TITLE: It's time to fix the biodiversity leak

AUTHORS: Andrew Balmford[1,2]*, Thomas S. Ball[1,2], Ben Balmford[3], Ian J. Bateman[3], Graeme Buchanan[4], Gianluca Cerullo[1,2], Francisco d'Albertas[1,2], Alison Eyres[1,2], Ben Filewod[5], Brendan Fisher[6,7], Jonathan H.M. Green[8], Kyle S. Hemes[9], Jody Holland[1,2], Miranda S. Lam[1,2], Robin Naidoo[10], Alexander Pfaff[11], Taylor Ricketts[6,7], Fiona Sanderson[12], Timothy D. Searchinger[13,14], Bernardo B.N. Strassburg[15] & David R. Williams[16]

AFFILIATIONS:
[1] Department of Zoology, University of Cambridge; Cambridge CB2 3EJ, UK.
[2] Conservation Research Institute, University of Cambridge; Cambridge CB2 3EJ, UK.
[3] Land, Environment, Economics and Policy (LEEP) Institute, Economics Department, University of Exeter Business School; Exeter EX4 4PU, UK.
[4] RSPB Centre for Conservation Science, RSPB Scotland; Edinburgh EH12 9DH, UK.
[5] Grantham Research Institute on Climate Change and the Environment, London School of Economics and Political Science; London WC2A 3PH, UK.
[6] Gund Institute for Environment, University of Vermont; Burlington, VT 05405, USA.
[7] Rubenstein School of Environment and Natural Resources, University of Vermont; Burlington, VT 05405, USA.
[8] Stockholm Environment Institute York, Department of Environment and Geography, University of York; York YO10 5NG, UK.
[9] Woods Institute for the Environment, Stanford University; Stanford, CA 94305, USA.
[10] World Wildlife Fund; Washington, DC 20037, USA.
[11] Sanford School of Public Policy, Duke University; Durham, NC 27709, USA.
[12] RSPB Centre for Conservation Science, Royal Society for the Protection of Birds; The Lodge, Sandy SG19 2DL, UK.
[13] World Resources Institute; Washington, DC 20002, USA.
[14] School of Public and International Affairs, Princeton University; Princeton, NJ 08540, USA.
[15] Rio Conservation and Sustainability Science Centre, Department of Geography and the Environment, Pontifícia Universidade Católica; Rio de Janeiro 22451-900, Brazil.
[16] Sustainability Research Institute, School of Earth and Environment, University of Leeds; Leeds LS2 9JT, UK.

*Corresponding author. Email: apb12@cam.ac.uk

ABSTRACT: The risk that locally successful nature conservation projects may increasingly be shifting problems elsewhere can no longer be ignored

MAIN TEXT: As momentum builds behind hugely ambitious initiatives like the Global Biodiversity Framework (GBF) 30 x 30 target and the European Union's (EU's) Biodiversity and Forestry Strategies, there is a danger that hard-won local conservation gains will be dissipated through leakage, the displacement of human activities that harm biodiversity away from the site of an intervention to other places (1). These off-site damages may be less than on-site gains—in which case the action is still beneficial but less so than it superficially seems. However, if activities are displaced to more biodiverse (or less productive) places, leakage impacts may exceed local benefits, so that well-intentioned efforts cause net harm. There is a pressing need for leakage effects like this to be acknowledged and as far as possible avoided or mitigated—through demand reduction, careful selection of conservation or restoration sites, or compensatory increases in production in lower-impact areas.

Conservation interventions on land or at sea are intrinsically vulnerable to leakage because most threatened species are in trouble from farming, fishing, hunting, or wood harvesting. It follows, then, that effective conservation or restoration actions generally lower current or future food or fiber production—by preventing habitat conversion, reducing the intensity of production, or stopping it altogether. Under local, so-called activity-shifting leakage, actors directly affected by an intervention then relocate to farm, log, hunt, or fish elsewhere. But as supply chains become more globalized and area-based conservation efforts expand in scale, it is increasingly likely that they lead to what is termed market leakage (2). Here, by reducing local production and so raising prices, conservation actions inadvertently incentivize the expansion of harmful production by other actors, sometimes after a delay, and even in other countries.

As one carefully analyzed example, although US government actions to conserve old-growth forests in the Pacific Northwest reduced annual timber harvests there by ~2.1 billion board-feet, they incentivized a 1.7 billion board-feet increase in softwood harvesting elsewhere in North America (3), where it is likely to have had substantial biodiversity impacts. Currently, there are growing concerns that as large-scale conservation and wider environmental initiatives accelerate in temperate regions such as Europe and China, resulting production shortfalls are stimulating accelerated land conversion in more biodiverse, less well regulated parts of the world (4, 5).

LEAKY CONSERVATION

It appears that, as in the market for forest-carbon credits (*2*, *6*–*8*), leakage is seriously underrecognized in the biodiversity sector. At the site level, preliminary results from a new survey of 100 managers responsible for tropical conservation projects found that 37% said they were unaware of the concept of leakage, and less than half reported undertaking efforts to mitigate its extent (*9*). At larger scale there is, extraordinarily, no mention of the problem of leakage in the recent Global Biodiversity Framework goals or targets, where the text calling for at least 30% of Earth's land and sea "to be effectively conserved and managed" says nothing about whether this might simply shift the negative impacts of food and wood production elsewhere. Likewise, the Japanese government's plans for a pesticide-free Green Food System and the EU's Biodiversity and Forestry Strategies (*5*) are mute on how the leakage of forgone production will affect biodiversity and other environmental outcomes farther afield; in Europe, the EU's Anti-Deforestation Regulation signals an intention to consider impacts beyond its borders but is undermined by trade regulations (*10*).

So why is leakage still largely overlooked in conservation? We think there are several reasons. Biodiversity projects, programs, and policies focus largely on local, national, or regional targets; impacts induced outside the defined domain of interventions are then not considered. Additionally, quantifying leakage and its biodiversity impacts robustly is hard—and what is not measured is often ignored. Also, mitigating leakage can be a daunting and costly challenge. Finally, incorporating leakage effects will generally lead to conservation impacts being revised downward, creating perverse incentives to instead be unduly optimistic about leakage.

Yet as with carbon projects (*6*–*8*), there is widespread evidence that biodiversity interventions often cause leakage. As one example, an assessment of deforestation in and around 423 East African protected areas (PAs) reported that rates of forest loss in their buffer zones often exceeded average regional losses, particularly for the National Parks that successfully slowed deforestation within their boundaries (*11*). Attributing causality in cases of apparent activity-shifting leakage like this is difficult, but market leakage too is challenging to analyze (*2*). Because of the dispersed and interlinked nature of many markets, the actors who respond to such price signals may be far from the intervention site and thus difficult to track. Most assessments of market leakage therefore rely on hard-to-parameterize equilibrium models of how consumers and suppliers react to the price changes caused by reduced production (*2*, *8*). The resulting estimates of the magnitude of leakage are inevitably uncertain (*2*) but potentially major (*3*). Nevertheless, using available data on production, trade, and species' distributions, it is possible to make some inferences about the range of likely biodiversity impacts of market leakage arising from conservation projects in different regions (see the figure).

Consider two hypothetical but plausible restoration programs in agricultural landscapes, assessed using real-world data and preliminary, simplified analyses. In one (see the figure, left), restoring natural habitats on soy-producing land in a high-biodiversity region causes market leakage, but mostly to less biodiverse countries. In this case, local biodiversity gains probably exceed losses elsewhere: The intervention is less beneficial than it might first seem but still generates net conservation gains. In marked contrast, in a second example (see the figure, right), restoration of currently productive arable farmland in a wealthy but low-biodiversity country boosts local biodiversity but raises food imports from higher-biodiversity countries. In this case, local gains would be exceeded by overseas losses, so that in net terms, the intervention harms global biodiversity.

Several conclusions about leakage from area-based conservation or restoration thus appear valid. First, despite the difficulties in robust assessment of displaced production from such efforts, off-site biodiversity damage from leakage may be considerable. Second, real-world efforts to mitigate leakage or even acknowledge its importance in conservation are limited. This raises concerns that reported benefits of conservation actions will be overestimated—potentially weakening future political support for efforts to greatly increase the extent of area-based conservation and undermining the emerging market for biodiversity credits (*12*). Third, as illustrated by our restoration examples, we should be especially concerned about leakage from output-reducing conservation interventions in biodiversity-poor but wealthy parts of the world (such as Northwestern Europe), which can readily replace forgone production through imports. The resulting rises in imports can stimulate increased production in higher-biodiversity regions (*4*, *10*), causing damage there that may exceed domestic conservation gains. And finally, it seems likely that problems of leakage and its quantification will increase—as conservation and restoration efforts grow, as the footprint of food and fiber production expands, and as markets become increasingly interconnected.

FIXING THE LEAK

There is no single solution for tackling leakage from conservation interventions, but we summarize five possible approaches (see supplementary materials for more details).

Recognize and report forgone production and potential for leakage as rigorously as possible

Tracking changes in food or wood production in intervention areas is in principle relatively straightforward and should be integrated into routine program monitoring. Projects that report near-zero losses in production should be examined further to distinguish those with effective leakage mitigation from those with little or no conservation impact. National or international conservation policies or targets affecting land use should include explicit consideration of local and longer-range leakage. But environmental accounting rules that ignore production impacts incurred beyond country or regional boundaries, as well as poor-quality agricultural, timber, and trade data and the challenges of assessing consumer and producer dynamics, all mean that translating forgone production into leakage impacts will continue to be problematic (*2*). Data improvements and a shift to include jurisdictional assessment of interventions will help. However, we suggest that precise estimates of leakage should be treated with caution, and that most focus should instead be on its mitigation.

Reduce demand for high-leakage goods and improve efficiencies in line with decreases in production

If demand is cut as output falls, leakage is less likely. Actions that reduce waste or improve the efficiency of resource use may be particularly promising. For instance, an intervention coupling restrictions in unsustainable fuelwood harvesting with provision of more fuel-efficient stoves might prevent wood collection shifting elsewhere. More ambitiously, lowering demand for meat by encouraging uptake of lower-footprint alternatives may be possible in some contexts (*10*). But demand-side interventions raise several concerns, including the risks of reducing incomes and access to essential goods, and the possibility that any savings achieved through efficiency gains may stimulate increased purchases of other products with their own biodiversity impacts. There is also the question of who is best placed to tackle demand. Some actions—working to reduce farm-level food losses in an inter-vention area, for instance—might plausibly be delivered by conservation projects. But others, such as infrastructure improvements to cut retail food waste, or shifting high-footprint diets, will require much larger scale programs and necessitate partnerships with other sectors, such as food and farming, forestry, transport, and health.

Target conservation actions to places where conserving or restoring substantial biodiversity will cause limited displacement of production

One possibility here is the restoration of currently degraded areas that produce little food or wood but require help to restore their biodiversity value. An example could be tropical forests that are repeatedly cut in part to maintain land tenure, but never farmed (*13*) (so-called "Peter Pan" forests because, like the fictional character, they never grow up). Another could be the restoration of mangroves that were cleared to establish now-abandoned aquaculture operations. A second, broader option for limiting leakage is to focus interventions in areas (as in the figure, left) that are much higher in potential biodiversity value or where yields (production per unit area) are substantially lower than in areas to which forgone production is likely to be displaced. However, a general limitation to all these approaches is that conservation is most often needed in biodiverse landscapes with considerable current or future potential for producing food or wood: These are the areas where nature is at greatest risk.

Increase yields within or near project areas

If the yields of products can be sustainably increased nearby, land can be conserved or restored with little or no reduction in overall production, local food security, or livelihoods. The Gola Rainforest Project in Sierra Leone, for example, slows deforestation while limiting activity-shifting leakage by providing wide-ranging agronomic support to local farmers to boost cocoa and staple crop yields (*14*). In Spiti Valley, India, villagers received training and financial incentives for herding practices that reduce losses to snow leopards (and so boost yields) in exchange for setting aside land for wild ungulates. Given the marked yield gaps commonly observed in production systems in the tropics (*15*), there would appear to be widespread scope for locally targeted support for sustainable yield increases to be integrated into conservation projects, through actions ranging from provision of improved seeds and fertilizer to better access to credit and insurance. Even in intensively farmed regions such as Europe, innovative practices and technologies can increase yields sustainably (*10*). Safeguards are needed to limit the risk of rebound effects, whereby yield increases lower prices or raise profits and so stimulate increased production. Moreover, increasing yields sustainably and over the long run can be challenging and often requires several simultaneous interventions, which conservation-focused agencies or nongovernmental organizations may not have the capacity to deliver; again, other partners—in farming, forestry, and development—may be needed.

Direct displaced production to lower-impact areas beyond intervention sites

If increasing yields in or near a project area is not practical or cost-effective, large-scale programs or policies could encourage conservation organizations—or, more likely, agriculture or forestry specialists they might partner with—to replace forgone production by narrowing yield gaps in other places that supply the same markets but are less important for biodiversity. A new generation of restoration approaches is seeking to make this possible. Another option might be to allow limited habitat conversion in areas with high yield potential but low value for biodiversity. In either case, the environmental impacts and possible rebound effects of intentionally displaced production need to be tracked and deducted from estimates of intervention performance. It will also be important to assess and mitigate any negative socioeconomic effects of shifts in the location where goods are produced. However, deliberate displacement of production to known areas makes tracking and addressing such impacts more feasible than under unconstrained market leakage.

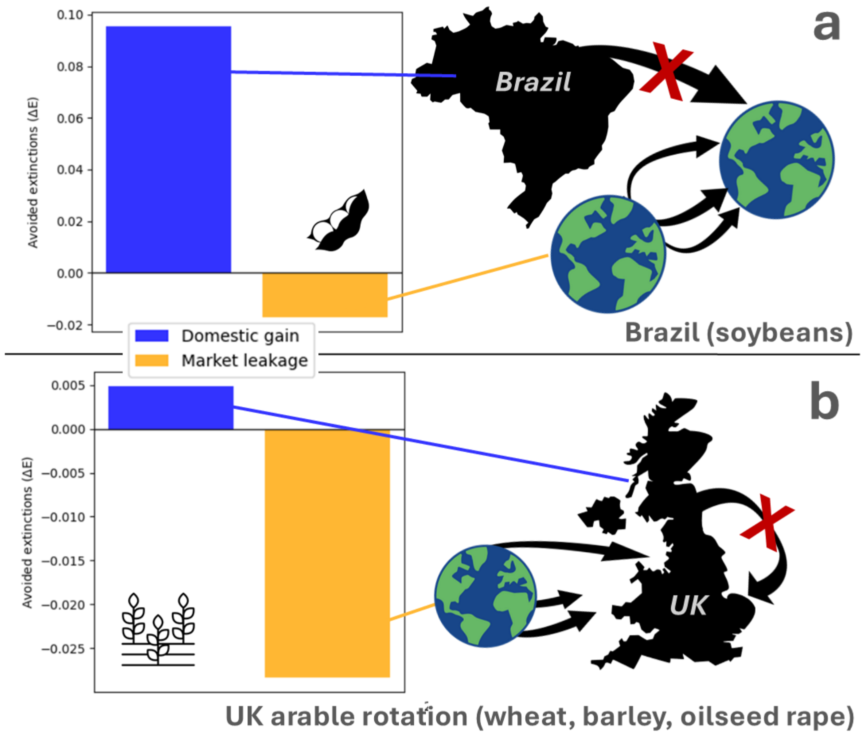
PROGRESS BY PREVENTION

Leakage can undo the hard work of otherwise successful conservation actions. We believe it demands far greater attention from a sector that seeks to shape how 30% of an ever-hungrier and more connected planet is managed. Several technological and research developments already underway—high-resolution data on farm and forestry yields, trade flows, and the distribution and sensitivity of biodiversity, and better methods for estimating displaced production—will help improve quantification of leakage. But much greater efforts are also needed to prevent leakage in the first place—by making measures such as demand reduction and sustainable compensatory yield increases (on or away from conservation sites) integral to biodiversity interventions in production landscapes, and by being cautious about expanding conservation efforts in high-yielding areas of lower-biodiversity regions of the world that can readily import replacement commodities.

For locally successful actions to be globally beneficial, conservation must recognize and address its unintended but increasingly wide-reaching impacts on production of the food, timber, and other goods that people need. Where the conservation sector focuses on site-level outcomes and ignores activity-shifting and especially market leakage, demands for forgone production will in many cases simply be met elsewhere, in some instances at net cost to biodiversity as a whole. Of course, tackling leakage effectively necessitates change not just within conservation but among commodity producers and traders too, which in turn requires regulatory support from governments so that businesses are operating on a level playing field. Fortunately, many of these actors share in the ambition of halting global biodiversity loss. Taking coordinated action to limit leakage is essential if this common goal is to be achieved.

BOX:

Regional variation in biodiversity impacts net of leakage



Examples of market leakage from two hypothetical habitat restoration programs chosen to illustrate how net impacts on biodiversity are likely to vary geographically. a: restoring natural habitat on 1000km2 of Brazilian soy-producing land benefits local biodiversity (expressed as the change in avoided of extinctions of species from land use; positive ΔE shown in the blue bar) but unless demand is cut or yields are increased elsewhere in Brazil, this will reduce the country's soy exports; this is in turn likely to stimulate increased production in other countries (mainly Argentina, USA, Paraguay, Uruguay and China) which export soy to the same markets, and hence lower their biodiversity (negative ΔE; the yellow bar). However, based on current yields and assuming forgone Brazilian production is substituted by increased production elsewhere proportional to current trade volumes, although losses due to market leakage are substantial, they will probably be exceeded by local biodiversity gains. b: restoring 1000km2 of arable farmland in the UK benefits local biodiversity but reduces production of wheat, barley and oilseed rape; if unmitigated, this forgone production will be met by increased imports of these commodities, very largely from higher-biodiversity countries. Based on current yields and assuming forgone UK production is replaced by the existing mix of UK imports, leakage impacts on biodiversity are likely to outstrip local benefits substantially, with 40% of these displaced impacts arising in Australia (from oilseed rape) and the remainder in France, Germany, Italy, Ukraine and Poland. In each example calculations are based on commodity- and country-specific marginal impacts of agriculture on extinction risk, linked with FAO production and trade data, and assuming 100% displacement of forgone production. Leakage losses would be proportionally lower if less forgone production was displaced or if some displaced production was achieved through yield intensification. Analyses are deliberately simplified, but indicate that while in some regions local conservation benefits will outweigh leakage costs, unless active steps are taken to mitigate leakage from conserving rich but low biodiversity parts of the world, large-scale efforts to restore their biodiversity risk causing net harm. See supplementary materials for methods, assumptions and data sources.

REFERENCES AND NOTES

1. R. M. Ewers, A. S. L. Rodrigues, Estimates of reserve effectiveness are confounded by leakage. *Trends Ecol. Evol.* 23, 113–116 (2008).
2. B. Filewod, G. McCarney, Avoiding carbon leakage from nature-based offsets by design. *One Earth* 6, 790–802 (2023).
3. D. N. Wear, B. C. Murray, Federal timber restrictions, interregional spillovers, and the impact on US softwood markets. *J. Environ. Econ. Manag.* 47, 307–330 (2004).
4. Y. Zhang, S. Chen, Wood trade responses to ecological rehabilitation program: Evidence from China's new logging ban in natural forests. *For. Policy Econ.* 122, 102339 (2021).
5. H. Zhong, Y. Li, J. Ding, B. Bruckner, K. Feng, L. Sun, C. Prell, Y. Shan, K. Hubacek, Global spillover effects of the European Green Deal and plausible mitigation options. *Nat. Sustain.*, 1–11 (2024).
6. W. Pan, M.-K. Kim, Z. Ning, H. Yang, Carbon leakage in energy/forest sectors and climate policy implications using meta-analysis. *For. Policy Econ.* 115, 102–161 (2020).
7. S. S. Atmadja, A. E. Duchelle, V. D. Sy, V. Selviana, M. Komalasari, E. O. Sills, A. Angelsen, How do REDD+ projects contribute to the goals of the Paris Agreement? *Environ. Res. Lett.* 17, 044038 (2022).
8. B. K. Haya, K. Alford-Jones, W. R. L. Anderegg, B. Beymer-Farris, L. Blanchard, B. Bomfim, D. Chin, S. Evans, M. Hogan, J. A. Holm, K. McAfee, I. So, T. A. P. West, L. Withey, "Quality assessment of REDD+ carbon credit projects" (Berkeley Carbon Trading Project, 2023); https://gspp.berkeley.edu/assets/uploads/page/Quality-Assessment-of-REDD+-Carbon-Crediting.pdf.
9. M. Lam, T. Swinfield, J. Lyons-White, A. Balmford, Practitioners' perceptions of leakage from conservation projects [Preprint] (2024); https://www.cambridge.org/engage/coe/article-details/662671c691aefa6ce11966de.
10. R. Fuchs, C. Brown, M. Rounsevell, Europe's Green Deal offshores environmental damage to other nations. *Nature* 586, 671–673 (2020).
11. M. Pfeifer, N. D. Burgess, R. D. Swetnam, P. J. Platts, S. Willcock, R. Marchant, Protected areas: mixed success in conserving East Africa's evergreen forests. *PLOS ONE* 7, e39337 (2012).
12. T. Swinfield, S. Shrikanth, J. W. Bull, A. Madhavapeddy, S. O. S. E. zu Ermgassen, Nature-based credit markets at a crossroads. *Nat. Sustain.*, 1–4 (2024).
13. P. H. S. Brancalion, A. Balmford, C. E. Wheeler, R. R. Rodrigues, B. B. N. Strassburg, T. Swinfield, A call to develop carbon credits for second-growth forests. *Nat. Ecol. Evol.* 8, 179–180 (2024).
14. M. Malan, R. Carmenta, E. Gsottbauer, P. Hofman, A. Kontoleon, T. Swinfield, M. Voors, Evaluating the impacts of a large-scale voluntary REDD+ project in Sierra Leone. *Nat. Sustain.* 7, 120–129 (2024).
15. B. B. N. Strassburg, A. E. Latawiec, L. G. Barioni, C. A. Nobre, V. P. da Silva, J. F. Valentim, M. Vianna, E. D. Assad, When enough should be enough: Improving the use of current

agricultural lands could meet production demands and spare natural habitats in Brazil. *Glob. Environ. Change* 28, 84–97 (2014).

ACKNOWLEDGMENTS

The authors thank the Biotechnology and Biological Sciences Research Council, the Gund Institute for the Environment of the University of Vermont, the Tezos Foundation, and Tarides for support. B.F. has provided paid consulting services to a company interested in providing tools to improve leakage quantification. T.S. has been a consultant to the World Wildlife Fund on nature-based credits. B.B.N.S. is the founder of re.green, a company dedicated to restoring native ecosystems, and has an equity stock.

SUPPLEMENTARY MATERIALS

science.org/doi/10.1126/science.adv8264