How could increasing agricultural yields help to make space for nature?

It's time to link yield increases with habitat conservation.

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Expansion of land area used for agriculture is a leading cause of biodiversity loss and greenhouse gas emissions, particularly in the tropics. One potential way to reduce these impacts is to increase food production per unit area (yield) on existing farmland, so as to minimize farmland area and spare land for habitat conservation or restoration. There is now widespread evidence that such a strategy could benefit a large proportion of wild species, provided that spared land is conserved as natural habitat (*1*). However the scope for yield growth to spare land by lowering food prices and hence incentives for clearance ("passive" land sparing) can be undermined if lower prices stimulate demand, and higher profits per unit area encourage agricultural expansion, increasing the opportunity cost of conservation (*2*, *3*). We offer a first description of four categories of "active" land-sparing mechanisms that could overcome these rebound effects by linking yield increases with habitat protection or restoration. The effectiveness, limitations and potential for unintended consequences of these mechanisms have yet to be systematically tested, but in each case we describe real-world interventions which illustrate how intentional links between yield increases and land sparing might be developed.

FOUR LINKING MECHANISMS. *1. Land-use zoning.* Zoning some land for conservation and some for agriculture limits agricultural expansion, provides security to landholders investing in agricultural productivity, and can incentivize yield increases to compensate for the scarcity of available land ("Boserupian innovation" (*4*)). However, zoning does not drive yield increases in agricultural zones directly. Hence, there is a risk of it leading to displacement of production outside the regions subject to zoning. Such "leakage" might be less likely where zoning restrictions are placed on the expansion of export commodities with high price elasticity of demand, rather than on staple foods (*2*).

In Costa Rica, after the government zoned forests as off-limits for agricultural expansion, the rate of clearance of mature forests halved (*5*). Export-oriented agriculture shifted from cattle pasture towards high-yielding pineapple and banana crops, (for fuller information and references for this and other case studies, see Supplemental Materials (SM), including Table S1). Beef production declined, albeit temporarily, while production of pineapples and other crops has continued to increase. The risk of leakage could be reduced by prioritizing less productive land for conservation to minimize loss of production, and by combining zoning with other interventions (*6*).

2. Economic instruments such as payments, land taxes, and subsidies. These can in principle be tailored to stimulate yield increases, discourage habitat conversion, and make receipt of benefits conditional on habitat conservation. Incentive programs often involve contracts, and difficulties can arise through hidden actions and information asymmetries. For example, recipients might conceal breaches of contract, or accept money for actions they would have carried out anyway. These risks can be reduced by building trust, understanding the people and places where interventions occur, developing cost-effective monitoring, and enforcing contracts.

An incentive program which has successfully spared land has been implemented in the Spiti Valley of Himalayan India (*7*). In exchange for designating land set-asides for the recovery of snow leopard prey, herders receive payments and technical assistance to reduce livestock losses to snow leopards (improving yield) and to organize insurance against losses. The program, which was developed collaboratively with herders and local government to ensure it addresses local priorities, reduced snow leopard predation of livestock by two-thirds in its first four years and eliminated snow leopard killings.

3. Spatially strategic deployment of technology, infrastructure, or agronomic knowledge. Land sparing can be encouraged if yield-enhancing measures (such as better soil, nutrient, or water management, improved germplasm, multiple cropping, or integrated pest and disease control) are intentionally directed towards certain areas and not others. Upgrading "extension" services that provide technical advice to farmers or improving road networks in established farmlands could enhance yields and reduce post-harvest losses, while concentrating capital away from frontiers of agricultural expansion and thus avoiding risks involved in stimulating agriculture in areas of extensive natural habitat (*8*). Increasing yields of staple crops, for which demand is inelastic to price changes, appears more likely to support land sparing than increasing yields of luxury or export crops (*2*). A limitation of strategic deployment is that it encourages yield increases directly but only protects natural habitats indirectly, by reducing pressure for conversion. It will often be necessary to combine this mechanism with others, especially land-use zoning. A key challenge is to ensure that benefits and costs are not unfairly distributed.

In the Philippine province of Palawan, introduction of irrigation helped lowland rice farmers produce two crops per year rather than one (*9*). They met their higher labor demands by employing upland farmers, who used part of their new-found income to invest in fertilizers, improving their own yields and reducing their need to clear forests. Deforestation rates in the uplands halved. Larger and poorer households were those most likely to benefit. Nevertheless, addressing social justice remains practically and ethically complex, is often hampered by unequal power relations, and may often require additional measures, such as increasing non-agricultural job opportunities for marginalized groups.

4. Standards and certification. Voluntary standards could link yield growth to conservation by requiring habitat protection, defining sustainable yield-increasing practices, monitoring compliance, and rewarding good performance with market access and price premiums. Sparing or restoring natural habitats at farm scale can be more bene-

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ficial for biodiversity than certifying lower-yielding 'wildlife-friendly' practices (*10*). To maximize their contribution to landscape-level conservation, certification schemes should widen their focus from individual farms to coordinated actions by groups of farmers in places where potential conservation gains are greatest.

Participating farmers in the Ibis Rice scheme in northern Cambodia receive technical assistance and a price premium, which makes it easier to afford simple technology and additional labor (*11*). At the same time, they agree to a village-level land-use plan that protects habitats. These agreements are maintained in part by social pressure: a major infraction would put everyone's benefits at risk. Together with other initiatives, the scheme has reduced deforestation and increased rice harvests. It illustrates one way of making landscape-scale conservation relevant and feasible for individual farmers.

CONDITIONS AND SYNERGIES. Some conditions make successful implementation of land-sparing mechanisms more likely. Labor- and capital-intensive technologies and practices are those most likely to be conducive to land sparing *(8)*. Knowledge networks can also help improve implementation of sustainability standards or payment schemes (*12*). For example, thousands of Landcare groups in Australia share knowledge on accessing funds, conserving habitats, and improving agricultural techniques. Landcare participants are more likely to protect and restore native vegetation, and to adopt practices that sustain agricultural yields (*13*). Markets also matter. For commodities with globalized markets and elastic demand, limiting rebound effects through demand-side measures and restrictions on land use will be crucial. In the case of staples grown by smallholders, supporting them to increase their yields (thereby limiting leakage) might be more appropriate.

Each mechanism is most likely to be effective if implemented in synergy with others, so that strong protection is provided to habitats, and adequate support is provided to farmers to increase their yields. Command-and-control zoning policies will more likely be accepted as legitimate if accompanied by incentives, improved access to technology and infrastructure, and knowledge sharing (*14*). Because of the risk of rebound effects, strategic deployment will often have to be integrated with mechanisms such as zoning that apply over large areas. Environmental and agricultural policies need to be co-ordinated to work in synergy, rather than in conflict.

Brazil provides an example of how multiple policy interventions can work together. Natural habitats are conserved through several instruments including protected areas, indigenous reserves, and Forest Code requirements on private lands (*15*). Government-subsidized loans are provided to farmers to increase productivity on degraded pastureland. Partly due to these initiatives, and despite widespread non-compliance with the Forest Code, deforestation in the Brazilian Amazon declined steeply after 2004, while agricultural production continued to grow.

Whether these trends can be sustained, and replicated elsewhere, will depend largely on the political will to deliver strong environmental governance. There is a risk that environmental regulations will be corrupted or diluted by powerful special interests, as happened in Europe with the Common Agricultural Policy (*16*). Further efforts to reduce habitat loss must do so while safeguarding the interests of smallholders, as agricultural credit programs in Brazil seek to do by supporting family farms. In many parts of the world, higher yields have eroded not only on-farm biodiversity, but also water, soil and air quality. Much remains to be done to reduce these impacts by applying improved agronomic and agroecological knowledge (*17*).

Harnessing the potential of higher-yield farming to make space for nature at scales that matter will not be straightforward, but the examples described here illustrate that it can be done. The challenge is to move on from thinking about higher yields simply as a means to produce more food, and to use them to free up land for conserving biodiversity and ecosystem services. Reconciling agriculture and conservation is one of this century's greatest challenges. We hope that by describing some promising solutions, we can stimulate the proposal, testing, and application of many more.

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Acknowledgments. We thank T. Gardner, M. Fagan, A. John, A. Mould, G. Shively, E. Beauchamp, C. Mishra, T. Clements, N. Selva and three anonymous reviewers for comments. Funding: Zukerman fellowship, King's College, Cambridge (B.P.); Natural Environment Research Council NE/K015419/1 (L.V.D.); Gordon and Betty Moore Foundation and Norwegian Agency for Development Cooperation (B.B.N.S.); Biotechnology and Biological Sciences Research Council BB/J014540/1 (E.K.H.J.zE.).

10.1126/science.aad0055

Figure 1. Costa Rica has protected its forests through land-use zoning while increasing yields on agricultural land.