**Bending the curve of land degradation to achieve global environmental goals**

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**Abstract**

Land plays a vital role in sustaining human communities, nurturing diverse ecosystems, and regulating our planet's climate. As such, current rates of land degradation pose a major environmental and socioeconomic threat, driving climate change, biodiversity loss, and social crises. Preventing and reversing land degradation are key objectives of the United Nations Convention to Combat Desertification and are also fundamental for the other two Rio Conventions —the United Nations Framework Convention on Climate Change and the Convention on Biological Diversity. Here we argue that the targets of these conventions can only be met by “bending the curve” of land degradation and that transforming food systems is fundamental for doing so. We showcase multiple actions for tackling land degradation that also yield climate and biodiversity benefits, while fostering sustainable food systems that contribute to avoiding the risk of a global food crisis. We also propose ambitious 2050 targets for the three Rio Conventions related to land and food systems. Finally, we urge collective action to acknowledge the pivotal role of land in achieving the goals of the Rio Conventions and to embed food systems within intergovernmental agreements—enabling decisive progress on the complex and interconnected global crises we face.

**Main text**

Food production is the dominant land use on Earth1. With the potential for feeding more than 8 billion people, this industrial scale enterprise comes with a heavy environmental toll: degrading terrestrial and aquatic ecosystems, depleting and polluting water resources, and accelerating climate change2,3. Under a business as usual scenario of global development, these consequences will only intensify as projected population growth and socioeconomic changes will demand a staggering 35–56% increase in food production by 2050 relative to 20104. This intensification of food production heightens the risks to land integrity, which is the foundation for benefits vital to human health and development, including water regulation, food security, energy production, carbon sequestration, habitat conservation, and livelihood support2. Ongoing rates of land degradation (Fig. 1), fueled by climate change and unsustainable agricultural practices5, contribute to a cascade of mounting global challenges, including food and water insecurity, forced relocation and population migration, social unrest, and economic inequality2,6. These interconnected issues pose a significant threat to achieving the Sustainable Development Goals (SDGs)7 and to maintaining our planet within safe boundaries for environmental and human wellbeing3. Hence, transforming global food systems, which include the production, processing, packaging, storage, transport, consumption, distribution, and disposal of food8, is paramount to achieving the interconnected goals enshrined within the three Rio Conventions: the Convention on Biological Diversity (CBD), the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations Convention to Combat Desertification (UNCCD).

Despite the clear interdependencies between the Rio Conventions9–13, and the fundamental role of healthy land systems to address their targets14–18, most research on their implementation has treated the agreements separately. In terms of financial investments and attention, efforts to combat land degradation (the realm of the UNCCD) remain far below those directed towards the UNFCCC and the CBD19, even though the Global Environment Facility seeks to support transversal, integrated projects and actions that address multiple and concurrent environmental threats. The consecutive Conferences of the Parties (COPs) to the three Rio Conventions held in the final quarter of 2024 —CBD’s COP16 in Cali, UNFCCC’s COP29 in Baku, and UNCCD’s COP16 in Riyadh— reinforced their commitment to a coordinated response to interconnected environmental crises. Building on UN General Assembly resolutions 79/207 (paragraph 32) and 79/208 (paragraph 47), which emphasize leveraging synergies among the Rio Conventions, these COPs have taken joint action through efforts such as the “Rio Trio” initiative20 to catalyze integrated, systemic solutions. Recent outcomes from these COPs, particularly COP16 of the UNCCD, also indicate a growing momentum for prioritizing land and its degradation21. Furthermore, there is increasing recognition of the indispensable role of land and sustainable agricultural practices in resolving environmental crises3, and the critical role food systems play in achieving the objectives of the three Rio Conventions22. However, food systems have not yet been fully incorporated into intergovernmental agreements, nor do they receive sufficient focus in current strategies to address land degradation, which are often focused on the restoration of degraded natural and semi-natural ecosystems through flagship initiatives such as the Great Green Wall23 or the Bonn Challenge24.

To achieve the goals of the Rio Conventions, we must move beyond diagnosing the problem of land degradation towards identifying and implementing systemic, actionable solutions. In this Perspective, we propose a set of concrete, science-based interventions on food systems that align with global commitments and have the potential to bend the curve of land degradation by 2050. These include: (i) reducing food waste by 75%, (ii) restoring 50% of degraded land through sustainable land management practices, and (iii) shifting dietary patterns to increase the consumption of sustainable seafood and seaweed. These strategies are summarized in Table 1, which quantifies their co-benefits for land, climate, and biodiversity. We also explore implementation pathways to realize these interventions and effectively reverse land degradation trends. Finally, we call for urgent, coordinated action to: i) recognize the pivotal role of land in achieving the Rio Conventions’ objectives, ii) integrate sustainable food systems into intergovernmental frameworks, and (iii) deliver on existing 2030 and proposed 2050 targets through a unified, cross-sectoral agenda that addresses the interconnected global crises of our time.

**Key levers to bend the degradation curve**

Food production is, by far, the largest human use of land, representing 34% of Earth's available (ice-free) terrestrial surfaces (Fig. 2). Under current consumption trends and policies, this is projected to increase to 42% by 2050 (Fig. 2, business-as-usual scenario). Food systems contribute approximately 21% of global greenhouse gas emissions25, drive 80% of deforestation2, account for 70% of freshwater consumption3, and collectively are a major driver of terrestrial biodiversity loss2. Unsustainable food production practices degrade land by increasing soil erosion and salinization, depleting soil nutrients and groundwater reserves, and contaminating the soil, surface waters, aquifers, and freshwater resources with herbicides, pesticides, and excess nutrients2,3,5. Transforming food systems thus provides a pivotal opportunity to bend the curve of ongoing land degradation while simultaneously addressing root causes of climate change and biodiversity decline (Table 1). A strategy to bend the land degradation curve focused on key targets to improve food systems can deliver a fair and sustainable future where the capacity of land to support people and biodiversity is maintained, restored, and enhanced26. The following sections outline coordinated actions within food systems that, if implemented at scale, have the potential to bend the curve of land degradation.

***Reduce food waste by 75%***

Over one third of the food produced each year —representing 1.4 billion ha of land27— is wasted, amounting to estimated losses of US$ 1 trillion28. Halving global food waste by 2030 is a key objective of SDG 12 (Target 12.3) and the Kunming-Montreal Global Biodiversity Framework Target 16 that requires collective actions from Parties of the UNFCCC, CBD, and UNCCD. We propose extending this objective beyond 2030, with a target of reducing food waste by 75% by 2050 relative to 2020 levels. As shown in Table 1, reducing food waste by 75% could spare 13.42 million km² of land and avoid the emission of 102.20 Gt of CO₂ equivalent (CO₂e) by 2050 (Table 1). This strategy delivers immediate benefits for food security, biodiversity, and climate mitigation, and plays a key role in enhancing food security worldwide. The economic savings from such a substantial reduction in food waste could also contribute significantly to closing the $278 billion annual funding gap needed to achieve the UNCCD’s goals 29.

To reach the ambitious goal of reducing food waste by 75% in 2050, both the production and consumption sides must be addressed simultaneously. On the production side, it is crucial to urgently implement policies that incentivize food waste prevention and facilitate food redistribution, while also limiting the disposal of food waste and penalizing wasteful practices at the farm level in developed countries, especially when these result from overproduction30. Such interventions might include banning buyer contracts that specify produce size and shape requirements, as the cosmetic requirements of food purchasers are responsible for much of the farm-gate losses31. Detrimental subsidies for destroying part of the production *in situ* as a mechanism to protect farmers against low prices, as currently done in the European Union32, should also be abandoned. As a standard practice, food that is regularly discarded for cosmetic reasons should be sold by retailers at discounted prices —to incentivize their purchase by consumers— or donated to local food banks or soup kitchens33. Similarly, subsidies to protect farmers from low prices could be reallocated to support such donations. Additional measures include canning facilities to support long-term food storage; improved food production planning, such as determining what crops are planted and where—allowing for better yield forecasting; and enhanced early warning systems, particularly in areas where food insecurity is projected to increase34. Similarly, understanding the implications of a changing climate, which may render currently suitable areas less viable for large-scale food production (or may require the planting of different crop varieties or the grazing of different animals), can also provide a buffer against climate-related food security threats34. A key lever for managing such issues might involve the strategic allocation of irrigation permits or subsidies that actively prevent overproduction. Indeed, overproduction is a major problem driven by current agricultural policies and market trends, and improved efforts should be made to better match land use to local environmental constraints. Laws should be passed to ensure that production costs for farmers are met —via tax credits or incentives as needed33— and to reduce the influence of intermediaries that do not add value to food products or that speculate with food prices and bear considerable responsibility for food price inflation35.

We acknowledge that protectionist and subsidy policies currently in place in many countries often create conflicting incentives that encourage overproduction and undermine efforts to reduce food waste. Actions to minimize the impact of such policies include: i) redirecting agricultural subsidies toward smallholder farmers and sustainable farming initiatives that prioritize waste reduction at the source; ii) integrating food waste reduction targets and provisions into international trade agreements; iii) embedding waste reduction measures within food security policies, including improvements to food distribution and conservation infrastructure, investments in community-based food recovery programs, and the development of mechanisms to valorize unavoidable food surplus; and iv) implementing taxes on unhealthy, ultra-processed foods, which contribute up to one-third of diet-related greenhouse gas emissions, land use, and food waste production in high-income countries36 and have detrimental implications for human health37, while incorporating measures to mitigate potential regressive impacts on low-income households38. A timely example is Spain’s recent enactment of Law 1/2025 on the Prevention of Food Loss and Waste39. This comprehensive legislation requires supermarkets to donate surplus food, to display and sell a portion of misshapen or “imperfect” produce, and to sell food that will soon expire at a discounted price. Additional measures include obligating restaurants to provide takeaway containers upon request, and requiring all actors across the food supply chain —from primary production onward— to implement formal food waste reduction plans.

In addition, it is imperative to continue reducing consumer food waste, which currently amounts to 19% of all food globally40. This can be accomplished through behavioral changes, implementing educational programs for school children, and raising attention about the scale of the issue and ways to minimize it within households. Notable examples include the “Love Food Hate Waste” campaign in the UK or the “Zu gut für die Tonne” in Germany41. Other measures include promoting smaller restaurant portion sizes, offering subsidies to low-income households to support the purchase of fresh foods, and launching public education campaigns to raise awareness of the health and economic benefits of choosing fresh over processed options. In addition to reducing pressure on land, greenhouse gas emissions, and biodiversity impacts, these policies will generate dramatic improvements in public health37, with associated economic and social benefits.

***Restore 50% of degraded farmland***

Major forms of land degradation include soil erosion and carbon and nutrient depletion, caused by unsustainable industrial agricultural practices42,43 that rely on the intensive use of machinery, fertilizers, and pesticides. Sustainable land management (SLM) uses natural resources and technologies such as compost application, cover crops, crop rotation, green manures, no-till or reduced tillage, agroforestry, and/or organic production (see Table S1 for a definition and examples and ref. 44 for a complete list of SLM practices and technologies). Sustainable land management can play a fundamental role in avoiding and reducing land degradation18,44, achieving land degradation neutrality by 2030, accelerating actions on land restoration commitments45, and promoting biodiversity conservation (Table 1).

We propose that 50% of degraded food production areas (as compared to the 2020 baseline) should be actively restored and managed using SLM practices44,46. As shown in Table 1, doing so could spare 3 million km² of land and avoid the emission of 21.73 Gt CO₂e by 2050, with additional biodiversity benefits (Table 1). Restoring 50% of degraded food production areas would also contribute to the achievement of Target 10 of the Kunming-Montreal Global Biodiversity Framework on ensuring all areas under agriculture are managed sustainably. It also aligns with the discussions and recommendations from UNCCD COP16, where Parties acknowledged that scaling up SLM approaches on agricultural lands helps reduce pressure to convert non-agricultural lands for agricultural use21.

Implementing SLM in degraded food production areas at scale requires focusing on traditional food production methods, small farms (i.e., farms with a size below 2 ha)47, and family farms (i.e., farms operated by an individual, group, or household where most of the labor is provided by family members)47. Small and family farms account for over 90% and 84% of all farms worldwide, respectively, and are responsible for producing approximately 35% and 80% of the world’s food47. Often passed down through generations, these farming systems typically employ traditional SLM practices that are tailored to local conditions, resilient to environmental stress, and beneficial for soil health, water conservation, and biodiversity48. Scaling up these production systems is a strong strategy to achieve land restoration goals using SLM, while promoting food security, preserving cultural heritage, and strengthening social cohesion49. Moreover, providing smallholder farmers with more secure land tenure, better and fair access to markets, and modern sustainable agricultural technologies and inputs can improve their productivity and income potential. This is particularly crucial in regions like sub-Saharan Africa, where food insecurity and poverty are prevalent50. Diversifying crops and integrating innovative farming techniques could enhance resilience and economic stability for these farmers50. However, many traditional subsistence farms remain too small to lift farmers out of poverty50. Land consolidation —meaning the planned readjustment and reorganization of fragmented parcels into larger, more viable holdings— may be necessary to enable the adoption of technologies essential for sustainable intensification, particularly in densely populated areas51. Establishing small-scale farmer cooperatives can be a particularly effective mechanism to facilitate this process52. Likewise, establishing gender-responsive land governance is crucial, as women with secure land rights have been shown to be more likely to adopt SLM practices53,54.

***Restore 50% of degraded non-farmland***

We propose restoring 50% of degraded non-agricultural land to help achieve a 50% reduction in total global land degradation by 2050, relative to 2020 levels (Fig. 2). Doing so could spare 9.87 million km² of land and avoid the emission of 127.95 Gt CO₂e by 2050, with additional biodiversity benefits (Table 1). Applying this target expands existing commitments, such as the ambition to achieve a 50% reduction in degraded land by 2040 expressed by G20 countries in 202055, setting a baseline that can be accounted for, while delivering substantial land, climate, and biodiversity co-benefits.

Achieving the proposed restoration target requires engaging a wide range of stakeholders in an equitable and inclusive manner, as well as fully utilizing available scientific, traditional, and local knowledge 56–58. It is also important to address the ecological, cultural and socio-economic contexts throughout the process, and to consider land tenure and power dynamics59. If ignored, these issues can undermine restoration efforts and create social and economic conflicts18,57,60,61.

Ensuring successful, long-term benefits from land restoration requires formalizing land tenure by explicitly recognizing local rights, supporting participatory and transparent planning processes, securing prior and informed consent from affected communities before restoration projects are executed, and ensuring adequate attention to the distribution of costs and benefits (employing impact mitigation measures where needed)18,62. By introducing appropriate market-based incentives (e.g., carbon credits or payments for ecosystem services) and providing compensation or alternative livelihood opportunities (e.g., roles as custodians or caretakers of restored lands) 63, alongside ensuring the equitable inclusion of all relevant groups in decision-making64 and addressing the often-overlooked epistemic and power dynamics, barriers to land restoration can be further reduced, thereby enhancing both its social and environmental benefits.

***Shift to sustainable aquatic-based diets***

Bending the curve of land degradation requires a comprehensive approach that addresses the interconnectedness of land and ocean systems, with food systems as a crucial link. Aquatic foods are essential for ensuring critical nutrient supplies, providing healthy alternatives to terrestrial meat, reducing dietary environmental footprints, and delivering just economies and livelihoods under a changing climate65. A recent assessment concluded that increasing aquatic food production can reduce consumption of red and processed meats, preventing both diet-related non-communicable diseases and approximately 166 million cases of inadequate micronutrient intake66. Despite their promise, discussions on land degradation have largely overlooked the opportunities offered by better integration with ocean-based food systems67,68. These systems remain underutilized yet hold considerable power to advance the goals of all three Rio Conventions—by easing pressure on land resources and providing high-quality, sustainable nutrition69,70.

Sustainable seafood and seaweed farming, in particular, could emerge as foundational elements of a healthy diet for both people and the planet69,71. Pelagic fish, wild salmonids, and farmed bivalves provide more nutrients with lower emissions and nearly-zero freshwater and synthetic chemical footprints compared to most terrestrial animal food sources72,73. Seaweeds, which are rich in health-promoting compounds such as dietary fiber, fatty acids, essential amino acids, and vitamins (e.g., A, B, C, and E)74, could significantly reduce land use pressure if adopted more widely around the world. Research shows that ~650 million hectares (Mha) of ocean could support seaweed farms, potentially delivering ~6.5 billion tons of biomass for food, feed, and fuel75. Replacing 10% of human food consumption with seaweeds could spare 110 Mha of land, increasing to 150 Mha if farmed seaweed is also used for livestock feed (10%) and biofuel production (50%)75. We propose a dietary shift in which sustainably farmed seaweed76 replaces 10% of vegetable consumption, while sustainably sourced seafood—primarily small pelagic fish, salmonids, and mollusks—substitutes 70% of red meat intake. Such dietary shift could reduce land used for food by 17.50 million km² and avoid 145.17 Gt CO₂e, while supporting healthier diets and marine conservation (Table 1).

We acknowledge that the proposed dietary shifts are most feasible and desirable in regions with high levels of meat consumption, typical of high-income and several middle-income countries77. Increasing meat and animal-based food consumption remains important for addressing nutritional deficiencies in low-income countries, especially among vulnerable groups like children, adolescents, and pregnant or lactating women77,78. In regions where access to marine resources is constrained by geography and/or inadequate infrastructure, sustainable red meat production —achieved by mechanisms such as grazing land management79 and support for mobile pastoralism80,81— can be maintained, while prioritizing seafood and seaweed consumption wherever feasible.

Integrating marine and land-based food production requires careful consideration to prevent transferring environmental issues to the ocean. Aquaculture should prioritize seaweed and lower-trophic-level species, such as detritivores and filter feeders, and use polyculture systems whenever possible. Polycultures can create local food webs that enhance production while reducing waste82. Whenever possible, feed should be produced on-farm to reduce external impacts and preserve small fish for direct human consumption, a crucial consideration for low-income countries83. These actions can play a key role towards the ecological intensification of aquatic food production, enabling increased food output while safeguarding biodiversity, conserving and/or restoring ecosystems, and ensuring nature’s contributions to people84.

We also acknowledge the economic, social, environmental, and policy challenges associated with the proposed shift to marine-based nutrition85–87. To overcome these, governments should promote sustainable fisheries, seaweed farming, and regenerative aquaculture88, and increase seafood and freshwater fish consumption to promote healthier diets. Regenerative aquaculture, defined as “commercial or subsistence aquaculture performed with focus on social, economic, and ecological responsibility and stability, with minimal external input to and impact on the environment”88, targets species and practices that deliver a high nutritional value with low, or even positive (such as in the case of seaweed farming89) environmental impact. In high-income countries, this can be done by lowering the cost of sustainable seafood through subsidies, reduced tariffs, and support for small-scale fisheries and regenerative aquaculture to help them compete in the market and contribute to local economies. Financing these measures could be achieved by diverting existing subsidies to terrestrial animal production industries and by offering tax incentives to businesses that produce and sell sustainable seafood. Developing infrastructure for transport and distribution in low-income countries to make fresh and affordable seafood available in both urban and rural areas, establishing fair trade practices, and providing technological and financial support for local communities to engage in sustainable seafood and seaweed farming is also needed and would offer new, meaningful employment and livelihood opportunities. Doing so would further ensure that the nutritional and environmental advantages of ocean food systems reach those most in need. In regions where adopting a seafood-rich diet is not feasible, such as landlocked countries, management and policy efforts should focus on promoting sustainable meat production77, inland aquaculture90, and alternative protein sources. These include pulses, which are vital for food security and livelihoods in many low-income countries91, and edible insects, which are already part of diets in 128 countries worldwide92. The proposed measures for both high- and low-income countries should be accompanied by actions such as public awareness campaigns about the reduced environmental footprint of seafood compared to red meat, by including more seafood options in school and community meal programs to familiarize children and families with seafood consumption from an early age, and by enforcing mandatory labeling of seafood origin, fishing methods, and sustainability status to inform consumer choices.

**Pathways to bend the land degradation curve**

Here we present four mutually reinforcing strategies that can bend the curve of land degradation and support the achievement of the Rio Conventions’ goals (Table 1): i) reducing food waste by 75% by 2050 through shifts in production incentives, regulatory frameworks, and consumer behavior; ii) restoring 50% of degraded agricultural land by scaling up sustainable land management (SLM) practices and empowering smallholder farmers; iii) restoring 50% of degraded non-agricultural land through inclusive and equitable stakeholder engagement; and iv) promoting dietary shifts by replacing 70% of red meat consumption with sustainable seafood and 10% of vegetable consumption with seaweed to reduce environmental footprints. Together, these interventions could reduce land degradation by 54% and decrease global land use for food production by 56% by 2050, relative to 2020 levels (Fig. 2, Table S2).

To create enabling conditions for achieving the ambitious targets proposed for 2050, we must implement more accurate accounting and pricing of environmental externalities—such as greenhouse gas emissions, soil and water pollution, and aquifer depletion—which are rarely reflected in the cost of food. This should be accompanied by reforms to taxation systems that incentivize sustainable practices. An example would be the implementation of a “land tax” for imported food like the European Union's Carbon Border Adjustment Mechanism93, which is set to take effect in 2026. This mechanism will impose import charges on products such as steel and cement depending on the amount of CO2 emitted to produce them and could also be deployed to incentivize food producers that follow SLM practices. Such rewards could also be realized by implementing measures to enhance traceability within the agri-food system, with priority given to developing low-cost and accurate systems for the measurement, reporting, and verification of greenhouse gas emissions94. Applied in a globally consistent way, such policy instruments and measures would reward and increase the competitiveness of companies that act as good stewards of the land95. At the same time, they would incentivize the transition to more sustainable practices among the more than 608 million farms existing globally47. Evidence indicates that smallholder farmers generally adopt more sustainable practices and produce with lower emissions compared to large-scale agricultural producers that are typically more land- and emission-intensive96–100. Consequently, the introduction of a “land tax” could enhance the competitiveness of smallholder farmers. A focus on smallholder farmers when planning agricultural subsidies is important, as large landowners and companies are typically the primary beneficiaries of agricultural subsidies101. Reducing subsidies for large-scale farms in regions with high domestic agricultural subsidy rates like the EU or the US can also contribute to achieving multiple SDGs101.

The use of certified product labeling that better reflects the environmental (and particularly land) impacts of food102 should also be implemented to increase consumer awareness and promote more sustainable local options. Such labeling schemes can be developed in ways that strengthen and transform local and regional markets and that do not increase inequalities or prevent producers from low-income countries from accessing international markets. Policies are essential to support small-scale farmer cooperatives to help them meet the costs and requirements of certification schemes, while regional trade agreements and policies can also push towards implementing good and fair practices and standards through international or national laws52.

Future land use decisions must be approached systematically, integrating and balancing competing demands on land resources to optimize their capacity to deliver multiple benefits. This requires embedding principles of equity and sustainability into spatial planning, informed by a comprehensive understanding of diverse stakeholder needs and interests and the drivers behind their decisions. Such an approach seeks to balance environmental, economic, and social priorities, enhancing both productivity and conservation while preserving the autonomy of individual and communal land managers to adapt to emerging opportunities. It is crucial to involve national and regional stakeholders, large landholders, Indigenous peoples, and underrepresented and local communities in land-related decision-making processes103, with a strong focus on promoting social justice. Inclusive governance structures ensure that the knowledge and needs of all stakeholders, including women, youth and other marginalized groups, are considered, ultimately leading to more locally appropriate and effective land management strategies104. Experiences from community-based adaptive land management have demonstrated improved land quality and productivity in various contexts by leveraging local knowledge and fostering a sense of ownership and intergenerational commitment among community members104, helping to both manage resources sustainably and reverse land degradation54. This approach to land governance has been discussed in previous studies57,58 and was emphasized at the recent UNCCD COP16, which encourages Parties to foster an enabling environment for sustainable land use systems through multi-stakeholder partnerships, participatory governance, and the integration of Indigenous and traditional knowledge105. Finally, restoration programs and funding specifically targeting degraded croplands and rangelands should be designed to facilitate the achievement of global restoration targets while providing additional income for farmers. Existing initiatives, such as the Land Degradation Neutrality (LDN) fund106, can be particularly useful for doing so.

**A call for action to the Rio Conventions**

Land and food systems play a key role in advancing towards the goals and targets of the Rio Conventions. Leveraging the potential of sustainable and integrated food systems to achieve these and the SDGs would also enable countries to uphold the recently approved basic human right to a clean, healthy environment107 while delivering a resilient, enduring, and peaceful future for all. We thus call on Parties to the Rio Conventions to adopt policy decisions that promote multilateral actions on land and food systems within their different mandates in a coordinated and collaborative manner. To facilitate this, Parties should harness the potential of the Rio Conventions Joint Liaison Group and establish formal mechanisms for cooperative scientific assessments across existing science-policy interfaces. We advocate for further strengthening the UNCCD Science-Policy Interface (SPI), which was made a standing body of the UNCCD at its COP16. Such a permanent interface supports the delivery of policy-relevant information, knowledge, and advice, and complement assessments conducted by the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). Parties at UNCCD COP16 have also requested that the secretariats of the UNCCD and other relevant scientific bodies and panels, acting within their respective mandates, explore the establishment of a “Global Science-Policy Alliance on Land”108. It would be highly desirable to establish mutually agreed mechanisms for cooperation between SPI, IPCC, IPBES and other land-focused science-policy interfaces. In addition, Parties to the Rio Conventions should include food systems in intergovernmental policy decisions to recognize their central role in achieving targets and objectives, and to achieve SDGs.

Despite decades of debate, systemic barriers have made the implementation of solutions to climate change, biodiversity loss, and land degradation challenging. These barriers include the nonlinear, complex nature of these global issues2,3,84, short-term political cycles, economic concerns, the lack of international coordination and enforcement109, and the powerful influence of established interests110, to name a few. However, as the environmental crises addressed by the Rio Conventions become more acute and urgent, there is increasing momentum for coordinated actions to tackle these difficult challenges. Public pressure, technological innovation, and shifts in economic incentives are creating new opportunities to overcome these systemic barriers. The urgency of achieving the goals of these Conventions together has never been clearer, making it crucial for policymakers to learn from past delays and prioritize integrated and effective strategies. The challenge of achieving these goals, and the targets proposed herein, lies not just in providing scientific guidance or finding solutions, as many of these are already on the table. Rather, it is about bridging the gulf between current initiatives and the global actions necessary to halt further land degradation and transform food systems. This requires an immediate, game-changing response to bend the curve of land degradation.

We are at a moment where many countries are updating their Nationally Determined Contributions, National Adaptation Plans and LDN targets, and developing new National Biodiversity Strategies and Action Plans aligned with the Kunming-Montreal Global Biodiversity Framework, all at the same time. We thus urge Parties of all Rio Conventions to act now to achieve all existing commitments being pursued by 2030, striving to achieve a land degradation-neutral world and bending the curve towards a net-nature positive trajectory. This should be done in an integrated way across the agendas for the UNCCD, UNFCCC, and CBD, and following all social and environmental safeguards.

Even if all Parties to the Rio Conventions act with maximum speed and urgency, it is unlikely to be sufficient for achieving a net-nature positive trajectory by 2030. Therefore, they must begin planning the next round of commitments to reach this goal by 2050. To this end, we propose a 75% food loss and waste reduction, the restoration of 50% of degraded land, and the adoption of diets that harness the full potential of healthy and sustainable seafood by 2050 as key targets for the UNFCCC, CBD, and UNCCD. It is readily apparent, if not widely appreciated, that there is simply not enough land relative to the demands being placed on it to sustainably support global populations now, let alone into the future18. Addressing this land system crisis while securing food for a growing human population requires a strategic and integrated approach111. Recent initiatives to increase the coordination and alignment of the Rio Conventions offer a unique and timely opportunity for the Parties to work in a concerted manner to push for the ambitious commitments we propose. Doing so would deliver a clear message that amplifies the fundamental role of sustainable land and food systems in averting the impending environmental catastrophe we face.

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**Disclaimer**

The views expressed herein are those of the authors and do not necessarily reflect the views of the United Nations.

**Contributions**

F.T.M. and C.D. conceptualized the article, with input from all authors. F.T.M. prepared the first draft, with all co-authors participating in its editing and refinement. Estimations of land degradation, amount of land, and mitigation potential were done by E.G. and F.T.M., with the assistance of T.T. and M.M.

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**Competing interests**

The authors declare no competing interests.

**Methods**

***Estimating land degradation and calculating the amount of land across land uses for the different scenarios considered***

To estimate land degradation, we used the land degradation neutrality (LDN) approach put forward by the United Nations Convention to Combat Desertification (UNCCD)46,125. This approach quantifies land degradation using three indicators (or sub-indicators according to the UNCCD terminology126): trends in net primary productivity (NPP), trends in soil organic carbon, and changes in land uses1. These indicators were approved by the Parties of the UNCCD in 2013127 and are already being widely used globally (see ref. 128 for a recent review). They align with SDG Target 15.3, which aims to achieve LDN by 2030, and leverage existing datasets and technologies, making them cost-effective and scalable129. They are also complementary (for example, a decrease in land productivity often correlates with changes in land cover and reduced carbon stocks), and provide straightforward, interpretable metrics that policymakers can use to track progress and design interventions. Additionally, these indicators are context-dependent (e.g., soil carbon contents and productivity vary across geographic locations). Therefore, they can inform policy makers and stakeholders by ensuring that interventions incorporate context-specific ecological information125,126, effectively addressing both the social and ecological dimensions of sustainable development. See Table S3 for additional rationale and references about the scientific basis and relevance of these indicators.

In the context of Land Degradation Neutrality (LDN), land degradation is defined as a decline in land-based natural capital within a specific area and timeframe125. It is measured by a significant reduction in soil organic carbon (SOC), net primary productivity (NPP), or adverse land cover change, as determined by national definitions within agreed international guidelines112. The integration of the three LDN indicators follows a “one-out, all-out” approach, meaning that if any of the indicators shows a significant negative change, it is classified as a loss125. Conversely, a gain is recorded if at least one indicator shows a significant positive change while none show a significant negative change. Therefore, land degradation is considered to have occurred in a given area when at least one indicator demonstrates a negative trend.

For estimating land degradation, we used the most recent data available (2020) from the Trends.Earth database113,129 (accessed on 30th May 2024) and followed the UNCCD guidelines112. Land use data in Trends.Earth come from the European Space Agency's Climate Change Initiative (ESA CCI) Land Cover product130, soil organic carbon data from the SoilGrids database131, and net primary productivity from the MOD13Q1 product132. The maps presented in Fig. 1 and Figs. S1-S3 were created with the QGIS software (<https://qgis.org/>), version 3.34.3-Prizren, using the Trends.Earth plugin, version 2.1.14 (<https://plugins.qgis.org/plugins/LDMP/>).

Land degradation was calculated for both 2020 and 2050. For 2050, land degradation is estimated under three scenarios: i) Business as usual (BAU); ii) Rio, where existing Rio conventions´ targets are met by 2030 (i.e., The Paris Agreement, the Kunming-Montreal Global Biodiversity Framework, and SDG Target 15.3 and related land degradation neutrality targets under the UNCCD). For practical purposes, this scenario assumes that no additional degradation of agricultural or non-agricultural land occurs beyond 2030, alongside a 50% reduction in food waste, protection of 30% of land, and restoration of 30% of degraded land; and iii) Rio+, a scenario in which the targets of the existing Rio Conventions are expanded to include a 75% reduction in food waste, restoration of 50% of degraded land, and the adoption of a healthy diet by 2050. This diet features a 10% substitution of vegetables with sustainably farmed seaweed and a 70% reduction in red meat consumption (relative to current levels123), replaced by sustainably fished and farmed seafood.

The BAU scenario assumes current trends continue with no significant changes in policies or behaviors, leading to increased consumption and growth. Therefore, cropland area, pasture area and land degradation increase accordingly. Land use for food production was estimated considering both the per capita amount of cropland and pasture (2020 data) and population trajectories for 2030 and 2050. Population data and projections were obtained from the United Nations population division portal (https://population.un.org/dataportal/). To estimate land degradation in 2050, we first estimated the per capita extent of degraded land in 2020 using global population data and degraded land figures from Fig. 1. Next, we estimated the total degraded land for 2050 based on population growth trajectories. While a necessary simplification given the plethora of factors affecting current and future land degradation, population growth has been identified as a key driver of land degradation across the globe133–136.

To assess the land impacts of restoring 30% (Rio scenario) or 50% (Rio+ scenario) of degraded land by 2050 we assumed that LDN is achieved in 2030 and thus that no additional land degradation occurs beyond this year. The restoration targets of 30% and 50% were thus applied to the projected 2030 levels of degraded land, obtained as described in the previous paragraph but using population growth estimates for 2030.

To quantify the impacts of dietary shifts on land use we calculated the total land area per capita based on the current global diet, which includes croplands and livestock feed areas. According to ref. 75, substituting 10% of human food consumption by seaweeds would spare ~110 Mha (1.1 x 106 km2) of land. This study estimated that 0.491 x 106 km2 and 0.609 x 106 km2 of these 1.1 x 106 km2 corresponded to grasslands and croplands, respectively. Assuming that 66% of total croplands are being used for human consumption137, we estimated that replacing 10% of vegetables for human consumption would reduce food production areas by 0.402 x 106 km2. We also assume that to produce 100 gr of fish (farmed) protein we need to use 47 times less area than to produce 100 gr of beef and lamb protein (3.7 m2 vs 174.2 m2 138). According to these assumptions, reducing 70% of red meat by sustainable seafood would reduce the area devoted to food production by 17.1 x 106 km2. The adoption of the diet proposed in the Rio + scenario alone would thus reduce the amount of cropland area by 17.5 x 106 km2 (Table 1).

To quantify the land impact of a 50% or 75% reduction in food waste, we considered that about 56.5 million km2 are nowadays used to produce food (this area includes both croplands and rangelands; Table S2) and that food waste amounts to as much as 33% of the food produced globally (14% of food produced is lost at the farm [post-harvest stage]139, and 19% is lost at the retail, food service and household stages39). The amount of agricultural land spared is assumed to be proportional to the fraction of food waste avoided.

Regarding urban land uses, we calculated the per capita urban land in 2020 and projected it for 2050 based on population forecasts as described above and assuming that population growth is consistently the dominant determinant for urban land expansion globally140. The current extent of protected areas (15% of total land mass in 2020) was obtained from ref. 141. The amount of natural unprotected areas was calculated by subtracting the total land area from the sum of areas occupied by other land uses.

***Calculating the mitigation potential of proposed measures***

The mitigation potential of the 75% reduction in food waste target was obtained from Scenario 2 in ref. 142. That of the restoration of 50% of degraded croplands was obtained by multiplying the amount of degraded croplands restored (3.06 x 106 km2) by the average mitigation potential value obtained from Scenarios 1 and 2 from ref. 143 (0.07 Gt CO2e per Mha over the 2020-2050 period). Similarly, to quantify the mitigation potential of restoring 50% of non-cropland areas we used the average mitigation potential value obtained from refs. 144–150 (0.13 Gt CO2e per Mha over the 2020-2050 period) and multiplied this value by the amount of degraded non-cropland areas restored (9.87 x 106 km2).

To estimate the mitigation potential of the diet proposed in the Rio + scenario (10% of vegetables replaced by seaweed and a 70% reduction in red meat consumption compared to current levels, which is replaced by seafood) we proceeded as follows. First, we estimated how much area for seaweed farming would be needed to replace 10% of vegetable production. According to FAO, the global vegetable production is currently 2.1 billion tonnes151. Assuming fresh vegetables have about 90% water (a reasonable estimate as the content of water typically ranges between 85% and 95%152), this would be equivalent to 210 million tonnes dry weight·yr-1. Thus, for a 10% replacement, 21 million tonnes dry weight/year from seaweed should be produced. Assuming an average yield of 10 tonnes of dry biomass·ha-1·yr-1, which is a conservative estimate commonly used in the literature75, producing the necessary amount of seaweed would require approximately 2.1 Mha of ocean farming area.​ Second, we multiplied this surface by the mitigation potential average of the two scenarios provided by ref 153, who estimated that seaweed cultivation in the ocean can sequester 0.19 Gt CO2e per Mha over the 2020-2050 period. According to these estimations, replacing 10% of vegetables by seaweeds would sequester 0.39 Gt of CO2e by 2050. We assume that such a dietary shift would also be accompanied by a reduction of 10% of the cropland area used for human consumption, as seaweed would replace these land-produced vegetables. We considered that food systems are responsible for 26% of the global emissions (13.6 of 52.3 Gt of CO2e·yr-1) and that crop production for human food accounts for 21% of such emissions (2.86 Gt CO₂e·yr-1)25. Reducing the amount of area of crop production for human food by 10% (0.28 Gt CO₂e·yr-1) would thus mitigate 8.58 Gt of CO2e by 2050. In addition, we propose a 70% reduction in the dietary intake of beef or lamb and replacing it with sustainably fished and farmed seafood. Producing cows or lamb averages 219 g CO2e/g, while farmed seafood and wild fisheries average 31.75 g CO2e/g154. The proposed dietary change would thus reduce up to 59.86% the emissions associated with livestock production. Assuming that livestock production is responsible for approximately 14.5% of all anthropogenic greenhouse gas emissions155 (i.e., 7.58 of 52.3 Gt of CO2e·yr-1), the proposed replacement of livestock by seafood would reduce 4.54 Gt of CO2e·yr-1, equivalent to 136.20 Gt of CO2e by 2050. In total, we estimate that the proposed dietary changes would avoid the emission of 145.17 Gt of CO2e until 2050.

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**Figure captions**

**Figure 1.** **Global extent of land degradation in 2020**. This map was obtained using the default data provided by UNCCD Parties (countries and the European Union) for the development of national reports and SDG indicator 15.3.1 estimates. Land degradation data were obtained by combining three indicators (land use change, changes in terrestrial productivity, and soil organic carbon) according to the methodology commonly employed to estimate SDG indicator 15.3.1112. Data was retrieved from the Trends.Earth113 database on 30th May 2024. See Figs. S1-S3 for separate maps of each of the indicators used, Table S3 for additional rationale about these indicators, and the Methods section for detailed explanations on how land degradation was estimated.

**Figure 2.** **Current (2020) extent of degraded and protected land across major land uses and forecasts for 2050**. These forecasts are provided for three scenarios: business as usual (BAU); Rio, where existing Rio Conventions´ targets are met; and Rio+, where Rio Conventions´ targets are expanded. The BAU scenario assumes no significant changes in policies or behaviors, maintaining current land use and degradation trends. The Rio scenario includes targets such as the Paris Agreement, the Kunming-Montreal Global Biodiversity Framework, and Land Degradation Neutrality (30% protected land, 30% restored degraded land, achievement of land degradation neutrality, and a 50% reduction in food waste by 2030). The Rio+ scenario proposes a 75% reduction in food waste, 50% restoration of degraded land, and the adoption of a diet where 70% of red meat is replaced by sustainable fished and farmed seafood and where 10% of vegetables are replaced by seaweed. Land degradation was estimated according to the methodology commonly employed to estimate SDG indicator 15.3.1112 (see Fig. 1 for a global map of land degradation). Details on scenario calculations are described in the Methods section, and surface areas for each land use can be found in Table S2.

**Table 1.** **Proposed 2050 targets under the Rio Conventions for land and food systems, their associated land, climate, and biodiversity co-benefits, and the key actions required for implementation**. Land impacts represent reductions in cropland and rangeland use estimated for each 2050 target relative to 2020 levels (see Fig. 1 and Table S2). Estimates of climate mitigation potential refer to the cumulative values projected for the 2020–2050 period. Details on calculation methods are provided in the Methods section. Additional specific measures, key stakeholders, and relevant spatial scales necessary for successful implementation are discussed in the main text and presented in Table S4.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Proposed 2050 target** | **Basis for target** | **Land impacts** (x 106 km2) | **Mitigation potential** (Gt of CO2e emissions) | **Biodiversity benefits** | **Other benefits** | **Actions to achieve the target**  |
| 75% reduction in food waste | SDG 12.3 and Kunming-Montreal Global Biodiversity Framework Target 16 | 13.42 | 102.20 | Conservation of terrestrial ecosystems and species and avoidance of extinctions114,115 | Reducing hunger, increasing water availability, and development of added-value products (e.g., antioxidants, fertilizers, packaging materials, prebiotics)32,40,116 | 1. Implement policies and enhance laws and regulations to reduce overproduction2. Enhance food redistribution and donations3. Raise consumer awareness and education 4. Reform trade and agricultural policies5. Improve food labeling and traceability |
| Restoration of 50% of degraded food production areas | G20 Global Land Initiative  | 3.06 | 21.73 | Enhancement of soil biodiversity, conservation of pollinators and birds117,118 | Increasing drought resilience and overall soil quality and health119,120 | 1. Scale up sustainable land management practices2. Secure land tenure for smallholder farmers3. Improve market access and agricultural support for smallholder farmers4. Implement gender-responsive land governance |
| Restoration of 50% of degraded natural areas | G20 Global Land Initiative | 9.87 | 127.95 | Increasing the number and abundance of terrestrial species locally and avoidance of extinctions121 | Creating jobs, improving human health and well-being, and increasing resilience to drought117,120,122 | 1. Engage a wide range of stakeholders inclusively2. Formalize land tenure and recognize local rights 3. Create alternative livelihood opportunities |
| Diet with reduced red meat and increased proportion of sustainably managed seafood and seaweed | Refs. 69–75,123, 124 | 17.5 | 145.17 | Increase the local number and abundance and diversity of marine organisms associated with seaweed, and conservation of terrestrial ecosystems and species69,89,90 | Reduced water use, developing new markets, creating jobs, improving human health, and reducing cost of public health systems70,74,89,90  | 1. Incentivize seafood and seaweed as health promoting diet and increase their consumption2. Expand sustainable aquaculture and seaweed farming3. Ensure feasibility and accessibility of seafood-based diets4. Promote sustainable alternatives to red meat where marine resource access is limited |