore to bring together the biophysical-technical and social-political approaches that dominate the current discourse. Both clusters are characterized by a desire to engage with a broad range of potentially intersecting issues. Moreover, both clusters frame the food security–biodiversity nexus within the broader normative framework of sustainability. While the cluster on "sustainable intensification" addresses sustainability through efficient resource use, the "agroecology and food sovereignty" cluster is more focused on sustainability as an issue of inter- and intragenerational justice. These are not mutually exclusive framings. In particular, efficiency is not an intrinsic goal, but rather an instrumental means. We see no compelling reason why the technical, "allocative" approaches suggested by the current sustainable intensification literature could not be considered within a more localized and sociopolitically contextualized actor-centric manner, as proposed in the agroecology literature.

To facilitate greater cross-fertilization between research clusters, one major challenge will be recognition of the benefits and limitations of models favoured by the two broad approaches to the food security–biodiversity nexus—relatively simple, generalizable "neat" models versus relatively "messy," complex- and context-dependent models. Bridging this divide will require explicit consideration of the scientific traditions and related, often normative, assumptions that underpin different heuristic models (Fischer et al. 2008). George Box and Norman Baker famously stated that "all models are wrong, the practical question is how wrong do they have to be to not be useful" (Box and Draper 1987 p. 74). This is a question that researchers on the nexus of food security and biodiversity conservation need to engage with more deeply. In particular, how can relatively simple, biophysical-technical models be usefully contextualized to account for important social, political, and ecological factors that determine real-world food security and biodiversity outcomes?

A second challenge is the "scale of analysis gap" between the more globally focused biophysical-technical literature (e.g., Foley et al. 2011) and more locally focused social-political literature (e.g., Barbieri et al. 2014). At the most basic level, biophysical-technical approaches may be useful for identifying regions, or even landscapes, where potential opportunities or conflicts regarding biodiversity conservation and food security may exist. Such "regions of interest" could then be explored in more detail through a more nuanced social-political lens. For example, while yield gap analyses can identify where there may be opportunities to increase production, a social-political approach is required to understand what the long-term outcomes of increased agricultural production are likely to mean in any given landscape, both in terms of biodiversity and food security.

From a more integrated perspective, a social-ecological systems approach might also facilitate improved integration across the two research branches. Both aggregate levels of agricultural production and local conditions influence food security and biodiversity conservation outcomes at multiple scales. Systems approaches acknowledge such cross-scale interactions and thereby provide a potential bridge across different methodological approaches. Here, the outcomes in terms of food security and biodiversity conservation are conceptualized as responses to dynamic, interacting, multiscale, biophysical, socioeconomic and political processes, or system properties. Relevant system properties include land-use patterns, levels of production and intensification, but crucially also the mediating sociopolitical factors from local to global scales.

Conclusion

Research on the nexus of food security and biodiversity conservation is a relatively recent phenomenon. However, already this research appears to be coalescing into two distinct and potentially oppositional worldviews, which are driven by different underlying assumptions regarding both the nature of the problem and the best means to address this problem. Our analysis suggests there may be scope for bridging the gap between broad stroke, globalized biophysical-technical solutions, and more complex, locally contextualized social-ecological solutions. To do so requires open and constructive dialog on both sides of this divide, and explicit regard of the often hidden assumptions and foundational analytical frames that underpin these two broad approaches.

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