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The challenge of feeding the world while conserving half the planet

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Amid widespread concerns about biodiversity loss, a single clear conservation message is engaging leading conservationists: the proposal to give half the surface of the Earth back to nature. Depending on the landscape conservation strategy, we find that, globally, 15–31% of cropland, 10–45% of pasture land, 23–25% of non-food calories and 3–29% of food calories from crops could be lost if half of Earth's terrestrial ecoregions were given back to nature.

The Convention on Biological Diversity, signed by 196 parties, is the world's primary multi-lateral, legally binding treaty for protection and sustainable use of the planet's biological resources. Through it, world leaders made a commitment to halt biodiversity loss by 2010, but failed[1]. This led to the development of the Strategic Plan for Biodiversity 2011–2020, and 20 ambitious Aichi Biodiversity Targets[2]. With less than two years to go, these complex and ambiguous targets to halt biodiversity loss by 2020 seem out of reach[3].

Amid these signs of probable failure, prominent conservation leaders are congregating around an even more ambitious goal to give half the surface of the Earth back to nature (http://www.half-earthproject.org/ and http://natureneedshalf.org/). This proposal roughly equates with expanding the yet-to-be-achieved Aichi Target 11—to conserve 17% of the world's terrestrial and 10% of its marine areas—by roughly 3 and 5 times, respectively. In doing so, the project claims the potential to conserve ~85% of existing species[4], by moving towards a system of interconnected high-quality habitats of sufficient scale locally, regionally and globally to support the persistence of natural populations[5]. The added value of the so-called 'Half-Earth' project is in its branding: the idea is conceptually simple and visionary, creating a single banner under which other scattered conservation initiatives could operate. As an aspirational goal, it is a powerful message that could motivate and empower the public and local organizations to take positive action to protect the biosphere at the level needed to reduce biodiversity decline.

Yet, despite these benefits, the practical costs of Half-Earth incurred through trade-offs with other land uses, and its impacts on already disadvantaged populations around the world, remain poorly understood[6,7]. Possibly the greatest trade-off embedded in the Half-Earth proposal is with agriculture: the dominant land use competing for space with other species on this planet and the nexus of multiple Sustainable Development Goals linked to human health and wellbeing, climate change, biodiversity loss and water security[8]. While relationships between food production and biodiversity conservation have been analysed previously[9,10], the food production costs of Half-Earth are yet to be assessed.

In this paper, we offer an initial assessment of the potential global trade-offs between devoting half a planet for nature and agricultural production. We do this by assessing Half-Earth conservation strategies designed to maximize the protection of key biodiversity areas and existing wild lands while minimizing crop calorie losses caused by displacing arable agriculture. We conduct analyses at the global, country and ecoregion scales, giving half of the land within each geographic boundary at each scale back to nature (see the Methods for further details of our ranked prioritization used in the analyses). We run these analyses for two drastically different conservation approaches: 'nature-only landscapes', in which conservation displaces all crop production in regional landscapes[11] (~8.4 km × ~8.4 km pixels), and 'shared landscapes', in which conservation and crop production are allowed to coexist within each landscape (8.4 km × ~8.4 km pixels), in any possible spatial configuration (that is, both intensive and extensive production are possible; see ref. [12] for details of the debate surrounding these extremes). The shared landscapes approach is scale invariant, reflecting the implementation of fine-scale conservation strategies.

Our results demonstrate clear potential for trade-offs between Half-Earth and agricultural production that are strongly mediated by the approach taken and the spatial scale of the land units used for conservation planning. First, there is a strong negative effect of the spatial scale of conservation units, with trade-offs increasing across global ($n = 1$) versus country ($n = 182$) or ecoregion ($n = 775$) scales. At the global level, under a nature-only landscapes strategy, we see ~12% of cropland, ~21% of pasture, ~10% of non-food (that is, feed, biofuel and other) calories and ~11% of food calories lost—numbers that increase to ~31% of cropland, ~45% of pasture, ~25% of non-food calories and ~29% of food calories at the ecoregion level (Fig. 1). Second, there are massive differences in trade-offs between conservation approaches. Under shared landscapes, where agricultural production and conservation are allowed to coexist, productivity costs are much lower, demanding ~15% of cropland, ~10% of pasture land, ~23% of non-food calories and ~3% of food calories at the ecoregion level (Fig. 1). However, even under a shared landscapes approach, if pasture is converted to conservation before cropland, and non-food calories are abandoned before food calories, losses of non-food calories remain high. Overall, reaching the Half-Earth target without calorie losses could be achieved in only about 14% of Earth's ecoregions through a nature-only approach, while the shared approach could achieve this across more than 4 times as many ecoregions (65%) (Supplementary Fig. 1). Simply put, the trade-offs between agriculture and Half-Earth will be much lower if landscapes are allowed to remain as mosaics of shared land uses, and will be much higher if large contiguous areas are given back, as may be required for the conservation of some species, such as megafauna.

There are also differences in the spatial distribution of Half-Earth's agricultural trade-offs, depending on the conservation

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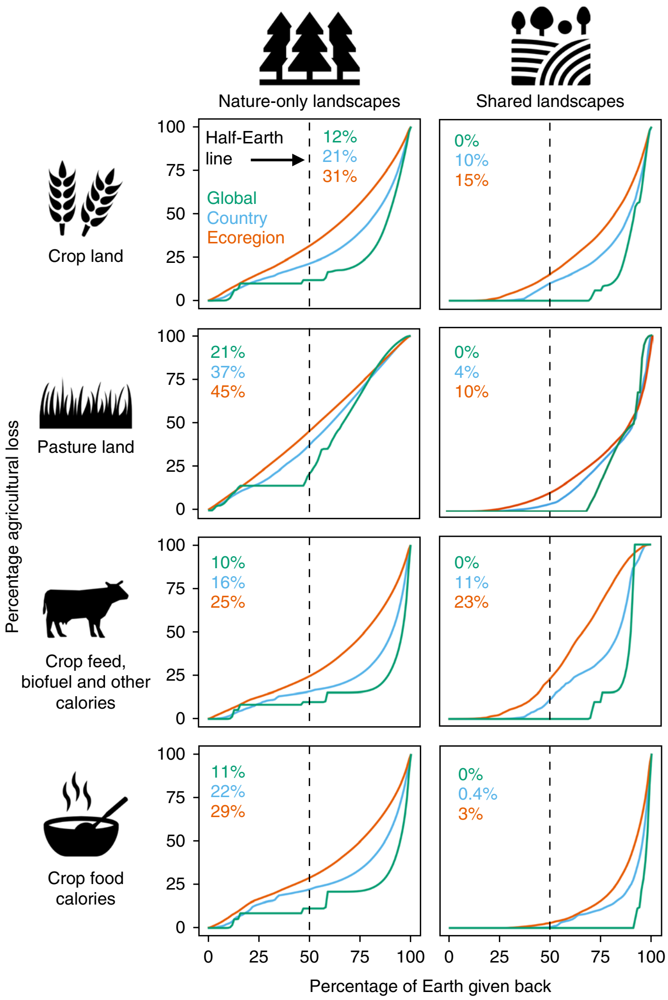

Fig. 1 | Feeding the world under a global deal for nature. Scenarios were computed using a simple land-allocation algorithm operating at global (green), country (blue) and ecoregion (red) scales, each allocating 50% of the planet back to nature. All agricultural area was given back in order of least agricultural productivity, based on the caloric content of 41 major crop plants. The allocation in each scenario was ordered by: (1) existing protected areas; (2) key biodiversity areas; (3) non-agricultural lands (that is, forests, wetlands, shrublands, grasslands and ice-covered areas); (4) pasture lands; (5) non-food-producing croplands (for example, feed, biofuel and other); (6) food-producing croplands (for example, calories for food crops) and (7) urban areas. Under a nature-only landscapes approach, we allocated land back to nature on a pixel-by-pixel basis, representing a sharp division between conservation and agriculture at the landscape scale, whereas under a shared landscapes approach, we allocated land back to nature on an areal basis, allowing the area within pixels to be shared between conservation and agricultural land uses. All analyses were run at a pixel size of 8.4 km × 8.4 km.

approach (Fig. 2; only calorie losses shown). Notably, a shared approach dramatically minimizes the extent of spatial trade-offs. Yet, regardless of the conservation approach, food calorie losses occur in many locations and countries with marked food insecurity. At the country scale, even a shared approach results in substantial losses of food calories in both China (12%) and India (22%)—countries with the highest absolute numbers of undernourished people on the planet (133.8 million and 194.6 million, respectively[13]). Under any strategy other than global, substantial calorific losses also occur locally in Africa and elsewhere in Asia (Fig. 2).

As our analysis highlights, there are major political consequences for national food systems embedded within global strategies for achieving the Half-Earth conservation targets, if the goal of feeding the human world equitably is to be balanced with sharing the planet with other species. Even with current populations and energy demands, potentially massive calorie losses would need to be offset by massive increases in the intensity of food production (that is, by closing yield gaps to achieve 45–70% increases in crop production[14]), reductions in food waste (that is, by mitigating the ~24% of calories lost in global supply chains[15]) and/or dietary shifts away from animal products (that is, by diverting the 36% of crop calories currently fed to animals towards direct human consumption[16]). However, all of these co-strategies are extremely challenging ambitions in themselves.

The demands of future human populations and losses of pasture-fed animal calories are not considered here, nor did we conduct an explicit spatial prioritization for maximizing the coverage of species ranges or connectivity (which may prioritize more productive lands than those given back in our analysis), so our findings should be seen as conservative with respect to Half-Earth's potential negative impacts on agriculture. That said, land use conversion from agriculture to conservation (for example, either from pasture or cropland) would produce significant co-benefits too, such as gains in woody perennial vegetation cover and carbon sequestration, including up to a 40% increase in tropical deciduous forest cover globally and a 36% increase in temperate deciduous forests, no doubt helping to meet climate targets while providing other socially valuable benefits of nature conservation (Supplementary Fig. 2)[17].

While our analysis has focused almost exclusively on agricultural production, the practical challenges of achieving Half-Earth are many, and go far beyond the metrics discussed here. For example, a key concern is the potential worsening of land tenure insecurity and increasing land prices, which together with loss of food security and sovereignty may further impoverish or displace rural peoples[18]. These impacts, if not carefully managed, may lead to losses in conservation effectiveness over the long term. Another important question concerns possible agricultural intensification in the other half of the planet under future population and economic growth[19], and how different species and taxonomic groups might respond to this. Finally, while conservation spending (for example, by governments, trust funds and donors) has proven effective where allocated[20], economic costings for global conservation priority areas are too narrow in scope, and the ecological, political, sociocultural, economic and business models needed to sustain a global conservation project of such scale and ambition over decades and into the deep future have yet to be developed.

We show that any discussion of Half-Earth needs to explicitly evaluate the local, regional and global consequences of displacing land from agriculture and its consequences for food security. The trade-offs between nature and agriculture are potentially large, but depend strongly on the strategies used to achieve Half-Earth, highlighting the possible strengths of shared landscape approaches to expanding conservation with lower trade-offs for agricultural production. However, we find no clear pathway to give half our planet to nature at a scale that maintains ecosystem connectivity and still feeds the world, without at least some nations or sub-populations losing out. Under this context, protection of existing vulnerable, malnourished and food-insecure populations is a key priority and a prerequisite for humans and nature to coexist into the future.

Methods

To assess the trade-offs between Half-Earth and agricultural production at 3 scales (global, country and ecoregion) and with 2 conservation strategies (that is, nature-only landscapes versus shared landscapes approaches), we compiled 8 spatial datasets: cropland and pasture area[21]; Moderate Resolution Imaging Spectroradiometer land cover[22]; calorie production for the world's 41 major crop plants[16]; protected areas[23]; key biodiversity areas[24]; ecoregion boundaries[5]; country boundaries[25]; and potential natural vegetation[26]. All datasets were rasterized,

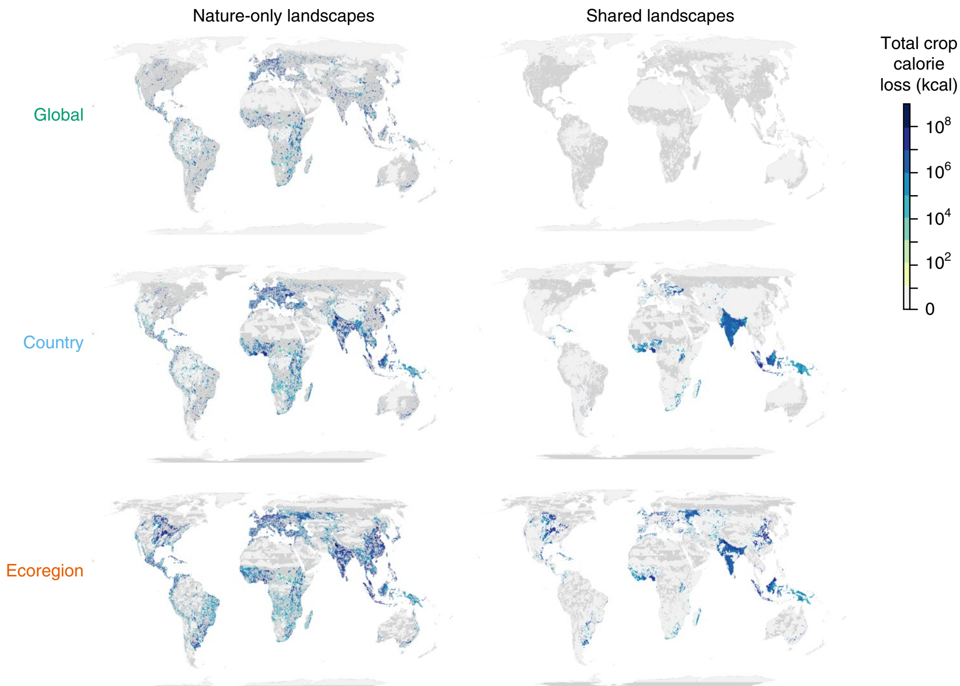

Fig. 2 | Maps of calorie losses under each Half-Earth scenario. Pixels show the summed caloric losses (from non-food and food crop calories) in each pixel on the planet under three different scales of analysis (global, country and ecoregion) and two different conservation approaches (nature-only landscapes versus shared landscapes). Even under a shared landscapes approach, giving back half of every country or ecoregion on the planet leads to significant losses in geographic locations of major food security concerns (that is, India, China, Indonesia, West Africa and Madagascar). Land allocations were made by minimizing calorie losses to show the lowest possible caloric costs to Half-Earth under current production, but we do not mean to advocate that farmers working on marginal lands should be compromized first, as this would probably be deleterious to food security for populations with limited access to farming technology and inputs, or access to land with good growing conditions.

projected to Eckert IV's equal area at a spatial resolution of ~8.4 km × ~8.4 km (the most accurate scale for the reproduction of global sums for dataset[16]) and set to a common extent. We focused on ecoregions because the Half-Earth targets have already been deemed achievable or attained in ~49% of Earth's 846 terrestrial ecoregions[5] by previous authors, who argue that maintaining these geographic boundaries is critical for maintaining global conservation planning, as opposed to focusing conservation exclusively on global biodiversity importance maps, which would disproportionately bias the tropics (for example, ref. [19]).

Our analysis involved additional processing, as follows. First, we created a new land-class variable merging the above datasets from refs [21–24]. To do this, we used the World Database on Protected Areas[23], and World Database of Key Biodiversity Areas[24] to define cells containing protected areas and key biodiversity areas. Following this, we used ref. [21] to define cells containing cropland, pasture or cropland-pasture, and then for the remaining cells used the numeric identifiers in ref. [22] to represent water (ID: 0), non-agricultural land (IDs: 1:9, 11 and 15:16) and urban (ID: 13). We then ranked all pixels for this new land-class variable in the following order: protected areas > key biodiversity areas > non-agricultural lands (forests, wetlands, shrublands, savannahs, grasslands and barren land covered in snow or ice) > agricultural lands (pasture > cropland-pasture > cropland) > urban, and then ordered each pixel within each rank in order of increasing calorific production based on the data from ref. [16]. Finally, we estimated the proportion of each pixel that was occupied by non-agricultural land, land producing non-food crop calories (feed, biofuel and other) and land producing food crop calories (that is, for direct human consumption) using the fractional cropland area coverage of ref. [21] and proportional allocation to each calorie class from ref. [16]. We then adjusted the total calorie ranking to allow for differences in the rank order of non-food calories and food crop calories within a given pixel. All water pixels were removed from the analysis so as to focus on only terrestrial Half-Earth.

We simulated agricultural losses (cropland area, pasture area, feed/biofuel/other calories and food calories) under Half-Earth with the two different conservation approaches and at the three different geographic scales. We assessed agricultural losses by identifying the proportion of pasture land, cropland and calories included in the pixels summing to 50% of the total area (nature-only landscapes approach) or sub-pixel areas summing to 50% of the total area (shared landscapes approach) within each of the focal geographic boundaries (global, country and ecoregion) included in the analysis. Under the shared landscapes approach, we maintained a priority ranking as: protected areas > key biodiversity areas > non-agricultural areas > non-food-calorie (feed/biofuel/other)-producing land and pasture land > food-calorie-producing land > urban, so that we prioritized giving back land area producing non-food calories and pasture lands before food-calorie-producing croplands. Analyses were performed in R 3.4.2 (ref. [27]). A flow diagram with an overview of this analysis is given in Supplementary Fig. 3.

Data availability. Additional analyses and a full-set R code to reproduce the results are supplied in the Supplementary Information. The data used in this study are either publically available, or available from third parties on request but not distributable by the authors. Full details of each dataset, download links, and points of contact for third parties are provided in the Supplementary Information.

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Author contributions

Z.M., E.C.E. and N.R. designed the analyses. Z.M. compiled the data and conducted the analyses. Z.M. wrote the paper with input from E.C.E. and N.R.

Competing interests

The authors declare no competing interests.

Additional information

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