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Reconciling Food Production and Biodiversity Conservation: Land Sharing and Land Sparing Compared

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The question of how to meet rising food demand at the least cost to biodiversity requires the evaluation of two contrasting alternatives: land sharing, which integrates both objectives on the same land; and land sparing, in which high-yield farming is combined with protecting natural habitats from conversion to agriculture. To test these alternatives, we compared crop yields and densities of bird and tree species across gradients of agricultural intensity in southwest Ghana and northern India. More species were negatively affected by agriculture than benefited from it, particularly among species with small global ranges. For both taxa in both countries, land sparing is a more promising strategy for minimizing negative impacts of food production, at both current and anticipated future levels of production.

Given multiple competing demands for land, how might humanity minimize the impact on biodiversity of producing food for 9 billion people (*1*–*3*)? One strategy—land sharing—involves integrating biodiversity conservation and food production on the same land, using wildlife-friendly farming methods (*3*–*6*). A contrasting alternative—land sparing—consists of separating land for conservation from land for crops, with high-yield farming facilitating the protection of remaining natural habitats from agricultural expansion (*3*–*7*). Achieving land sparing is fundamental to reducing emissions from deforestation and forest degradation (REDD) and requires the sustainable intensification of agriculture (*1*, *8*, *9*). Land sharing is often an aim of agri-environment and certification schemes, and can result from some forms of agroforestry and organic farming (*10*–*13*). Increases in crop yields do not guarantee land sparing (*14*–*17*), and land sharing schemes do not guarantee benefits to biodiversity on farmed land (*12*, *18*); instead, both approaches require careful design and implementation to be effective. Here we address a more fundamental question: Assuming that they could be implemented properly, which would do the least harm to biodiversity: land sharing or land sparing?

Answering this question requires information on variation in species' population densities among comparable areas with a range of quantified levels of crop yield (*3*). These data can be used to construct a density-yield function for each species, from which one can identify the yield that maximizes the species' total population size on farmed and unfarmed land combined, at any given level of food production (the production target) (*3*). We report this information for birds and trees in Ghana and India, where both land sharing and land sparing have been advocated for reconciling food production and biodiversity conservation (*19*–*22*).

We measured the mean population densities of 167 bird species and 220 tree species in 25 1-km^2 squares in Ghana, and of 174 bird species and 40 tree species in 20 1-km^2 squares in India (*23*) (figs. S1 and S2). Both study regions contained remnants of forest within a matrix of farmland ranging from diverse low-yielding mosaic agriculture to large-scale high-yielding monocultures and have experienced growth in food production through a combination of cropland expansion and yield increases. We fitted separate density-yield functions for each species, for two yield currencies (food energy and profit). From these functions, we classified species according to whether (i) their total population on farmed and unfarmed land combined was higher or lower than that if the province was all forested, and (ii) their total population on farmed and unfarmed land combined was highest if land was farmed at the lowest permissible yield (land sharing), at the highest permissible yield (land sparing), or at an intermediate yield (*3*).

Most species had density-yield curves with one of four simple forms (Fig. 1, A to D; proportions are shown in Fig. 1E). We defined as winners those species with higher total populations with agriculture, at all permissible yields, than in the all-forest baseline (Fig. 1, A and B). Changing the extent and intensity of agriculture is unlikely to threaten them. We defined as losers those species that had lower total populations when there was farming (Fig. 1, C and D, and fig. S3, A, B, and F). The total population for species with more complex density-yield functions can be greater or less than the baseline population, depending on yield (fig. S3, C to F): We conservatively included as losers those species with lower than baseline populations at any permissible yield for a given production target, regardless of whether they had larger populations at

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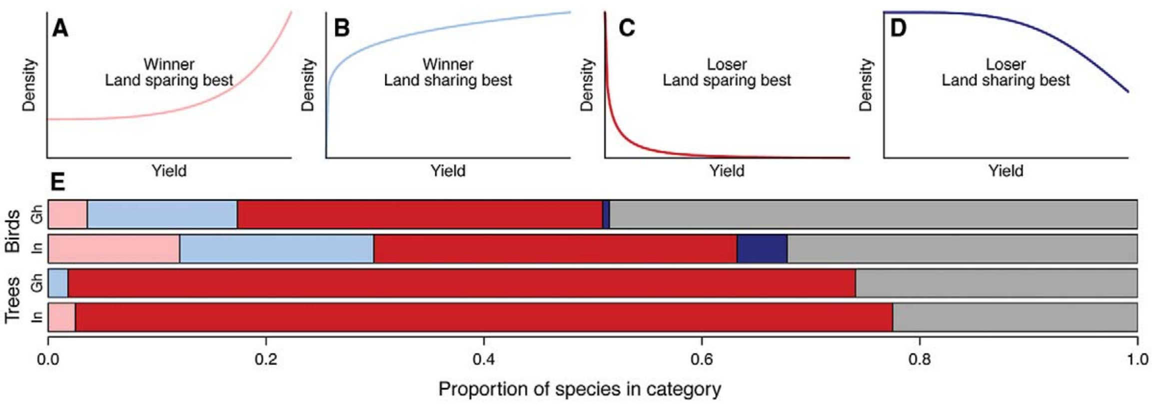

Fig. 1. Representative examples of functions relating population density to food energy yield, and their frequency among birds and trees in southwest Ghana (Gh) and northern India (In). Species with the lowest density in forest (**A** and **B**) are winners because their total population size (on farmland and unconverted land combined) is always higher when the study province contains farmed land than when it does not. Those with density on farmed land lower than that in forest at some or all permissible yields (**C** and **D**) are losers, because their total population can be lower than that expected if the whole province is forested. At any production target, species with convex density-yield functions [(A) and (C)] have highest total populations under a land sparing (highest permissible yield) strategy, whereas those with concave functions [(B) and (D)] have highest total populations under a land sharing (lowest permissible yield) strategy. Colored bars in (**E**) indicate the proportion of species with each type of curve. Various other more complex functions (gray parts of bars; fig. S3) can only be categorized as winner/loser and/or by optimal strategy at specific production targets, because the categories change with the production target: This further categorization is presented in Fig. 2 (*23*). *N* = 167 Ghana birds, 220 Ghana trees, 174 India birds, and 40 India trees.

other yields (fig. S3, C to E). Losers are of conservation interest because their total population is sometimes or always reduced by farming.

We next considered whether land sharing or land sparing would result in the largest population size for a given species. Species with convex density-yield functions (Fig. 1, A and C) have their highest overall population when land is farmed at the highest permissible yield and other land is conserved (land sparing), whereas those with concave density-yield functions (Fig. 1, B and D) have their highest population with the lowest permissible yield (land sharing) (*3*). The optimal strategy for species with more complex density-yield functions changes with the production target (fig. S3, A to F) and can switch between land sharing, land sparing, and intermediate-yield farming. However, at any given production target, we can define whether such species were winners or losers and identify the optimal strategy (Fig. 2). We present results separately for species with small and large global ranges, because small-range species tend to be at elevated risk of global extinction (*24*, *25*).

At all production targets, there were fewer winners (Fig. 2, pale colors) than losers (Fig. 2, dark colors), particularly for trees (Fig. 2, E to H) and species with small global ranges (Fig. 2, B, D, F, and H). Among losers, land sparing (dark red) resulted in the highest total population for the majority of species in each taxon, country, and range-size group, at almost all production targets. Only at production targets well below the current level for wide-ranging Ghana birds did the number of losers with highest populations from land sharing equal that of losers with highest populations from land sparing. The ratio of losers for which land sparing results in the highest population (dark red) to those for which land sharing is best (dark blue) was greater for species with smaller global ranges and higher for trees than for birds. There were few losers for which the highest total population occurred at an intermediate yield (dark purple).

To more fully assess the consequences of different land-use strategies, we calculated the expected abundance for each species, expressed as a ratio of total population size to that for our all-forest baseline, for 2007 and for three illustrative land-use strategies for 2050 (Fig. 3) (*23*). For all strategies, we expect that the total populations of more than half of all bird and tree species will be lower in 2050 than in 2007. Because densities of most forest species were much higher in the forest than outside, we predict that populations of most forest species will decline in proportion to forest area (the lowest circle in each stack in Fig. 3 indicates the number of such species).

In southwest Ghana, populations of many species were lower under current land use in 2007 (gray) than we project them to be in 2050 under intermediate yield (purple) or highest yield (red) strategies (Fig. 3, A and B). In contrast, under a lowest-yield land sharing strategy (blue), most tree species and around half of the birds would be

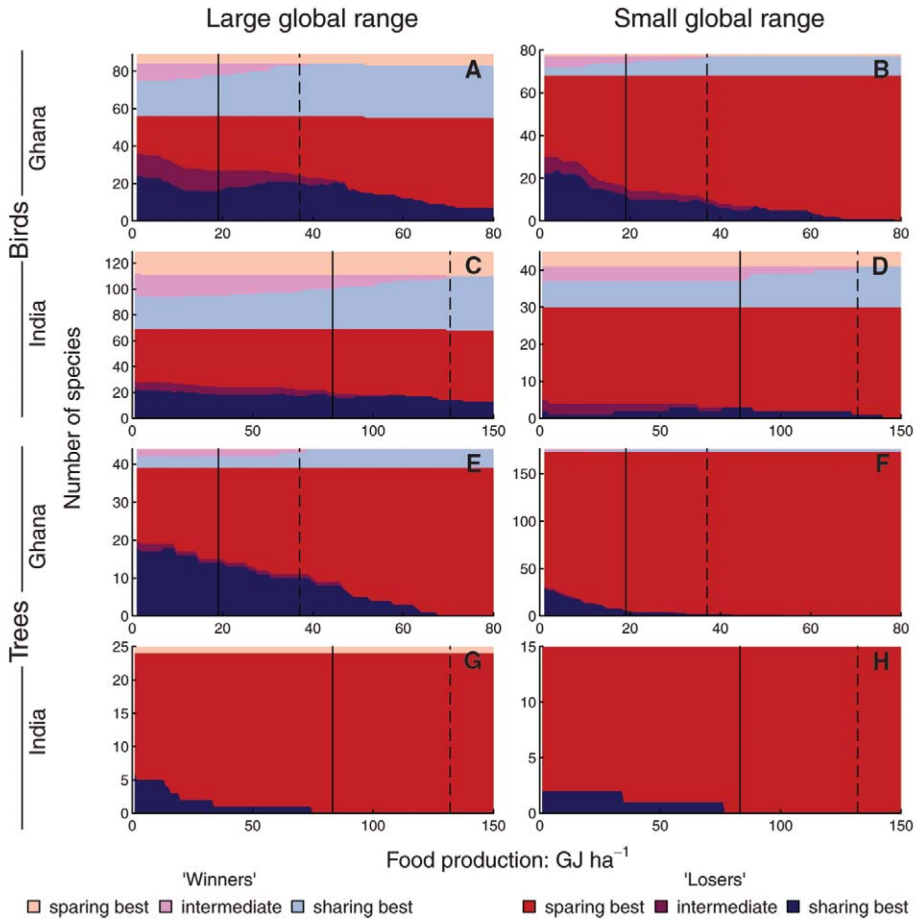

Fig. 2. Numbers of winners and losers and of species for which land sharing or land sparing or an intermediate strategy gives the highest total population, in relation to production target. Production targets for 2007 (solid) and 2050 (dashed) are indicated by vertical lines. Winners are indicated by pale colors, losers by dark colors. For birds (**A** to **D**) and trees (**E** to **H**), most losers at most production targets will have higher overall populations under land sparing than land sharing. This tendency is especially marked for species with small global ranges [(B), (D), (F), and (H)], for trees, and as production targets rise. Maximum permissible yields were 99 GJ ha^{-1} (Ghana) and 182 GJ ha^{-1} (India): these were 1.25 times the highest yields we observed. Our conclusions are robust to the choice of maximum permissible yields, to choice of yield currency (food energy or profit), to varying the assumption that yields are uniform within the province, and to the exclusion of rarely recorded species (figs. S4, S6 to S8, S10, and S11). The *y* axes represent numbers of species, scaled so that the vertical extent of each panel, which represents the total number of species in the sample, is the same for each taxon-country combination.

expected to decline further or disappear from the study region. In northern India, we expect that land sparing (red) would result in little change in the populations of most birds and trees in 2050 relative to 2007, whereas land sharing (blue) or an intermediate strategy (purple) would likely result in further declines of many species (Fig. 3, C and D). These results suggest that both countries could produce more food with minimal further negative impacts on forest species if they were to implement ambitious programs of forest protection and restoration alongside sustainable increases in agricultural yield, but they could not if they adopted land sharing.

Our analyses do not address the question of how to protect natural habitats on land that, because of high yields elsewhere, is not required for farming. However, they do show that, if mechanisms to achieve this could be found, most species would have higher populations under land sparing than under land sharing or intermediate-yield farming. This result is consistent across taxa and countries, is robust to varying assumptions (supporting online material text and figs. S4 to S11), and is true for widespread species and especially those with small global ranges. Land sparing might also be the most effective land-use strategy for mitigating greenhouse gas emissions (*9*, *26*). Our illustrative strategies are deliberately simple: More-detailed scenarios could be developed, considering other objectives and constraints such as ecosystem services, externalities, spatial structure, long-term sustainability of yields, and equitable distribution of costs and benefits (*27*–*29*).

Although the conclusions from our analyses are similar for both study regions and for birds

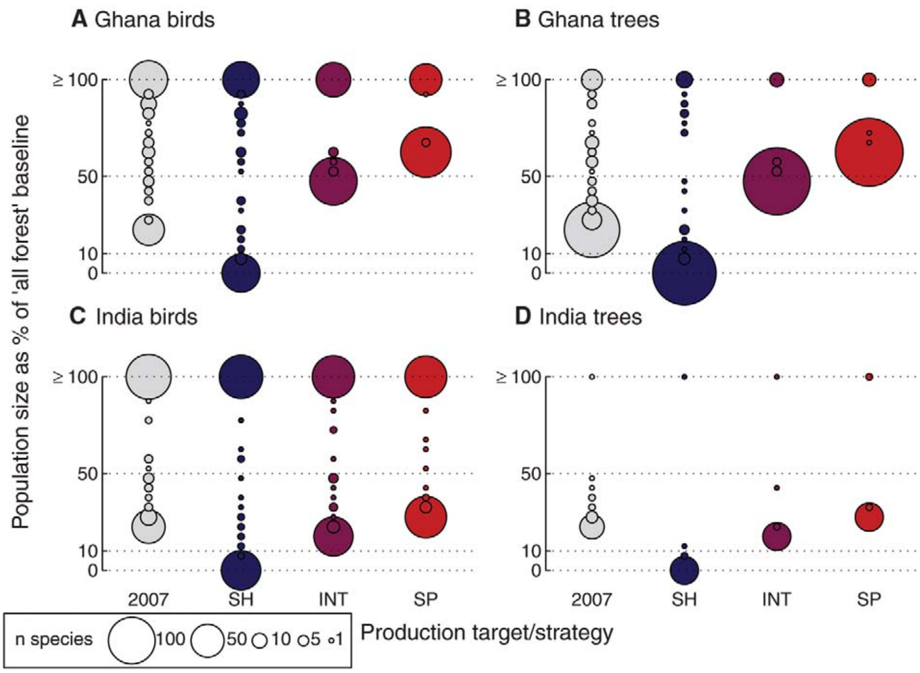

Fig. 3. Expected total population sizes of birds (**A**) and trees (**B**) in southwest Ghana and birds (**C**) and trees (**D**) in northern India in 2007 and with a projected 2050 production target for food energy achieved through three illustrative land-use strategies. Population sizes are expressed relative to an "all forest" baseline, which assumes that, in the absence of agriculture, all land would be forested. The area of each circle is proportional to the number of species with that relative population size. From left to right, each panel shows relative population sizes in 2007 (gray), those expected at the 2050 production target if all farming is at the lowest permissible yield (land sharing: SH, blue), with farming at the midpoint of the range of permissible yields (INT, purple), and with all farming at the maximum permissible yield (land sparing: SP, red) (*23*).

and trees, our sample size of two taxa in two regions with dominant natural land cover of forest is not enough to argue that land sparing is the optimal strategy for reconciling food production and biodiversity conservation everywhere and for all taxa. However, our study illustrates the practicality of methods that could readily be applied across a broader sample of regions and taxa. Coverage should be extended to include regions with a representative range of natural biome baselines, land-use histories, and past climatic regimes.

We echo others (*26*, *30*) in advocating a more sophisticated vision of land sparing than simply coupling traditional protected-area establishment with current practices found in large-scale agribusiness. Habitat protection can involve a range of mechanisms such as conservation concessions, indigenous reserves, areas comanaged with local communities, and habitat banking (*31*–*33*). Likewise, increasing yields in sustainable and socially equitable ways might involve context-specific knowledge- and labor-intensive innovations implemented by smallholder farmers, rather than dependence on agrochemicals and mechanization (*34*). Social and political constraints such as land tenure patterns are important but not insurmountable: Humans have the capacity to adapt their activities far more than do other species.

Future food production targets will have a large influence on the prospects for almost all wild species. Measures to reduce demand, including reducing meat consumption and waste, halting expansion of biofuel crops, and limiting population growth, would ameliorate the impacts of agriculture on biodiversity. But whatever the production target, prospects for land sharing win-wins in southwest Ghana and northern India appear to be distinctly limited. Instead, substantially increasing yields while simultaneously sparing and restoring natural habitat offers greater potential for people to meet escalating food demand with the least harm to other species.

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Supporting Online Material

www.sciencemag.org/cgi/content/full/333/6047/1289/DC1
Materials and Methods
SOM Text
Figs. S1 to S11
Tables S1 to S6
References (*35*–*72*)

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