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Better land-use allocation outperforms land sparing and land sharing approaches to conservation in Central Kalimantan, Indonesia

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ABSTRACT

Land sparing and land sharing are contrasting strategies often aimed at improving both agricultural production and biodiversity conservation in multifunctional landscapes. These strategies are embodied in land management policies at local to international scales, commonly in conjunction with other land-use policies. Evaluation of these strategies at a landscape scale, for multiple ecosystem service benefits, and multiple elements of biodiversity has not previously been attempted. We simulated the effects of applying land sharing and land sparing strategies to the agricultural zones designated by four future land-use scenarios (reflecting both current land-use and prospective land-use plans) in the Ex-Mega Rice Project region of Central Kalimantan, Indonesia. We assessed impacts of each strategy on biodiversity, agricultural production, and other ecosystem service benefits at a landscape scale. We examined whether it was possible to achieve predetermined targets that reflect the aspirations and entitlements of diverse stakeholder groups. We found that the prospective land-use plans for the region would deliver considerably more benefit than the current land-use allocations, and while not all targets can be achieved, additional progress could be made with reasonable and realistic levels of land sharing or sparing. We found that species and forest types sensitive to agricultural disturbance could benefit most if land in agricultural zones was spared and prioritised for conservation. Conversely, land sharing strategies favoured the more widespread and common species, particularly if the area of wildlife-friendly agriculture is increased. However, the effectiveness of agricultural-focused land management strategies is inherently limited by the extent of agricultural zones. While agricultural land sparing and sharing strategies can deliver some gains in target achievement for multiple ecosystem services, we find that they have a limited effect over the benefits achieved by implementing better land-use allocation from the outset.

1. Introduction

Increasing global population and changing consumption patterns, particularly towards animal protein and commodities such as soy and palm-oil, have led to suggestions that food production may need to double by 2050 (Tilman et al., 2001; Phalan et al., 2014). This increases pressure for intensification and expansion of agricultural land use and management (Stavins et al., 2003; Balmford et al., 2005; Pirard and Belna, 2012; Laurance et al., 2014), which is cumulatively reducing the viability of natural ecosystems and their ability to support biological diversity and ecosystem services (Strobl et al., 2008; Laurance et al., 2014; Phalan et al., 2014; Renwick et al., 2014). Managing the underlying production–biodiversity trade-off is becoming an increasingly complex issue in both developing and advanced economies where sustaining or developing the economics, culture, and ecology of agricultural landscapes ranks high among both social and political priorities (Hamblin, 2009; Bekessy et al., 2010).

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Land sparing and sharing represent the endpoints of a spectrum of agricultural land management strategies with a focus on, respectively, specialization and integration of conservation and production (Fischer et al., 2014), in order to improve both agricultural production and biodiversity conservation across agricultural landscapes (von Wehrden et al., 2014). Both strategies can be effective given appropriate contexts (Martinet and Barraquand, 2012; Cunningham et al., 2013; Phalan et al., 2014), and decision makers need to determine which strategy is preferable in specific applications, or if alternative approaches, such as better land use planning from the outset, demand management, or addressing inefficiencies in food processing, distribution, and consumption, may better achieve their land-use objectives.

Land sparing takes a specialization approach, and is based on the assumption that primary habitats are (usually) the most species-rich (Gibson et al., 2011; Laurance et al., 2014), and harbour species which are intolerant of disturbance (Chazdon et al., 2009). Sparing hinges on land allocation, specifically setting aside land primarily for biodiversity conservation (Chandler et al., 2013; Lindenmayer and Cunningham, 2013), coupled with intensification of agriculture in remaining production areas (Green et al., 2005; Fischer et al., 2008; Phalan et al., 2011a; Phelps et al., 2013). Agricultural intensification is often assumed to occur via actions that may negatively impact on biodiversity and other non-market environmental and societal values (Phalan et al., 2014). For example, this can occur through reduced or altered habitat diversity (e.g. monocultures or irrigation; Koh et al., 2009; Cunningham et al., 2013), or as a result of pollution associated with inappropriate use of fertilizer and pesticides (Green et al., 2005). These actions can often lead to complex off-site environmental and social impacts (Castella et al., 2013; Cunningham et al., 2013).

In contrast, land sharing is an integrative approach, defined as making production land more conducive to biodiversity conservation, often at a cost of reduced yield (Lindenmayer and Cunningham, 2013). Land sharing provides an alternative to the conventional 'protected area' model of biodiversity conservation—which may be limited by the availability of pristine areas for conservation, particularly in developed regions (Troupin and Carmel, 2014). Land sharing capitalises on the opportunities for conservation in the matrix, particularly of species tolerant of disturbance (Polasky et al., 2005, 2008; Wilson et al., 2010; Troupin and Carmel, 2014). Land sharing includes a variety of methods to increase the heterogeneity and multi-functionality of farming systems (Green et al., 2005; Macchi et al., 2013), as well as reducing harmful impacts of fertilizers, pesticides, and other on-farm activities (Kremen and Miles, 2012; Mahood et al., 2012; Mendenhall et al., 2014a; Villoria et al., 2014). However, if land sharing results in a reduction in agricultural efficiency and production, it may cause economic costs to agricultural stakeholders (Kremen and Miles, 2012; but see Clough et al., 2011). Further, if food demand cannot be reduced (nor efficiencies gained in processing, distribution, or consumption), land sharing could require additional land to be allocated to agriculture as compensation for declines in yield, or demand will need to be satisfied from elsewhere.

Recently there have been several syntheses of the efficacy of land sharing and land sparing strategies (Phalan et al., 2011a; Balmford et al., 2012; Grau et al., 2013). However, only a few studies have undertaken such comparisons over entire landscapes consisting of multiple agricultural types and other land uses (for examples see: Hodgson et al., 2010; Phalan et al., 2011b; Chandler et al., 2013), for multiple ecosystem services (for examples see: Anderson-Teixeira et al., 2012; Lusiana et al., 2012; Mendenhall et al., 2013), or under different plausible land-use scenarios. Literature promoting land sharing has generally focused on site-by-site comparisons (Kremen and Miles, 2012). In contrast, literature supporting land sparing strategies has focused on broad patterns across gradients of agricultural intensity, but otherwise no spatial considerations (Green et al., 2005; Phalan et al., 2011b). Landscapes are typically heterogeneous, with variability in production potential, and in environmental and social values due to unique combinations of environmental, social, and historical contexts (Fahrig et al., 2011; von Wehrden et al., 2014). This heterogeneous nature of landscapes means that solutions that consider the whole landscape may not necessarily be a simple sum of the parts (Seppelt and Voinov, 2002; von Wehrden et al., 2014). There has also been much interest in integrating objectives for an increased variety of ecosystem services into land sharing and land sparing evaluations (e.g. Fischer et al., 2008; Benayas and Bullock, 2012; Tscharntke et al., 2012), and despite advances in ecosystem service modelling (Nelson et al., 2009; Maes et al., 2012; Bagstad et al., 2013), this has not yet been achieved.

Integrating multiple goals in land-use planning requires an objective way to compare outcomes for multiple stakeholders. Threshold-based targets represent a simple way to objectively quantify planning objectives relative to stakeholder demand (Carwardine et al., 2009; Segan et al., 2010), and to compare outcomes using the common metric of per cent target achievement. Such targets may reflect stakeholder aspirations, such as biodiversity targets expressed in international conventions (CBD, 2010). Alternatively, targets may reflect current entitlements, such as the economic returns expected from current oil-palm or timber concessions. No ideal method for target-setting exists and the process is often limited by available data (Rondinini and Chiozza, 2010), notwithstanding the issues of subjectivity, inaccuracy, and uncertainty (Di Minin and Moilanen, 2012). Assessments of target achievement can however be useful for multi-objective land-use planning (Rondinini and Chiozza, 2010; Runting et al., In press), for example to assess the implications of target achievement on other objectives (Bryan et al., 2011). Policy evaluations should also consider effectiveness in relation to a specified baseline (the land use trajectory in the absence of policy application; Ferraro, 2009). Therefore, it is prudent to compare impacts of land sharing and sparing strategies given the constraints of current land-use allocations and also proposed land-use plans.

In this paper we analyse the potential to achieve predetermined targets for diverse stakeholders in the Ex-Mega Rice Project area of Central Kalimantan, Indonesian Borneo, given alternative land-use scenarios. This region is a high biodiversity area with substantial pressures for economic and agricultural development, as well as a globally important area for reducing carbon emissions from land use (Page et al., 2002; Ballhorn et al., 2009; Hooijer et al., 2010; Bos et al., 2013). Development of the region concerns diverse stakeholder groups, and the potential for objectives for the region to be in conflict results in a complex land-use planning problem (Law et al., 2015). We assess the level of target achievement for 14 biodiversity and four ecosystem service features, across five land-use types, under four land-use scenarios. Two land-use scenarios are based on current land-use patterns and existing concessions, and two are prospective land-use plans for the region. Given these land-use scenarios, we determine which features can reach or exceed the targets and also quantify any shortfall in target achievement. We then evaluate six different land sharing and land sparing strategies applied to the agricultural zones designated under each land-use scenario, to test the extent to which they might improve the attainment of targets while working within the constraints imposed by each land-use scenario.

2. Methods

2.1. Study region

The Ex-Mega Rice Project area of Central Kalimantan (referred to herein as the case study region; Fig. 1) has recently been a focus of agricultural development and landscape carbon planning and management. The 1.4 million hectare region was subject to an agricultural self-sufficiency and development policy implemented from 1996 to 1998 that led to the clearance or degradation of almost one million hectares of tropical lowland peat swamp forest, the creation of 4000 km of canals for drainage and irrigation, and transmigration of over 15,000 families to the area (Page et al., 2009). The project failed to achieve its agricultural objectives, with subsequent agricultural land abandonment and on-going degradation resulting in considerable negative consequences for hydrology, peat subsidence, and carbon emissions (Wosten et al., 2008; Hooijer et al., 2010). Tropical peat swamp forests are highly threatened (Posa et al., 2011) and important for conservation of the Bornean orang-utan (*Pongo pygmaeus*; Meijaard, 1997; Morrogh-Bernard et al., 2003) and other taxa (Yule, 2010; Posa, 2011). Currently the case study region is 38% forest, 50% degraded land (including cleared, drained, and abandoned areas), and 12% agriculture (Fig. 1). Oil-palm (*Elaeis guinensis*) plantation concessions cover 29% of the region, but as of 2008 only a third of these have been planted. Agriculture is the predominant form of income in most of the region, however yields are generally low compared to provincial or national averages. In 2005, poverty rates exceeded 36% across the region and up to 75% in some transmigrant villages (de Groot, 2008). Recent land-use plans and policies call for the expansion and development of agriculture, including oil-palm, both within the case study region and Indonesia as a whole, ideals which sit uneasily alongside potentially conflicting goals of carbon emission reduction and conservation of remaining peat and biodiversity (Euroconsult Mott MacDonald et al., 2008; Jakarta Post, 2009; Obidzinski and Chaudhury, 2009; Meijaard, 2014).

2.2. Potential value of ecosystem service benefits

We identified relevant ecosystem services and threshold-based targets reflecting local, national, and international policy goals of associated stakeholders (Table 1). Key stakeholders and services were identified from key recent policy documents and reports, including the Presidential Instruction No. 2/2007 on Rehabilitation and Revitalisation of the Ex-Mega Rice Project Area in Central Kalimantan (INPRES 2/2007), and the subsequent "Master Plan for the Rehabilitation and Revitalisation of the Ex-Mega Rice Project Area in Central Kalimantan" (Euroconsult Mott MacDonald et al., 2008). We characterized ecosystem services as primarily benefiting the local community (production from smallholder agriculture), industrial operators (profit from oil-palm plantations and from timber production from government-licensed forestry concessions), or the global community (carbon emissions mitigation and conservation of 14 biodiversity features). We established the baseline value of benefit (*current benefit levels*) for each ecosystem service from each 100 hectare parcel of land given the land use and land cover as of 2008, the date of the most recent available comprehensive data (for both land cover and financial returns) across the region. Methods for spatial valuation of each ecosystem service are detailed in Law et al. (2015) and summarized below.

We determined the value of smallholder agriculture as the annual maximum potential (farm-gate) profit from a set of land systems, each characterized by a specific composition of crops. We modelled individual crop suitability across the landscape, and combined this with expected yield and price information (Law et al., 2015). We determined farm-gate oil-palm profitability using production, price, and cost data and land-suitability models. Potential economic returns from timber were estimated based on extant land cover, forest type, and transport costs to existing mills in the study region (Law et al., 2015).

We modelled potential carbon emissions reductions over 40 years with respect to a counterfactual baseline of maintaining the current land use configuration (Law et al., 2014). This model estimates emissions sequestered and released due to five processes (sequestration in vegetation, biomass loss to fire, biomass lost and temporarily stored in harvested timber, peat loss due to fire, and peat decomposition in the absence of fire).

We used the distribution of primates—the most intensively surveyed taxa in the region—as species-level metrics for biodiversity, complemented by the distribution of forest types as an ecosystem-level surrogate to reflect broader biodiversity patterns (Margules and Sarkar, 2007). Distributions for nine primate species and five forest types were modelled based on geographic and climatic variables (Law et al., 2015; Struebig et al., 2015). Forest types included mangroves, mixed swamp (shallow peat), low pole (deep peat),

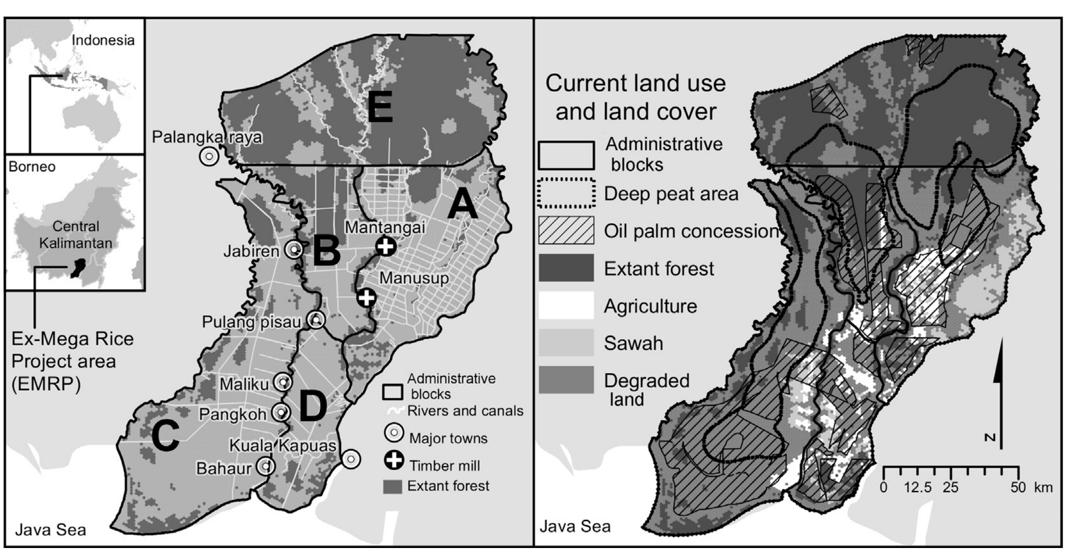

Fig. 1. Location of the study region, administrative blocks, and current land use and land cover.

Table 1
Ecosystem service benefits, targets and contributions of each land use to target achievement. Derivation of targets is described in Appendix A.

Ecosystem service	Smallholder agriculture	Oil-palm	Timber	Carbon emissions reduction	Biodiversity conservation
Primary beneficiaries	Local community	Industrial or commercial operators	Industrial or commercial operators	Global community	Global community
Target description	Adequate to support projected population growth above the poverty level, and aligned with economic growth targets	Potential value in existing oil-palm concessions	Potential value under full forestry development zoned by current regulatory plan (INPRES 2/2007)	Aligned with Indonesian national greenhouse gas emission reduction goals	Aligned with the Convention on Biological Diversity 'Aichi targets' (17% of original forest area; stabilisation of threatened species; no increase in threat status for non-threatened species)
Target value	$160,157,600	$1,285,296,509	$ 35,916,457	11.87 Gt	See Appendix A
Benefit metric (per planning unit)	Annual expected net profit	25 year NPV	40 year NPV	Potential cumulative emissions reduction over 40 years	An abundance-based metric for each species and extent of each forest

Land use	Description	Contribution of each land use to each target				
Smallholder agriculture	Allocation to smallholder agriculture	100%	0%	0%	Variable across planning units	Variable across planning units
Oil-palm	Allocation to commercial oil-palm	0%	100%	0%		
Forestry	Allocation to forestry, assuming no active restoration	0%	0%	100%		
Conservation	Hydrological management in existing forest and natural regeneration	0%	0%	0%		
Unmanaged	No active management	0%	0%	0%		

swamp (*nipah* palm), and river-riparian. To account for the contribution of different land cover and land management to the conservation value for each of the nine primate species, we took the modelled species distribution data and combined this with expert-derived habitat suitability estimates, and expected home-range size to calculate an index of abundance (following species sensitivities and methods in Wilson et al. 2010, as described in Law et al. 2015; Appendix A).

2.3. Targets

We selected targets for each benefit that reflect both the aspirations of stakeholders as well as current entitlements (Table 1, Appendix A). We based the targets on objectives stated in the policy documents of the Indonesian government or non-governmental organizations (for emissions reduction, biodiversity, smallholder agriculture), or current levels of entitlement (oil-palm, timber). Targets for biodiversity differentiated between threatened species, non-threatened species, and forest types (Table 1, Appendix A).

2.4. Land-use scenarios

Four land-use scenarios were developed to reflect either current land uses and concessions, or prospective land-use zoning plans for the region (Fig. 2, Table E1):

(a) *Scenario 1: Current land uses.* We assumed that all existing agricultural land covers, including *sawah* (wet rice field), are maintained as smallholder agriculture within an agricultural zone (12%). Oil-palm agriculture was not considered under this scenario. All other land is considered "unmanaged" (88%, of which 43% is currently extant forest, and the remainder degraded), i.e. not managed for agriculture, forestry, or conservation.
(b) *Scenario 2: Current concessions developed.* As for scenario 1, but we assumed that all land currently zoned as oil-palm concession is fully developed into an oil-palm plantation (29%). This results in the extent of smallholder agricultural land being reduced to 7% and the extent of unmanaged land to 63%, of which 52% is currently extant forest. In this scenario, 32% of land initially zoned as agriculture (both oil palm and smallholder agriculture) is currently in agricultural production, and 14% is extant forest.
(c) *Scenario 3: Current zoning plan.* Development as per the zoning plan outlined in Presidential Instruction No. 2/2007 on Rehabilitation and Revitalisation of the Ex-Mega Rice Project Area in Central Kalimantan (INPRES 2/2007). This is the current land management policy for the region, although it is largely unimplemented and considered a temporary or draft zoning map. Three land-use categories are defined: agriculture, forestry, and conservation. We assumed agriculture to be smallholder agriculture (20%), and oil-palm to occur where there is an oil-palm concession within this agricultural zone (8%). Of this combined agricultural zone, 31% is currently in agricultural use, and 21% is extant forest. Forestry zones cover 10% and conservation zones 61%, and no land remains unallocated (unmanaged). Conservation zones currently consist of 50% extant forest.
(d) *Scenario 4: Alternative zoning plan.* Development as per the zoning plan outlined in the Ex-Mega Rice Project area "Master Plan" report (Euroconsult Mott MacDonald et al., 2008). This plan was designed to improve on the current zoning plan, incorporating updated information from a range of stakeholders, but is not yet implemented into policy (Euroconsult Mott MacDonald et al., 2008). Four land-use categories are defined: agriculture, limited agriculture,

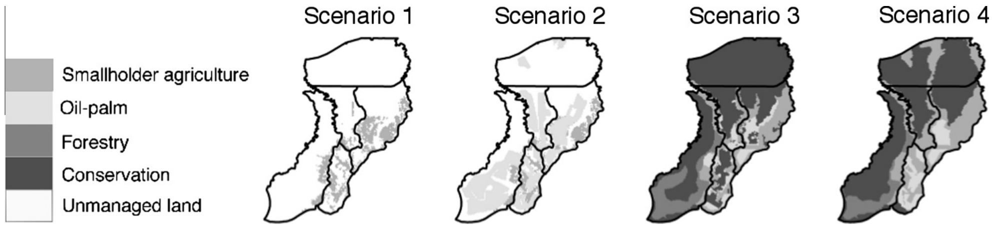

Fig. 2. Extent of land-use zones under current land uses (scenario 1), current concessions developed (scenario 2), the current zoning plan (scenario 3), and the alternative plan (scenario 4). Further details of land zone composition are provided in Appendix E.

forestry and conservation. As for scenario 3, we separated agriculture into both oil-palm (8%) and smallholder agriculture, but allocate limited agriculture as smallholder agriculture only, resulting in 31% allocation to smallholder agriculture. Of this agricultural zone 28% is currently in agricultural use, and 25% is extant forest. The remainder includes forestry zones (7%), and conservation zones (55%). Of the latter, 51% is extant forest.

For each of the four land-use scenarios we calculated the current benefit levels for each ecosystem service and biodiversity feature. We then assessed the benefits derived if agricultural land sharing and land sparing strategies of varying levels of effectiveness are implemented in the region. We therefore distinguish between these *a priori* 'zoning' plans (i.e. those represented by the land-use scenarios, and focus on land allocation only) and land sharing and land sparing strategies (which focus on improving particular land uses for specific objectives, sometimes in association with land-use re-allocation). These alternative strategies are applied in the context of the constraints of each zoning plan, predominately the extent of the agricultural zone. Land cover composition of the land-use scenarios and land-use transitions under land sharing and sparing strategies is provided in Appendix E.

2.5. Land sharing and land sparing strategies

To simulate the effects of potential land sharing and sparing strategies we modified the land-use allocation and/or the agricultural production value and biodiversity benefits for the agricultural zones (i.e. both smallholder agriculture and oil-palm zones; Table 2). Therefore, we assessed the anticipated outcomes of land sharing or sparing strategies, not specific policies that could be used to achieve them. Representative values for reasonable assumptions regarding the effectiveness of land sharing and sparing strategies, i.e. the relative benefits and costs expected from changes in land management associated with each strategy, were derived from a literature review and accounting for locally-relevant constraints (Appendix B).

We defined sparing and sharing strategies (Table 2) such that:

- In land sparing, 0–100% of the agricultural zone is spared (converted to conservation) and either total production declines, or production in the remaining agricultural zone is increased to compensate for lost area, up to ten times the current level. This represents an optimistic upper bound of the yield increase of converting traditional rice varieties and methods to high-yield practices (De Datta et al., 1968). We assumed that the biodiversity value of 'spared' land would reflect that of the current land cover placed into conservation management rather than the zoned land use. In this regard, we assumed that if there is currently extant forest this would gain the highest value for biodiversity, but if habitat needs to be restored the biodiversity value would be reduced comparatively (Law et al., 2015). The allocation of spared land was prioritized to provide maximum additional benefit to biodiversity, while being cost-effective in regards to the opportunity cost to agriculture. This included prioritising initially only species or forest types not reaching their respective abundance targets, based on the expected site-specific difference between the biodiversity value of conservation and production land uses (Appendix C). The results presented herein assume no further loss of biodiversity in agricultural land uses in response to increases in yield. This resulted in total biodiversity values only around five per cent greater than if we had allowed biodiversity benefits to decline by up to one quarter over the range of strategy levels explored (Appendix D).
- In land sharing, agricultural land uses experience an increase in biodiversity benefits from 0% to 200%. This is coupled with either no impact on agricultural production value, or a decline in production value proportional to the increase in biodiversity benefit. In the results presented herein, agricultural zones were assumed not to expand. In a separate analysis we explored outcomes of allowing agricultural zones to expand to compensate for production value foregone due to land sharing (Appendix D and also reported in Appendix E).

All analyses and programming were conducted in the R statistical package (R Core Team, 2012).

3. Results

Our analyses indicate that none of the land-use scenarios for the case study region will achieve all targets, either under baseline conditions or under reasonable levels of land sharing or land sparing (Fig. 3). For the current land uses and if the current concessions were developed (scenarios 1 and 2 respectively) the landscape would be characterised by relatively small agricultural zones that failed to reach agricultural production targets, with the exception

Table 2
Land sharing and sharing strategies. Change in parameter values of agricultural land under simulated land sharing and sparing strategies. All changes are assumed to be linear, with the exception of agricultural production value under higher land sparing intensities. The latter is represented by an exponential function reflecting the amount of production value increase required to compensate for total production loss due to spared land, capped to a maximum of 10 times the baseline production value.

	Land sharing	Land sparing
Biodiversity value of agriculture	Increases: +0% to 200% in smallholder agriculture +0% to 50% in oil-palm	Decreases: −0% to 25%
Production value of agricultural land	Decreases: −0% to 50%	Increases (to compensate): +0% to a maximum of 1000%
Area of agriculture	Increases (to compensate): +0% to 100% (increasing version shown in Appendix D)	Decreases: −0% to 100%

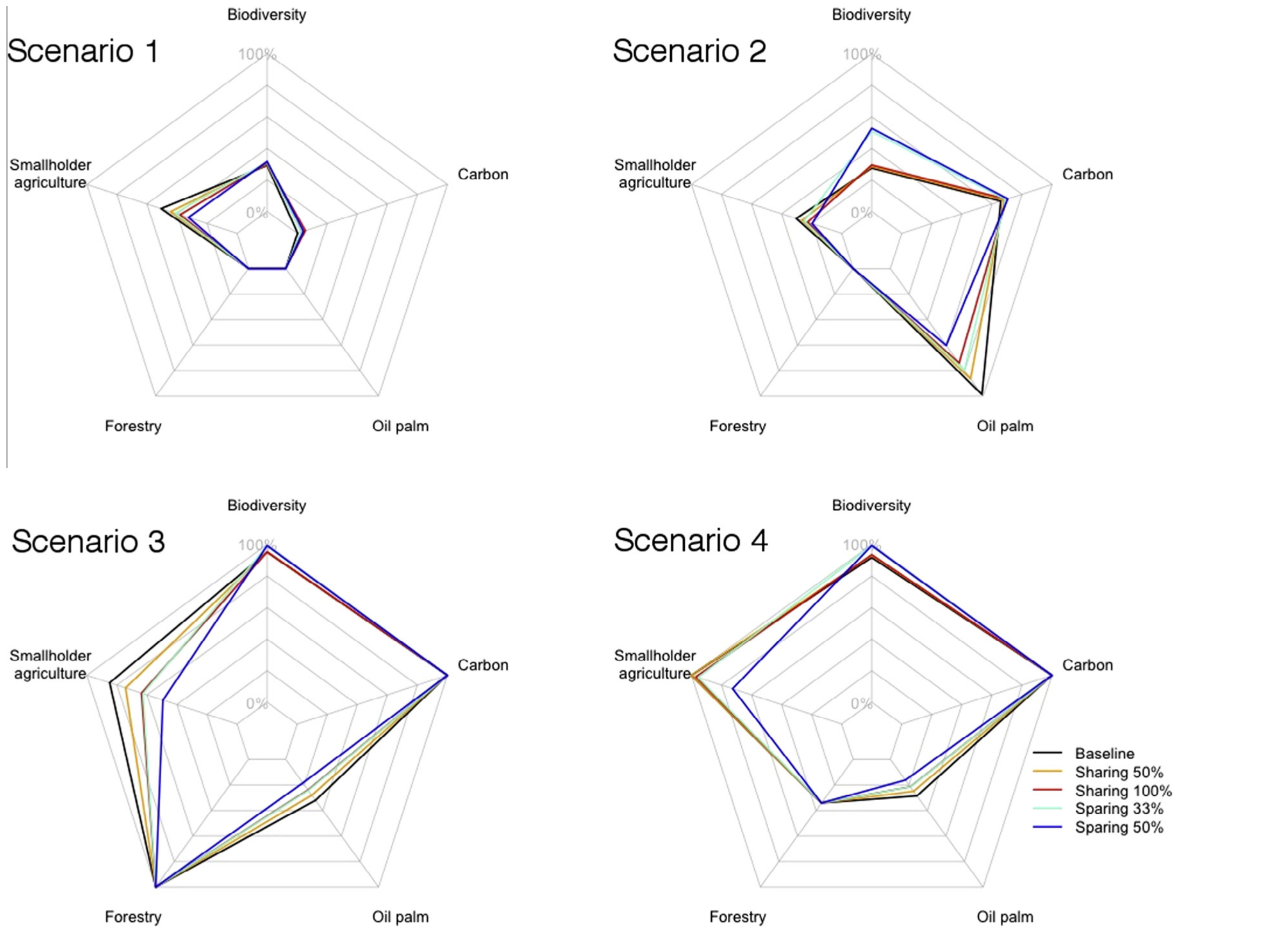

Fig. 3. Target achievement under baseline conditions and land sharing or sparing strategies for current land uses (scenario 1), current concessions developed (scenario 2), the current zoning plan (scenario 3), and the alternative zoning plan (scenario 4). Full score represents 100% target achievement, and any achievement above this level is not presented. For biodiversity, the score represents the average of the 14 targets. Sharing 50% denotes where the biodiversity benefit of agriculture is 50% better than the baseline, and similarly 100% is where the biodiversity benefit of agriculture is twice as beneficial as the baseline. Sharing strategies are shown here with no expansion of agricultural land (therefore total production decreases). For sparing strategies the percentage shown is the amount of area spared, and assumes further negative impact on biodiversity in agricultural land due to increase in agricultural intensity.

of oil-palm production for the latter scenario (at a cost of reduced smallholder agriculture). Despite small agricultural zones, the conservation benefit of these scenarios was also low, due to extensive area of unmanaged land. Further, only five primate species are potentially represented within the area of land currently in agricultural use, thus strategies that either share or spare land in this agricultural zone will not likely make a significant contribution to achieving the biodiversity targets, despite the potential to further reduce production (Fig. 4). Carbon mitigation benefits would be marginally improved above the baselines, but the target would not be achieved. If current concessions are developed (scenario 2) land sparing strategies would allow one additional primate and forest type target to be achieved, however due to the limited potential benefit of land sharing in oil-palm systems, land sharing would not improve target achievement (Fig. 4). If we assumed the extent of agricultural land could be expanded outside of the specified agricultural zones in order to compensate for yield foregone in land sharing strategies, we saw potential for additional biodiversity targets to be achieved, but only for species relatively tolerant to agriculture (Appendix D).

Under the current and alternative zoning plans (scenarios 3 and 4 respectively) land allocation includes extensive conservation areas and no unmanaged land. More emphasis is placed on smallholder agriculture, with target achievement of 85% and 129% under the current and alternative zoning plans (scenario 3 and 4 respectively), under baseline conditions. However, target achievement of oil palm is reduced, to 32% and 28% respectively, and while the current zoning plan (scenario 3) reaches the timber target, the alternative zoning plan (scenario 4) falls short by 66%. The large area designated to conservation would allow the carbon emissions mitigation target to be achieved, and vastly improve the level of target achievement for the primate species under baseline conditions. For the current zoning plan (scenario 3), only the proboscis monkey (*Nasalis larvatus*) fell slightly short of the target, which was easily reached under minor levels of sharing and sparing. In the alternative zoning plan (scenario 4) under baseline conditions, four species fail to reach the target (Bornean white-bearded gibbon, *Hylobates albibarbis*; western tarsier, *Tarsius bancanus*; proboscis monkey; slow loris, *Nycticebus menagensis*). Most of these were reached with minor land sharing or sparing, with the exception of the species most sensitive to agriculture (the slow loris), which did not achieve its target under reasonable levels of land sharing. The two forest types with the largest current extent (low pole and mixed swamp forest) would be adequately represented regardless of the strategy. The current zoning plan (scenario 3) also adequately represents swamp forest and river-riparian forest, and the alternative zoning plan (scenario 4) would achieve the targets for these forest types by sparing 10% of the agricultural area. The entire remaining extent of mangroves must be conserved to achieve the target for this forest type, but some of this area is

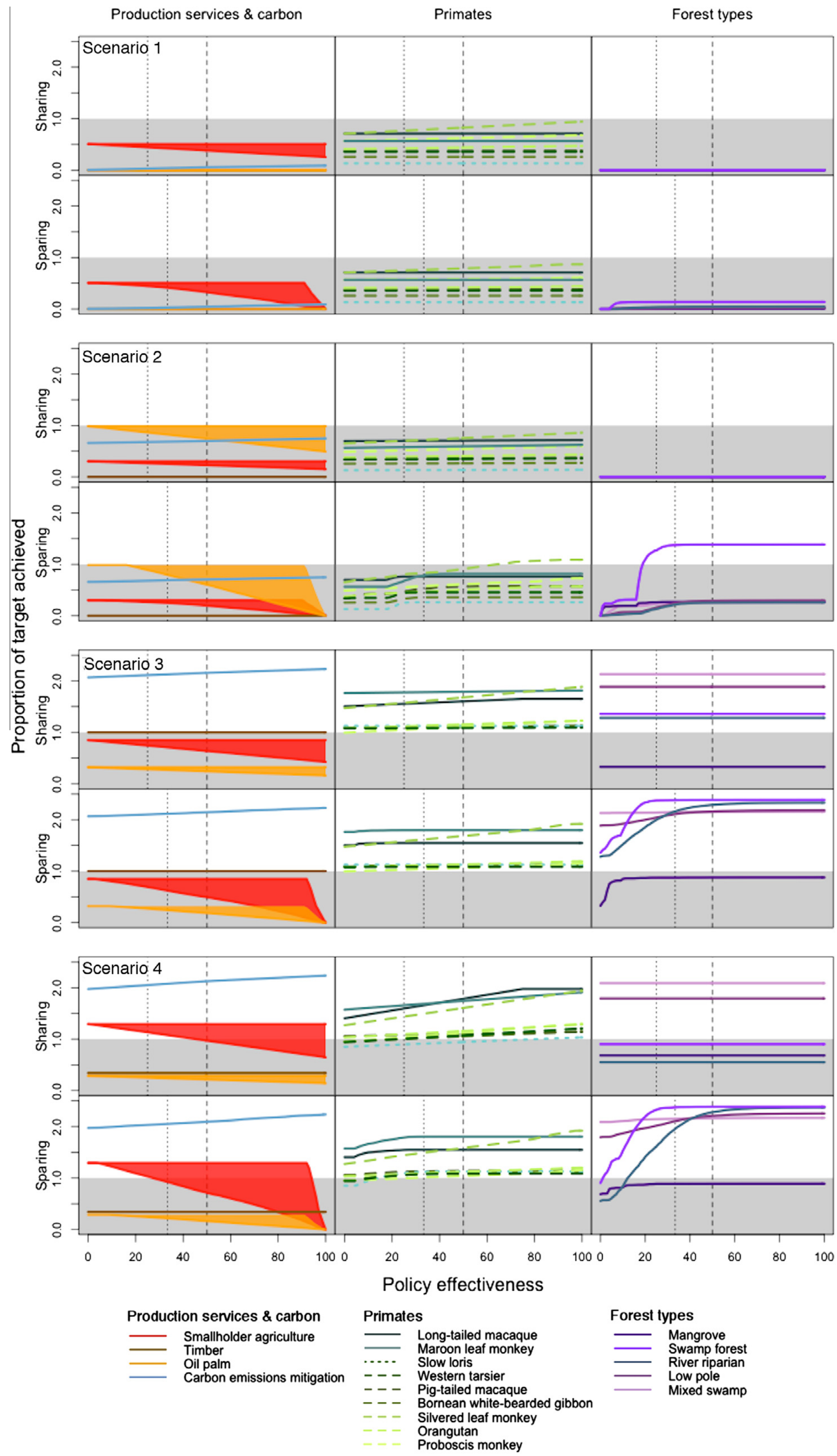

Fig. 4. Target achievement across a range of agricultural land sparing or sharing policy effectiveness for current land uses (scenario 1), current concessions developed (scenario 2), the current zoning plan (scenario 3), and the alternative zoning plan (scenario 4). For primates, solid lines are species tolerant of agriculture, dashed lines are moderately-tolerant species, and dotted lines are species sensitive to agriculture, with the lighter colours equating to a larger predetermined target. For smallholder agriculture and oil-palm, the upper bound of target achievement is expected when there is no impact of land sharing on agricultural production value, or when the production foregone due to sparing is completely compensated for by an increase in production value in the remaining agricultural land. Conversely, the lower bound is expected when land sharing reduces agricultural production value, and there is no compensation for production lost to spared land. Grey area indicates where targets are not achieved. The vertical dotted lines indicate levels of sharing or sparing intensity that may reasonably be expected, given no reduction in total production, whereas the dashed vertical lines indicate a reasonable level of sharing and sparing that would be expected if overall production declines.

allocated to timber production under both the current and alternative zoning plans (scenarios 3 and 4; Fig. 4).

If land sharing or land sparing were to be implemented, our results suggest most of the improvements in target achievement could be obtained at relatively modest levels of strategy effectiveness (due to diminishing marginal returns; Fig. 4). If land sharing strategies are implemented, most of the remaining primate targets are reached with reasonable improvements in the biodiversity value of agricultural land (50% improvement in smallholder agriculture and 12.5% in oil-palm; Fig. 4; Appendix B), which could potentially be obtained with only a small reduction in yield (Fig. 4). Similarly, if land sparing strategies are implemented, most benefits are gained with less than a third of the agricultural zone spared (requiring a 50% increase in yield from agricultural land to maintain total production; Fig. 4). Under land sparing strategies marginal agricultural land could be prioritized for being spared, nevertheless at high levels of sparing the impact on total production (both for oil-palm and smallholder agriculture) would be greater than equivalent levels of land sharing.

In land sharing, if declines in production value are compensated for by an increased extent of agricultural land this could benefit all species in the current land uses (scenario 1) and when current concessions were developed (scenario 2), as it replaces unmanaged land with wildlife friendly agriculture, and thereby may allow target achievement for the more tolerant species (Appendix D). In the current and alternative zoning plans (scenarios 3 and 4 respectively) extensions of agricultural land would come at the cost of conservation zones, yet due to prioritisation of agricultural expansion, we find that tolerant species could benefit from expansion of the agricultural zone in these scenarios, with little impact on other species (Appendix D). Under land sparing we found little difference in scenarios assuming either no or some additional biodiversity impact of intensive agriculture (Appendix D).

4. Discussion

We find that none of the land-use plans proposed for reversing the impacts of land conversion and degradation would fully satisfy the targets sought by diverse stakeholder groups in this globally important region. While the prospective land use plans represent vast improvements over current land use, even the extensive conservation areas that are planned for the case study region would be insufficient for meeting all biodiversity targets, and may restrict options for concurrent achievement of smallholder agriculture, oil palm, and timber production targets. Neither land sharing nor land sparing strategies provided options that strongly and consistently improved target achievement across the multiple biodiversity and ecosystem service objectives: the effectiveness of agriculture-focused land management strategies is inherently limited by the extent of agricultural zones, the conservation opportunities within them, and the baseline level of target achievement. For the case study region, this is a particular concern, as many areas are degraded and, in their current state, contribute little to any of the targets that are sought. In scenarios where large amounts of unmanaged land persists, allowing agricultural land use to expand into unmanaged or degraded areas and promoting land sharing strategies may provide more benefit than land sparing of current agricultural areas, particularly for species relatively tolerant of agricultural land uses. However, in scenarios with larger areas of agriculture coupled with planned conservation zones, land sparing was more beneficial for conservation of ecosystem types and features that were otherwise inadequately protected. Our results therefore support the potential value of production landscapes for species conservation (Daily et al., 2003; Rosenzweig, 2003; Tscharntke et al., 2005; Wilson et al., 2010; Wright et al., 2012; Edwards et al., 2014), but more so when these species and ecosystem types of conservation interest can benefit from improved agricultural practices or agricultural expansion (Cunningham et al., 2013).

We acknowledge that a diversity of avenues to increase agricultural production and profitability exist (Phalan et al., 2011a,b) and that there are many options for making agricultural land more compatible with biodiversity conservation (Kremen and Miles, 2012). Our intention was not to assess specific land sharing and sparing policies, but rather their anticipated outcomes. We note that the sustainable intensification of agricultural production (improving benefits for both agricultural production value and biodiversity) may warrant further investigation (Phalan et al., 2011a; Mendenhall et al., 2014a). This strategy could be especially relevant when starting from a poor yield or degraded landscape baselines (Kremen and Miles, 2012; Firbank et al., 2013), particularly in developing country contexts (Perfecto and Vandermeer, 2010; Clough et al., 2011; Waldron et al., 2012). Our results suggest that while a sustainable intensification strategy may improve the prospects for agricultural production, it would still need to be coupled with a sparing policy to deliver the most benefits for biodiversity in our case study region, and more generally address concerns of food security and equity within the broader context of achieving sustainability (Loos et al., 2014).

Our scenario-based analysis explicitly incorporates landscape heterogeneity, multiple ecosystem services, and multiple land uses. In the case study region, most of the potential benefits that could be achieved by either land sharing or sparing strategies would be gained within levels of policy effectiveness commonly reported in the literature. We caution our estimates for the potential production value and biodiversity benefits are approximations estimated from a wide variety of sources and intended to be only broadly indicative of expectations, and the prioritisation methods we applied reflect only one potential option. Appropriate data for estimating the impact of changes in land use management, even in data rich regions, are rare. Further, our species level metric was based on primates, which may not reflect diversity patterns or responses of all biodiversity elements of conservation interest (von Wehrden et al., 2014). Yet changes to these assumptions or metrics are unlikely to change our main conclusion that the overall benefit of land sharing and land sparing strategies, when applied within agricultural zones, is limited compared to more fundamental shifts in zoning regulation and development according to existing plans in this case study area.

Our results are driven by the heterogeneity of the landscape, and emphasize the importance of evaluating strategies across whole landscapes such that the biophysical and historical context can be accounted for (Swift et al., 2004; Egan and Mortensen, 2012; Kremen and Miles, 2012; von Wehrden et al., 2014). Landscape-scale studies incorporating multiple ecosystem services are inherently data intensive and this precluded our ability to account for important spatial and temporal dynamics. From a biophysical perspective we have not accounted for the hydrological dynamics of peat, which control floods and droughts, and also the occurrence of subsidence (Wösten et al., 2006). These dynamics necessitate sustainable agricultural practices and effective peat land management in the region, particularly if the increased seasonality of rainfall suggested by climate change modelling eventuates (Kumagai and Porporato, 2012; Wich et al., 2014). For example, peat subsidence as a result of drainage (associated with oil-palm, but also intensive agriculture crops and forestry) will result in localized or large-scale flooding, which will reduce yields and likely result in land abandonment thereafter (Hooijer et al., 2012; Abram et al., 2014). Similarly, we have not accounted for variability in economic parameters such as commodity prices (Barraquand and Martinet, 2011; Seppelt et al., 2013), which will determine the future development and viability of the oil-palm industry in the region. We have not accounted for differentiation within stakeholder groups, for example the local community stakeholders (associated with 'smallholder agriculture') are a culturally diverse and often geographically distinct population including indigenous communities, early transmigrants, and new transmigrants Euroconsult Mott MacDonald et al. (2008). Land-use outcomes are also highly dependent on the capacity of governance and institutions to implement, monitor, and enforce the set of policies used to enact land-use allocation and land sharing or sparing strategies, in particular to control displacement ('leakage') of economic production, or increasing competition for land use if agricultural efficiencies lead to increasing land rents (the 'Jevons Paradox'; Angelsen and Kaimowitz 2001; Ceddia et al., 2013; Fischer et al., 2014; Hertel et al., 2014; Mendenhall et al., 2014b).

As provincial-level land-use plans for Central Kalimantan are yet to be finalized (Sumarga and Hein, 2014) this study provides support and information for further refinement of current proposals. We reveal that none of the land-use plans currently proposed will adequately satisfy all stakeholders, and land sharing or sparing strategies applied to agricultural zones are unable to compensate for this fundamentally inadequate land-use planning (Lindenmayer and Cunningham 2013). Land use in this region is therefore likely to be highly contested. Land-use policies and plans will require prudent design accounting for political, social, economic, technological and biophysical factors (Mattison and Norris, 2005). For example, as not all stakeholder targets can be achieved under future land-use allocation or policy strategies, these targets and plans may need to be revised in collaboration with local and regional stakeholders. This could include consideration of recent initiatives such as the provincial government endorsed Forum Koordinasi Kelompok Tani Dayak Misik-Kalimantan Tengah (FKKTDM-KT), which aims to formalise customary land rights for indigenous Dayak in the region. The effectiveness of land management is dependent on the ability to provide adequate incentives, and capacity for monitoring and enforcement (e.g. Nelson et al., 2008; Bamière et al., 2011; Bryan et al., 2011; Martinet and Barraquand, 2012). Both of the prospective land-use plans provide much more positive outcomes for biodiversity and smallholder agriculture stakeholders, but may come under threat from on-going oil-palm development or insufficient resources to effectively manage conservation areas. As these threats are, in part, driven by global and regional economies and incentives, initiatives taken at an international level may support sustainable outcomes for this globally important region.

5. Conclusion

We have demonstrated that stakeholder-based ecosystem services assessment, supported by spatially explicit assessment of ecosystem benefits, provides a useful platform to evaluate the outcomes of land-use allocation and management strategies for heterogeneous and multifunctional landscapes. We found that targets expressing stakeholder aspirations and entitlements to be a practical way to integrate estimates of demand and social utility such that meaningful comparisons can be made between different land-use objectives. Land sparing strategies applied to agricultural zones would improve prospects for currently underrepresented biodiversity features, whereas land sharing strategies would facilitate conservation of species more tolerant to agriculture over a wider area. Gains from these strategies could be achieved under reasonable assumptions of land sharing or sparing policy effectiveness. However, neither land sparing nor land sharing of agricultural zones provided substantial improvement additional to benefits achieved by implementing improved land-use allocation from the outset, and no plan or policy scenario assessed could satisfy all land-use targets. Resolution of trade-offs between objectives and fulfilment of stakeholder demands will require improved land-use allocation, or else careful revision of targets.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.biocon.2015.03.004.

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