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Coordinating ecosystem service trade-offs to achieve win-win outcomes: A review of the approaches

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ABSTRACT

Ecosystem service (ES) trade-offs have been broadly recognized and studied over the past decade. However, how to coordinate the relationships among ES trade-offs to achieve win-win outcomes remains a considerable challenge for decision makers. Here, we summarize the current approaches applied to minimize ES trade-offs for win-wins and analyze the trade-offs among different ESs and their drivers. Based on a systematic review of the literature from 2005 to 2018, we identified 170 potentially relevant articles, 47 of which were selected for the review, recording 70 actual or potential trade-offs. Analysis of these case studies showed that trade-off pairs between provisioning services and regulating services/biodiversity accounted for 80% of total pairs. Furthermore, more than half of the ES trade-offs were driven by land use/land cover changes. Harvest and resource demand, natural resource management, and policy instruments were also among the main drivers. Four approaches to coordinate ES trade-offs were identified, including ecosystem, landscape-scale, multi-objective optimization, and policy intervention (and other) approaches. Based on the above, we recommend a rigorous understanding of the roles of different stakeholders, spatial scales of management, trade-off dynamics, and integrated implementation of diverse approaches to coordinate ES trade-offs in order to better achieve win-win outcomes.

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Introduction

Ecosystem services (ESs) can provide a wide range of advantages for humans, including provisioning, regulating, and cultural services that benefit both private and public interests in different sectors of society (Howe et al., 2014). Trade-offs occur when multiple ESs (e.g., agricultural production, water purification, carbon sequestration) are competitively used, that is, a particular ES is captured by one stakeholder at the expense of another (Rodríguez et al., 2006). One of the great challenges for decision makers is coordinating the relationships among ES trade-offs to achieve win-win outcomes (Howe et al., 2014).

ES trade-offs have been broadly recognized over the past decade. Rodríguez et al. (2006) classified ES trade-offs into four basic categories: spatial trade-offs, temporal trade-offs, reversible trade-offs, and trade-offs among services. The Economics of Ecosystems and Biodiversity (TEEB) assessment (2010) proposed similar classifications: spatial trade-offs, temporal trade-offs, trade-offs between beneficiaries, and trade-offs among ESs. Mouchet et al. (2014) reconciled the previous classifications into three categories: supply–supply, supply–demand, and demand–demand. Furthermore, the drivers of ES trade-offs have also been systematically summarized (Dade et al., 2018). As a result of increasing demands on natural resources from a growing human population, intensification of trade-offs between ESs will increase globally and certain regions will experience rapid changes in the production and distribution of ESs (Alcamo et al., 2005). Understanding potential trade-offs will allow managers and other practitioners to minimize or eliminate losses to alternative services and formulate more effective, efficient, and defensible decisions (Wong et al., 2015).

Various studies have focused on quantifying and visualizing ES trade-offs (e.g., Ying et al., 2013; Kang et al., 2016) to provide better management methods for institutions and government by using relevant indicators (Ying et al., 2013; Zheng et al., 2016b) or scenarios (Bai et al., 2012a, 2012b; Kang et al., 2016) or by exploring the relationships between ES trade-offs and human well-being (Xu et al., 2016). Although trade-offs among different ESs are dynamic and non-linear – which are challenging aspects of natural resource management (Rodríguez et al., 2006) – many researchers have attempted to coordinate ES trade-offs for win-win outcomes (Howe et al., 2014). In practice, however, substantial evidence suggests that win-win scenarios are unlikely (Bennett et al., 2009) without carefully designed interventions (Howe et al., 2014) and suitable environmental management (Tallis et al., 2008).

In this paper, we focused on the current approaches used to minimize ES trade-offs for win-win outcomes. We analyzed the trade-offs among different ESs and reviewed their main drivers, focusing on case studies applying coordination approaches. Finally, we summarized the main approaches

for coordination ES trade-offs and discussed their implications in mitigating ES trade-offs in the future.

1. Methods

We searched the ISI Web of Science databases on December 20, 2018 and all peer-reviewed journal articles written in English were considered. Search string words were “ecosystem service*” AND (trade-off* OR trade off* OR tradeoff* OR trade-offs* OR trade offs* OR tradeoffs*) AND (minimize* OR coordinate* OR eliminate* OR resolve* OR mitigate* OR reduce*). We set the timeframe for our search between 2005 and 2018 because post-2005 covers the period in which ES research received an increasing amount of attention. We screened 170 articles and excluded 17 review papers. We read the titles and abstracts to find where trade-off and mitigation approaches were discussed to select appropriate papers. We then read the full text of each chosen article. As a result, 47 papers met our criteria. In each article, we recorded the (1) name of the ES and ES trade-off pairs; (2) drivers leading to ES trade-offs; and (3) approaches used to minimize ES trade-offs (Fig. 1).

Because the names of specific ESs were not always consistent among the reviewed articles, we categorized each ES studied into “groups” using the Common International Classification of Ecosystem Services (CICES) V4.3. This allowed for consistency in the identification of ES types among articles (Dade et al., 2018). The ES groups (<http://cices.eu/>) included: biomass-nutrition (i.e., food production); water (for human consumption); biomass-materials (e.g., timber); water-materials (e.g., water used for industrial manufacturing); biomass-based energy sources (i.e., biofuel); mechanical energy (e.g., hydropower); mediation by biota (e.g., carbon storage and sequestration); mediation by ecosystems (e.g., mediation of noise or smells); mass flows (e.g., erosion control); liquid flows (e.g., flood mitigation); gaseous/airflows (e.g., air ventilation); lifecycle maintenance, habitat, and gene pool protection (e.g., pollination); pest and disease control (e.g., pest regulation); soil formation and composition (e.g., soil fertility); water conditions (e.g., regulation of water quality); atmospheric composition and climate regulation (e.g., regulation of greenhouse gases); physical and experiential interactions (e.g., hiking); intellectual and representative interactions (e.g., education); spiritual and/or emblematic (e.g., spiritual identity); and other cultural outputs (e.g., the enjoyment from the existence of wild species) (Haines-Young and Potschin, 2013).

Similarly, to maintain consistency in the identification of drivers of ES trade-offs across articles, we categorized the drivers of ES trade-offs using the drivers of ES changes identified in MA (2005), which include: demographic (e.g.,

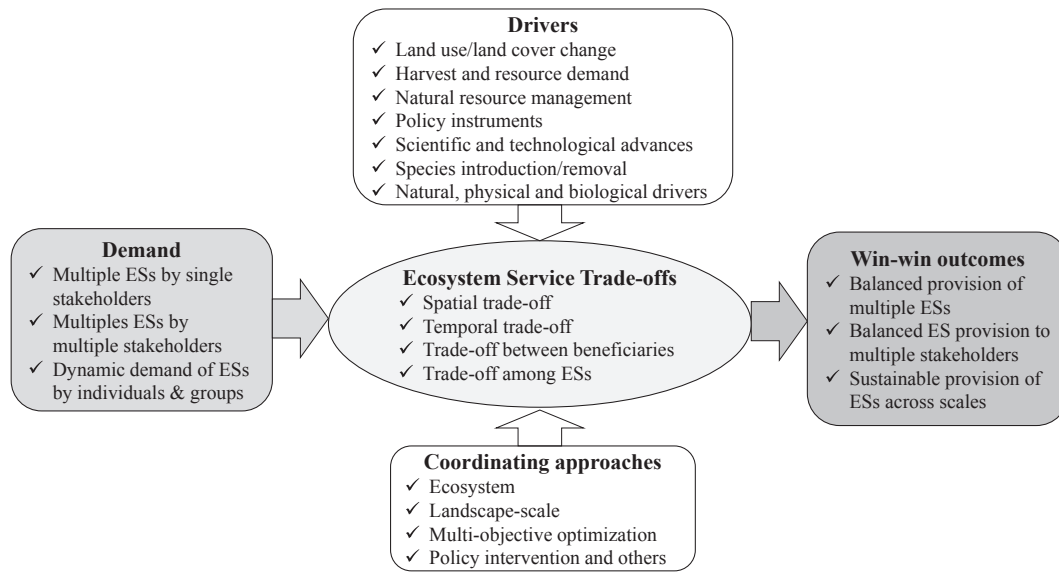


Fig. 1 – Framework for analyzing the types, drivers, and minimizations of ES trade-offs. Note: Drivers refer to MA (2005); Classification of Ecosystem Service (ES) trade-offs refers to TEEB (2010).

population size); socio-economic (e.g., average income); socio-political (e.g., type of governance); scientific and technological advances (e.g., advances in harvesting machinery); cultural and religious (e.g., religious values); policy instruments (e.g., incentives for behavioral changes); land use/land cover change (e.g., decreases in tree cover); species introductions/removals (e.g., introduction of pest control species); natural resource management (e.g., fertilizer use); harvest and resource demand (e.g., meat consumption); climate change (e.g., increasing atmospheric temperatures); and natural, physical, and biological drivers (e.g., soil type).

Based on the drivers of ES trade-offs, we classified the approaches to minimize ES trade-offs into four categories: ecosystem, landscape-scale, multiple objective optimization, and policy intervention (and other) approaches (Fig. 1). It is worth noting that in the context of this paper, win-wins or trade-offs do not refer to conservation and development exclusively, but relate to the competing uses of ESs, whether that is the same ES or multiple ESs within a given area, consistent with the rubric delineated by Howe et al. (2014).

2. Results

2.1. Main types of ES trade-offs

Of the 47 articles examined, a total of 70 ES trade-off pairs were assessed. The most common trade-off was between biomass (food production) and other ESs, mainly lifecycle maintenance, habitat, and gene pool protection (e.g., biodiversity) ($n = 12$), mediation by biota (e.g., carbon sequestration) ($n = 11$), water conditions (e.g., water quality) ($n = 9$), and water (e.g., nutrition) ($n = 5$) (Fig. 2).

The trade-off pairs between provisioning services (e.g., biomass-nutrition, biomass-materials) and regulating services

(e.g., mediation by biota, water conditions) and biodiversity (e.g., lifecycle maintenance, habitat, and gene pool protection) accounted for 80% of total pairs. Trade-offs existed between provisioning (e.g., biomass-nutrition, biomass-materials) and cultural services (e.g., physical and experiential interactions, other cultural outputs) (Fig. 2). In addition, trade-offs were also found among provisioning services (e.g., biomass-nutrition vs. water-nutrition) and among regulating services (e.g., mediation by biota vs. climate regulation) (Fig. 2).

2.2. Drivers and mechanisms of ES trade-offs

Many drivers of ES trade-offs were identified (Fig. 3). The most commonly identified driver was land use/land cover change (52.1%, $n = 25$). This included drivers such as vegetation cover and land use changes, especially conversion to cropland. Other common drivers of ES trade-offs were harvest and resource demand (e.g., timber production, forage provision, biofuel production, aquaculture; 20.8%, $n = 10$) and natural resource management (e.g., nitrogen or phosphorus application; 16.7%, $n = 8$). Policy instruments (e.g., price adjustment), scientific and technological advances (e.g., advances in agricultural technologies), species introduction/removal (e.g., exotic tree species), and natural, physical, and biological drivers (e.g., plant water use) were also associated with ES trade-offs (Fig. 3). Other drivers of ES trade-offs were not considered in the examined case studies.

2.3. Approaches to minimize ES trade-offs

In the reviewed studies, the main drivers of ES trade-offs included land use/land cover change, harvest and resource demand, and natural resource management (Fig. 3). These drivers also provide important information and actionable knowledge on how to minimize trade-offs among ESs. Land use/land cover changes alter ecosystem structures (e.g.,

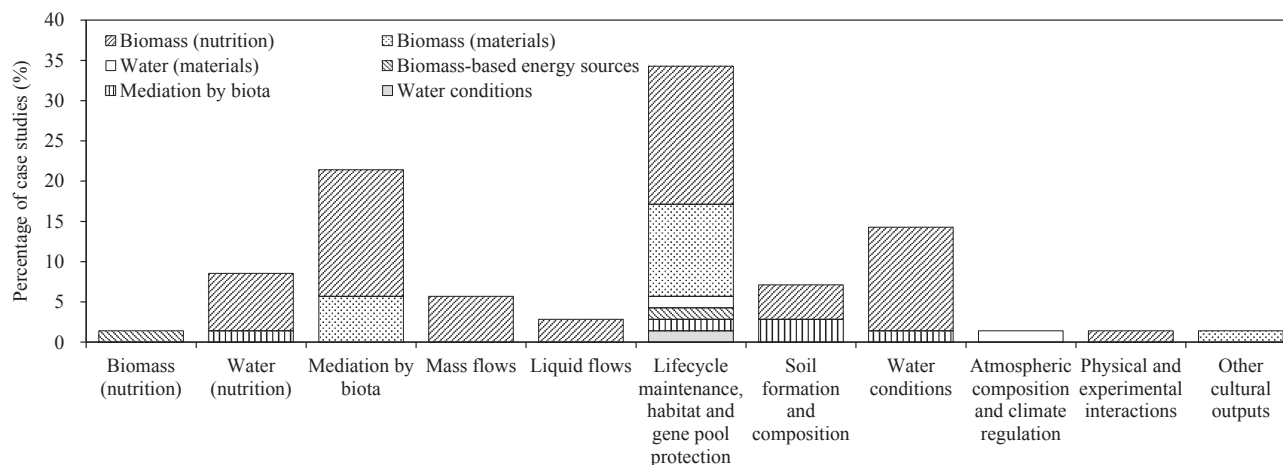


Fig. 2 – Percentage of reviewed case studies involving different types of ES trade-offs.

species composition, coverage, diversified layers), plant functional traits (e.g., tree height, leaf dry matter content, root depth, phenology) (Garnier et al., 2016), and landscape patterns (e.g., composition, configuration) (Qiu and Turner, 2015). Both cause direct changes that correspondingly impact ecological processes (e.g., primary production, water use efficiency, evapotranspiration rate) (He et al., 2018) and the delivery and interactions of ESs (e.g., product provision, carbon sequestration, flood mitigation, water purification) (Garnier et al., 2016). Other drivers (e.g., social consumption or demand, policy instruments) also indirectly impact trade-offs among ESs (Nelson et al., 2009). Rooted in direct and indirect drivers, ES trade-offs can be minimized through four types of approaches: that is, ecosystem, landscape-scale, multi-objective optimization, and policy interventions (and other) approaches.

2.3.1. Ecosystem approaches

In ecosystems, changes in plant composition and farming management are the main factors influencing ESs, which

also provide diverse regulating options for ES trade-offs. In particular, recent research has shown that plant functional traits significantly impact the delivery of ESs (Garnier et al., 2016).

Plant functional trait approaches. Land use and the abiotic environment strongly influence plant species composition and plant functional traits (e.g., tree height, leaf dry matter content), which drive differences in ecosystem properties and rates of photosynthesis, biomass allocation, and tissue turnover (Falster et al., 2018). Changes in plant functional properties and ecosystem properties correspondingly result in changes in ESs. By taking advantage of correlations and trade-offs among different functional traits, sustainable management of species and functional diversity can simultaneously conserve biodiversity and locally important ESs (Lavorel et al., 2011; Lavorel and Grigulis, 2012).

Many case studies have shown that plant morphological and functional traits can be used to minimize trade-offs between agricultural production and regulating services by combining

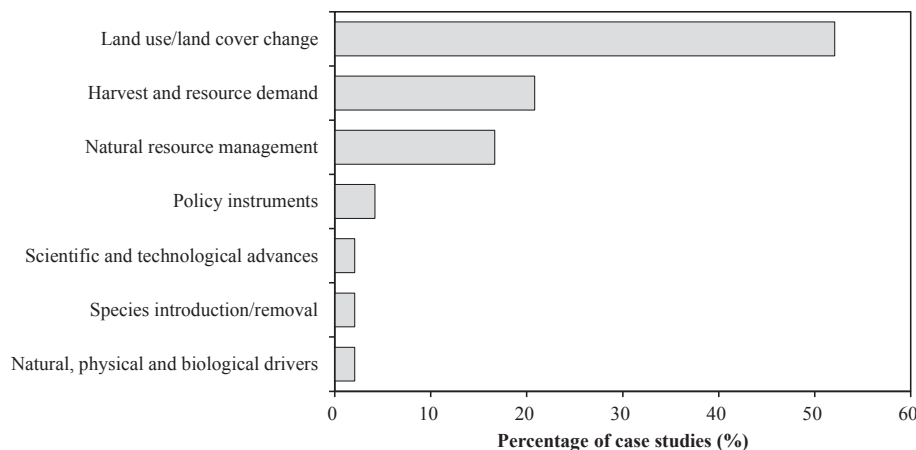


Fig. 3 – Percentage of examined cases that focused on drivers of ES trade-offs.

different shade trees in agro-forest ecosystems (Somarriba et al., 2013). The botanical composition of the shade canopy can provide many such traits (e.g., small canopies and small, light foliage; large, deep, and thick roots; rapid growth and high-density timber; inverted phenology; tall, cylindrical, and thick stem) to optimize shade canopy design. Design based on plant canopy traits has successfully helped to minimize trade-offs between cocoa production and carbon sequestration (Somarriba et al., 2013), as well as between rubber production and soil retention (Liu et al., 2016). However, low-shade agroforestry provides the best available compromise between economic forces and ecological needs. For instance, increased land use intensity in cacao agroforestry, coupled with a reduction in shade tree cover (moderate shade), provides greater biodiversity, maintains higher levels of ecosystem functioning, and increases farmers' net income (Steffan-Dewenter et al., 2007; Clough et al., 2011). Generally, increasing the diversity of plant functional traits through structural heterogeneity, large trees, and canopy gaps (e.g., nature-based management) can improve many ESs (e.g., timber production, biodiversity, carbon storage) (Lafond et al., 2015; Felipe-Lucia et al., 2018).

Farming management approaches. Effective management (e.g., fertilization, tillage, rotation, intercropping, resource harvesting) in farming systems can also help mitigate ES trade-offs. For example, zero tillage practices can help dampen the trade-offs between crop production and carbon sequestration (Manners and Varela-Ortega, 2018). Selecting different rotation lengths can help mitigate trade-offs between regulating (e.g., merchantable volume harvested, wood biomass production) and supporting services (e.g., soil fertility) (Gavito et al., 2015; Kang et al., 2016). Intercropping tea in rubber plantations can improve soil water retention and water use efficiency (Wu et al., 2016). The trade-offs between water yield and net primary production can be minimized by selecting drought-tolerant shrubs and grasses during ecological restoration in arid areas (Jia et al., 2014).

In fact, multiple farming management measures are often simultaneously utilized to reduce trade-offs among ESs in farming practice. For example, rotational grazing, stocking rate adjustments, and supplementary external inputs (e.g., fertilizer) can help to coordinate trade-offs between forage provisioning services, erosion control, and nutrient cycling (Daryanto et al., 2019). Combining different forest management regimes (e.g., setting aside continuous cover forests; adjustments to the frequency of thinning, timing of final felling, and the method of regeneration) can alleviate the negative effects of increased harvesting levels on biodiversity and non-wood ESs (Eyvindson et al., 2018). Applying diversified forest management planning (e.g., reducing thinning, extending the rotation period, and increasing the area set aside from forestry) can help minimize trade-offs between timber revenue, carbon storage, and biodiversity (Trivino et al., 2017).

2.3.2. Landscape-scale approaches

Landscape heterogeneity is an important driver of biodiversity and ESs. Dissimilar land-use types can complement each other by supporting different species pools and providing spatially or temporally separated resources for beneficial organisms (Tscharntke et al., 2012; Tarigan et al., 2016; Wong

et al., 2017). Habitat requirements for natural enemies and measures to prevent soil erosion and improve water quality require coordinated actions at the landscape scale (Geertsema et al., 2016). Optimizing landscape composition and configuration may influence the source-sink process and species composition and physical interdependency across space, which can, in turn, reduce ES trade-offs such as those between surface-water quality and crop production (Qiu and Turner, 2015) and between crop pollination and crop production (Elmqvist et al., 2013).

Landscape composition approaches. At the landscape scale, selective conservation of parts of natural habitats can mitigate the trade-offs between provisioning, regulating, and cultural services through enhancing the provisioning of important ESs (e.g., pollination, carbon sequestration). For instance, using strategic habitat conservation until 20%–25% of natural vegetation remains in the watershed, agricultural expansion can occur at little cost to biodiversity or water quality (Kennedy et al., 2016a). Given that up to 5% of land use/land cover can be modified within a sub-watershed, reducing cropland below 60% or increasing wetlands above 6% can largely mitigate phosphorus loading and enhance surface-water quality (Qiu and Turner, 2015). However, the delivery of ESs (e.g., maize production, pollination) is still dependent on crop location relative to other habitats (Werling et al., 2014; Brittain et al., 2013).

In addition, within heterogeneous landscape compositions, a multi-zoning approach, where by each zone receives a certain management intervention, is more beneficial than a single-zone approach. For example, multi-zoning can achieve up to 53% more co-benefits in terms of groundwater extraction for agriculture or recreational fisheries and biodiversity (Hermoso et al., 2018). In addition, a multi-zoning approach in which each zone contained multiple species but in different combinations is an effective way to provide multiple ESs at the landscape scale (e.g., tree biomass production and deadwood; dead-wood occurrence and game production potential; tree biomass production and production of bilberry and food for game) (Gamfeldt et al., 2013). Biodiversity-ES (e.g., carbon storage, recreation, esthetic and timber value) trade-offs could potentially also be addressed by targeting management interventions at different locations within a landscape (Cordingley et al., 2016).

Landscape configuration approaches. Landscape configuration also significantly impacts ecological processes, causing changes in ES delivery (Qiu and Turner, 2015). For instance, in sub-watersheds, relatively small changes in the spatial distribution of land cover (e.g., converting 5% of the area from cropland to wetland) can greatly enhance surface-water quality (Qiu and Turner, 2015). One important measure by which to coordinate ES trade-offs through optimizing landscape configuration is to establish buffer strips for croplands, roads, and rivers. A buffer strip that comprises only 10% of a given landscape's total area can make a 90% difference to sediment export (Chaplinkramer et al., 2016). Vegetation buffer strips for croplands can also help to reduce conflicts between food production and water purification (Sun and Li, 2017), water quality and carbon storage (Goldstein et al., 2012),

and crop production and water quality/yield (Zheng et al., 2016a).

Among “source-sink” landscape patterns, increasing the sink-landscape relative to the source-landscape can help mitigate trade-offs between agricultural production and nonpoint source pollution (Zhang et al., 2018). For example, installing wetlands (sinks for pollutants) can improve both corn production and water quality (Lentz et al., 2014). Furthermore, efficient spatial patterns of nitrogen use can reduce trade-offs between cereal production and water quality (Mueller et al., 2014).

Through spatially explicit geospatial analysis, choosing multiple management approaches targeting specific locations or different landscape types at the landscape scale can also help minimize conflicts between economic development and environmental sustainability (Johnson et al., 2014). Determining the best locations to intensify agriculture and conserve natural habitats can increase crop production (e.g., cocoa) and maintain far higher levels of carbon storage (Johnson et al., 2014; Wade et al., 2010). Similarly, selecting priority areas for development can help limit the degradation of biodiversity and ESs (e.g., aquaculture, carbon storage, recreation, esthetic quality) (Chung et al., 2015). Accepting a small loss in one service (e.g., wood production) may secure large gains in another (e.g., hunting and grazing) by imposing multiuse conditions as a minimum performance standard of the less profitable service (Kang et al., 2016). Trade-offs between timber harvest revenue and multiple species' habitat can be reduced by compromise solutions defined in terms of minimax regret – i.e., minimizing the maximum percentage of deterioration among conservation objectives (Mazziotta et al., 2017).

2.3.3. Multi-objective optimization approaches

Both ecosystem and landscape-scale approaches are effective at mitigating ES trade-offs, especially between provisioning and regulating services. One challenge is to simultaneously meet multiple objectives from multiple stakeholders at the landscape or regional scale. An increasing number of case studies have applied multi-objective optimization approaches to reduce ES trade-offs (e.g., Pohjanmies et al., 2017; Law et al., 2017). Such approaches can coordinate multiple objectives (e.g., crop/timber production, biodiversity conservation, carbon sequestration, water yield, water quality) (e.g., Kennedy et al., 2016a) in addition to the relationship between just two ESs (Johnson et al., 2014). These multi-objective optimization approaches can be used at multiple scales, including ecosystem, landscape, and regional scales. Therefore, potential overlaps likely exist between this methodological approach and the approaches outlined above in regard to minimizing ES trade-offs.

In multi-objective optimizations, the following tools have been widely used in the literature: efficiency frontiers, production possibility frontiers (PPFs), and spatially explicit optimization algorithms. Through joint planning for economic and environmental goals at the landscape scale, trade-offs among water quality (e.g., nitrogen, phosphorus, sediment retention), biodiversity, and agricultural profit (from sugarcane production and cattle ranching) can be mitigated (Kennedy et al., 2016b). An efficiency frontier from optimized

nitrogen application patterns to maximize both corn yield and water quality demonstrates the potential for more sustainable outcomes (Ewing and Runck, 2015). PPFs can characterize biophysical, socio-economic, and institutional dimensions of policy trade-offs in heterogeneous landscapes, which can help to identify strategies that give the greatest flexibility to achieve the targets (e.g., agroforestry production and biodiversity conservation) of all stakeholders (Smith et al., 2012; Law et al., 2017). Spatially explicit optimization algorithms can help to reduce trade-offs between biofuel production, biodiversity, and agriculture by identifying locations that maximize biofuel production from switch grass but minimize the negative impacts on biodiversity and agriculture (Behrman et al., 2015). Pohjanmies et al. (2017) reported that multi-objective optimization tools may be feasible even in small-scale forestry (100 stands or 200 ha) to mitigate conflict between timber production and carbon storage during management planning.

2.3.4. Policy interventions (and other) approaches

Policy intervention and market instruction are also important approaches in the mitigation of ES trade-offs (Nelson et al., 2009). Previous research has attributed the coordination of ES trade-offs to the creation of effective market mechanisms, including differentiated payment structures in consideration of socio-economic differences among stakeholders (Daly-Hassen et al., 2010; Dong et al., 2011; Newton et al., 2012). The use of wood, in particular, can provide many additional opportunities for win-win outcomes due to the link with climate change mitigation activities (Branca et al., 2013; Goldstein et al., 2012). For example, policy intervention and markets for carbon sequestration can help reduce trade-offs between commodity production and biodiversity, carbon sequestration, and storm peak mitigation (Nelson et al., 2009). It can also provide the financial incentives that allow for forests to function as a significant carbon sink in China (Qin et al., 2017). Forest code compliance at the landscape level also imposes small costs to businesses but can generate significant long-term benefits to nature (e.g., biodiversity, carbon storage, water quality) (Kennedy et al., 2016a).

Combining several policies may also be beneficial for ES trade-off mitigation. For example, a policy that combines a forest moratorium with livelihood support and increases in farm-gate prices of forest and agroforestry products may not only increase profitable and competitive local community benefits from the conservation of forest and agroforestry areas, but also reduce potential carbon emissions (Suwarno et al., 2018).

In addition, advances in agricultural technologies and public participation are also important for the mitigation of ES trade-offs (Mueller et al., 2014). For example, an increase in water productivity of cereal can greatly offset the trade-off impacts on downstream ecosystem sustainability by increasing runoff, which minimizes the trade-offs between midstream crop production and downstream ecological sustainability (Lu et al., 2015). Relatedly, residential participation is the best choice for implementing policies that promote the conversion of paddy land to dry land so as to achieve the best water purification and smallest negative effect on other ESs (Hu et al., 2018).

3. Discussion

Due to growing recognition that situations on the ground often involve competition rather than complementarity between social, economic, and ecological goals, we must re-adjust our thinking towards a trade-off perspective (McShane et al., 2011). Different from previous analyses of ES trade-offs (Rodríguez et al., 2006; Howe et al., 2014; Dade et al., 2018), our review focused on the approaches used to coordinate ES trade-offs to achieve win-win outcomes. Although there is no generalized formula with which to achieve win-win outcomes, diversified approaches to coordinate ES trade-offs indicate that such outcomes are nonetheless feasible. Focusing on these coordination approaches can initiate greater consideration of the variety of demands and relevant stakeholders at different scales.

Although we summarized their different drivers, ES trade-offs were also found to be associated with complex social dynamics, stakeholder behaviors, decision-making backgrounds, as well as geographic locations. Even the same ES trade-offs may have very different drivers, such as biophysical and socio-economic variations and management practices, socio-cultural preferences, access to markets, and patterns of trade (Zhang et al., 2007; Power, 2010; Martin-Lopez et al., 2012). For example, in the humid tropics, deforestation is primarily the result of commercial wood extraction, permanent cultivation, livestock development, and extension of overland transport infrastructure (Zhang et al., 2002; Sharpley and Wang, 2014). However, many regional variations on this general pattern have been found (Zhang et al., 2002; Sharpley and Wang, 2014). Analyzing the drivers of ES trade-offs requires understanding the differences in climate, economic, management, social system, and policy contexts. Drivers of ES trade-offs must be identified within the appropriate scope of complex socio-economic dynamics and in specific local contexts (Zhao et al., 2009). However, data availability plays an important role in determining whether drivers and mechanisms can be incorporated into analyses of ES trade-offs (Spake et al., 2017; Bagstad et al., 2018).

In practice, due to the diversity of drivers of ES trade-offs, a combination of different coordination approaches is often needed. Additionally, the implementation of effective coordination approaches to minimize ES trade-offs requires an understanding of: (1) multiple stakeholders; (2) spatial scale of management; and (3) dynamics of ES trade-offs.

Multiple stakeholders. Different actors have different perceptions of and access to ESs, and therefore have different wants and capacities to directly or indirectly manage for particular biodiversity and ecosystem characteristics (Díaz et al., 2011). Mechanisms of access determine which individuals or groups can benefit from different ESs (Daw et al., 2011). Different groups of people derive well-being from a variety of ESs, with different stakeholders valuing different management options for particular resources. Thus, winners and losers are created as ESs change, with trade-offs between different ESs leading to trade-offs in the well-being of different groups of people (Daw et al., 2011). This highlights the importance of considering multiple

stakeholders in analyzing ES trade-offs and their coordination approaches. The explicit inclusion of stakeholders in the consideration of trade-offs makes values intrinsic to ESs, whether or not those values are monetized (Brauman et al., 2007) and regardless of whether or not users are actively involved in ES changes.

Spatial scale of management. Stakeholders recognize the landscape as a relevant scale for interacting with peers, government agencies, and NGOs. A landscape focus also constitutes an appropriate socio-economic context for matching supply and demand of ESs (Opdam et al., 2013), although conflicts may arise between management for individual farm-scale benefits and joint landscape-scale benefits. Local stakeholders often lack appropriate instruments – such as payments for ESs or regional ecolabeling approaches – to effect coordinate change at the landscape scale. Further research is needed to help identify the relevant scales for management, underpin discussions with policy-makers, and identify appropriate tools to support the coordination of ES trade-offs at the landscape level (Geertsema et al., 2016).

Dynamics of ES trade-offs. ESs have been typically presented as site-based on static maps, thereby lacking dynamics (Tallis et al., 2008). However, environmental change, ecosystem feedbacks, food-web dynamics, and decision making can lead to unexpected consequences (Dobson et al., 2006; Nicholson et al., 2009; Rodríguez et al., 2006). These ecological feedbacks can intensify human modification of ecosystems, creating a spiral of ecosystem degradation (Carpenter et al., 2006). ESs may also lag by decades in contrast to economic signals that respond much more quickly (Tallis et al., 2008). Therefore, ignoring the dynamics of ES trade-offs may increase the risk of regime shifts that alter the ability of an ecosystem to provide goods and services for future generations (Carpenter et al., 2006; Nicholson et al., 2009; Bennett et al., 2009; Coggan et al., 2010). Studies should thus consider both the capacity (static) and flow (dynamic) of ESs and their relationships (e.g., Villamagna et al., 2013).

Minimizing or eliminating trade-offs among ESs can allow for more effective, efficient, and defensible management and policy decisions, and help to realize win-win outcomes for different stakeholders at different scales. There is abundant evidence showing that good environmental management can lead to win-win scenarios. In this paper, by focusing on coordination approaches to ES trade-offs, the trade-offs, their drivers, and mitigating approaches were systematically reviewed. We found that trade-off pairs between provisioning services and regulating services/biodiversity accounted for 80% of total pairs. Furthermore, about 50% of ES trade-offs were driven by land use/land cover changes. We also discussed the four coordination approaches frequently applied to minimize ESs trade-offs, categorized as ecosystem, landscape-scale, multi-objective optimization, and policy intervention (and other) approaches. Future challenges lie in understanding the important roles of multiple stakeholders, spatial scales of management, and trade-off dynamics, as well as the associated implementation of diverse approaches, in coordinating ES trade-offs in different contexts.

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