



Biodiversity effects of food system sustainability actions from farm to fork

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Diet shifts and food waste reduction have the potential to reduce the land and biodiversity footprint of the food system. In this study, we estimated the amount of land used to produce food consumed in the United States and the number of species threatened with extinction as a result of that land use. We predicted potential changes to the biodiversity threat under scenarios of food waste reduction and shifts to recommended healthy and sustainable diets. Domestically produced beef and dairy, which require vast land areas, and imported fruit, which has an intense impact on biodiversity per unit land, have especially high biodiversity footprints. Adopting the Planetary Health diet or the US Department of Agriculture (USDA)–recommended vegetarian diet nationwide would reduce the biodiversity footprint of food consumption. However, increases in the consumption of foods grown in global biodiversity hotspots both inside and outside the United States, especially fruits and vegetables, would partially offset the reduction. In contrast, the USDA-recommended US-style and Mediterranean-style diets would increase the biodiversity threat due to increased consumption of dairy and farmed fish. Simply halving food waste would benefit global biodiversity more than half as much as all Americans simultaneously shifting to a sustainable diet. Combining food waste reduction with the adoption of a sustainable diet could reduce the biodiversity footprint of US food consumption by roughly half. Species facing extinction because of unsustainable food consumption practices could be rescued by reducing agriculture's footprint; diet shifts and food waste reduction can help us get there.

biodiversity | diet | food waste | land use | sustainability

Humans are appropriating Earth's land and resources at an unsustainable rate (1, 2). Recently, the US presidential administration called for 30% of the land area of the United States to be protected by 2030 (3, 4), approximately twice the current extent of strictly protected areas (5). Expanding protected lands can preserve biodiversity by providing natural populations currently committed to extinction with adequate habitat to maintain stable numbers (6, 7). However, only land not needed to produce food can be set aside for biodiversity conservation. Without demand-side changes to the food system that reduce pressure on agricultural land, the land protection goal is likely unattainable. Two of the most promising actions for increasing the sustainability of the food system without compromising human well-being are food waste reduction and diet shifts (8). In this manuscript, we simulate the potential effects of both of these actions on the biodiversity impacts of food consumption in the United States.

Biodiversity has been historically neglected when assessing sustainability (9), although new standards have called for incorporating biodiversity into environmental assessments (10). Estimating biodiversity impacts is often technically challenging because impacts are localized and highly contingent on the existing background biodiversity (11). In addition, impacts on ecological communities from many simultaneous human-caused stresses are difficult to disentangle. However, the consensus is that the large-scale conversion of existing habitat to modern industrialized agriculture, a process accelerating and intensifying due to the global land rush (12), is detrimental to biodiversity (6, 7).

Natural communities are under threat from existing agricultural land use (6, 7) and cropland in the United States continues to expand, outpacing the rate of cropland abandonment (13). Populations are not instantly extirpated when a portion of their habitat is lost; many species may already be committed to extinction without any intervention because their remaining habitat is insufficient to sustain a nonnegative population growth rate (14). To reverse the negative trend in biodiversity (6), action is needed to reduce our land footprint by removing some agricultural land from production to make room for natural habitats. The United Nations' new Post-2020 Global Biodiversity Framework sets the concrete goal of slowing the rate of species extinctions 10-fold

Significance

The food system's negative impact on biodiversity is increasing over time. Conserving biodiversity requires immediate and widespread action to reduce the biodiversity footprint of food consumption, but biodiversity has historically been neglected in sustainability assessments. We combine high-resolution estimates of the biodiversity footprint with food system scenario modeling to predict the consequences of two key food system sustainability actions in the United States: diet shifts and food waste reduction. Taking these actions may benefit biodiversity in some places and harm it in others. The results of this study can help decision makers understand the trade-offs we must navigate to balance human health, economics, and environmental sustainability and help consumers understand how their diets and food waste behaviors influence global biodiversity.

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and explicitly links this objective with its Sustainable Development agenda (15). To achieve this ambitious goal, a better understanding of how the food system can contribute to, or hinder, biodiversity conservation is needed. Setting aside land to protect biodiversity without accounting for the resulting loss in agricultural output has the potential to exacerbate global inequalities in food security, impairing our ability to feed the world (16). In this study, we estimate how many species are committed to eventual extinction given the land footprint of our current consumption patterns, and how many could recover if we address food waste and unsustainable diets.

Previous work has explored the sustainability implications of nationally recommended diets (8, 17, 18). The interaction of adopting recommended diets with food waste reduction has rarely been considered, although combining sustainable diets with waste reduction was a key action area for the United Nations' 2021 Food Systems Summit (19). Furthermore, the UN Sustainable Development Goal 12.3 calls for 50% food waste reduction by 2030 (20). To better understand potential interaction among sustainability actions, we simulated food waste reduction and diet shifts in a 2×5 full factorial design (waste scenarios: baseline food waste rate and 50% food waste reduction; diet scenarios: baseline diet, EAT-Lancet Planetary Health diet, and three diets recommended by the US Department of Agriculture (USDA)/US Department of Health and Human Services (DHHS) Dietary Guidelines: healthy US-style, healthy Mediterranean-style, and healthy vegetarian diets, hereafter referred to as USDA-recommended diets). Within each counterfactual scenario, we first modeled the total value of domestic and imported agricultural production needed to satisfy US food consumption with an input-output model, then the global land footprint of that food production with an environmental extension to the input-output model. Finally, we used biodiversity threat characterization factors (21) to convert the land footprints to threats to global plant and vertebrate biodiversity (*SI Appendix, Fig. S1*).

By incorporating high-resolution biodiversity footprints into scenarios simulating multiple food system interventions, our work unites two major research threads. First, estimating biodiversity threats embedded in agricultural production and trade (22, 23) is critical for incorporating biodiversity into sustainability assessments. Recent methodological advances have enabled increasing both the taxonomic and the spatial resolution of biodiversity threat calculations, as well as estimating marginal threat increases resulting from each additional unit of land consumed (21, 24, 25). In this manuscript, we use the countryside species-area relationship (24, 26) to estimate the number of species under threat of extinction in each ecoregion of the United States based on the relationship between area and number of species and the tolerance of different taxonomic groups to different types of habitat loss and conversion. This approach enables us to trace food's biodiversity impacts to specific locations and more accurately predict changes to the biodiversity threat resulting from changes in consumption patterns. Second, food systems models have projected the impacts of sustainability actions into the future: For example, a recent study showed how a combination of diet shifts, technological advances, and food waste reduction is needed to collectively hold the food system within planetary boundaries (27). Another study simulated a combination of food system sustainability actions and biodiversity conservation actions to show that both are necessary to stem the loss of biodiversity and could potentially change the negative trend to a positive one (6).

Results

Agricultural Goods Consumption Footprints across Scenarios.

The total domestic production of agricultural goods required to satisfy nationwide food consumption was generally lower in the alternative scenarios than in the 2012 baseline case, with some important exceptions (*Fig. 1* and *SI Appendix, Fig. S4*). If the rate of avoidable food waste were halved, the total required domestic production would decline by an average of 17.0% by monetary value across all 10 primary agricultural goods categories. Alternative diets would result in reduced production of animal products, except for increased dairy cattle production to supply higher levels of milk and processed dairy products for all three of the USDA-recommended diets, and increased aquaculture production for the healthy US-style and healthy Mediterranean-style diets. Due to reduced requirements for animal feed, grains and oilseed production would also decrease for diets with reduced meat consumption. However, fruit, vegetable, and nut production would increase for all alternative diets, even under waste reduction scenarios.

Spatial Variation in Land and Biodiversity Footprints of Food Production.

The production-side land footprint is highest in counties primarily in the western United States with the largest amount of pastureland used for beef cattle production (*Fig. 2, Upper Left* and *SI Appendix, Fig. S15* and *Table S1*). The highest contributions to the biodiversity threat footprint are from those cattle-producing counties, as well as hot spots rich in endemic biodiversity such as tropical Florida and Hawaii (*Fig. 2, Upper Right* and *SI Appendix, Table S2*) and tropical countries (*Fig. 2, Lower Right* and *SI Appendix, Figs. S28–S33*) where fruit and nut crops with high resource requirements and low calorie yield per unit land are produced. Food production in western counties largely threatens mammals and reptiles, whereas threats to birds and plants are disproportionately high from Florida and Hawaii (*SI Appendix, Fig. S27*). Foreign imports account for a sizable chunk of the threats to plant and vertebrate biodiversity embodied in food consumed in the United States (*Fig. 3*): the imported products with the highest embodied threat are beef, lamb, and dairy products (imported from countries including Australia, Canada, and Mexico) and fruits, vegetables, and commodity crops such as coffee and cacao (imported from countries with high biodiversity including Colombia, Ecuador, and Mexico; *SI Appendix, Figs. S28–S33* and *Tables S4–S7*).

Total Land Footprint of Food Consumption across Scenarios.

The total land footprint is lower in the 50% waste reduction scenario without any diet shifts (−16.5%) and in the Planetary Health (−44.8%) and vegetarian (−53.2%) diet scenarios without any waste reduction, but higher in the US-style (+1.9%) and Mediterranean (+10.0%) diet scenarios (*Figs. 3* and *4*). The increase in land footprint in the Mediterranean diet scenario is mainly a result of increased requirements for land to produce feedstock for aquaculture, satisfying a sixfold increase in calories per day from seafood (*Fig. 1* and *SI Appendix, Figs. S13* and *S14*). Scenarios assuming both diet shifts and waste reduction achieve the highest reduction in land footprint (−54.8% Planetary Health + waste halved, −10.2% Mediterranean + waste halved, −16.2% US-style + waste halved, and −61.7% vegetarian + waste halved).

Total Biodiversity Footprint of Food Consumption across Scenarios.

The relative differences between the baseline case and alternative scenarios for threats to plant and vertebrate

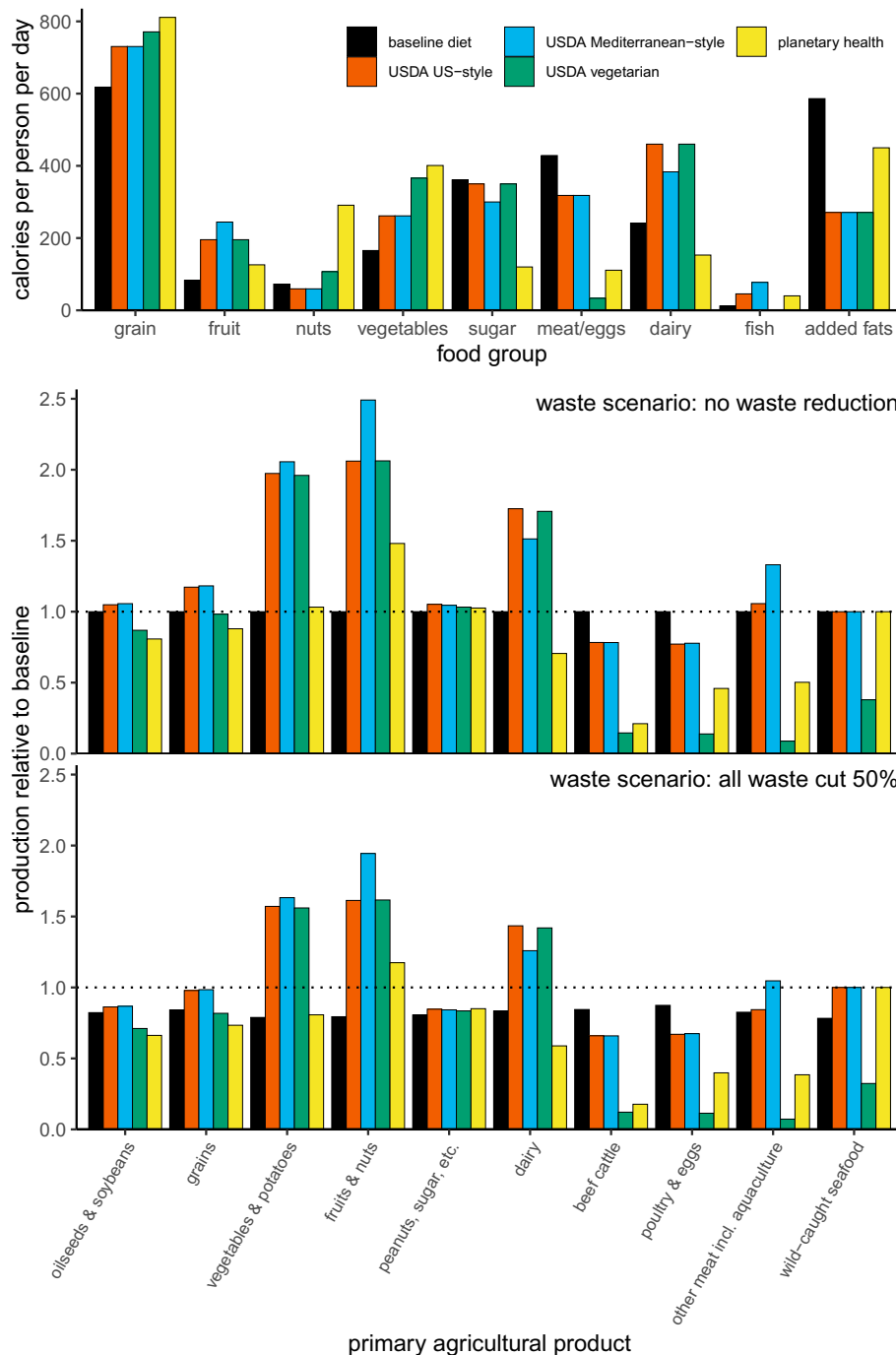


Fig. 1. (Top) Daily calories allocated to major food groups in the 2012 baseline US diet and four alternative diets. Total calories sum to a per capita average of 2,600 calories per day. (Middle and Bottom) Modeled relative changes to total domestic production of 10 primary agricultural goods across all combinations of diet shift scenarios and food waste reduction scenarios compared with the baseline scenario (dotted line at a ratio of 1 indicates no change), accounting for both direct consumer demand and indirect demand (e.g., grains used to feed livestock).

biodiversity due to food consumption in the United States roughly parallel the land footprints (Fig. 3 and *SI Appendix, Figs. S5 and S6*); a key difference is that the biodiversity threat footprint associated with food grown and produced outside the United States is disproportionately high (a full 39.1% of the biodiversity threat is imported, compared to only 20.0% of the land footprint; Fig. 3).

Threats to biodiversity due to consumption of food, summing across animal and plant kingdoms and across domestic and foreign origin, would decrease assuming a halving of food waste even without any diet shifts (−17.5%) and in the

Planetary Health (−29.7%) and vegetarian (−29.9%) diet scenarios without any waste reduction (Figs. 3 and 4). However, the US-style (+20.4%) and Mediterranean-style (+36.5%) diets would result in substantially higher biodiversity threats if food waste were not also reduced. This finding is largely due to increased biodiversity threats from increased fruit and commodity crop imports from tropical regions, especially Ecuador, Colombia, Mexico, and Indonesia (*SI Appendix, Figs. S28–S33*). Combining the US-style diet with 50% waste reduction would offset the additional biodiversity damage due to diet (−3.0%), but the biodiversity threat would actually increase

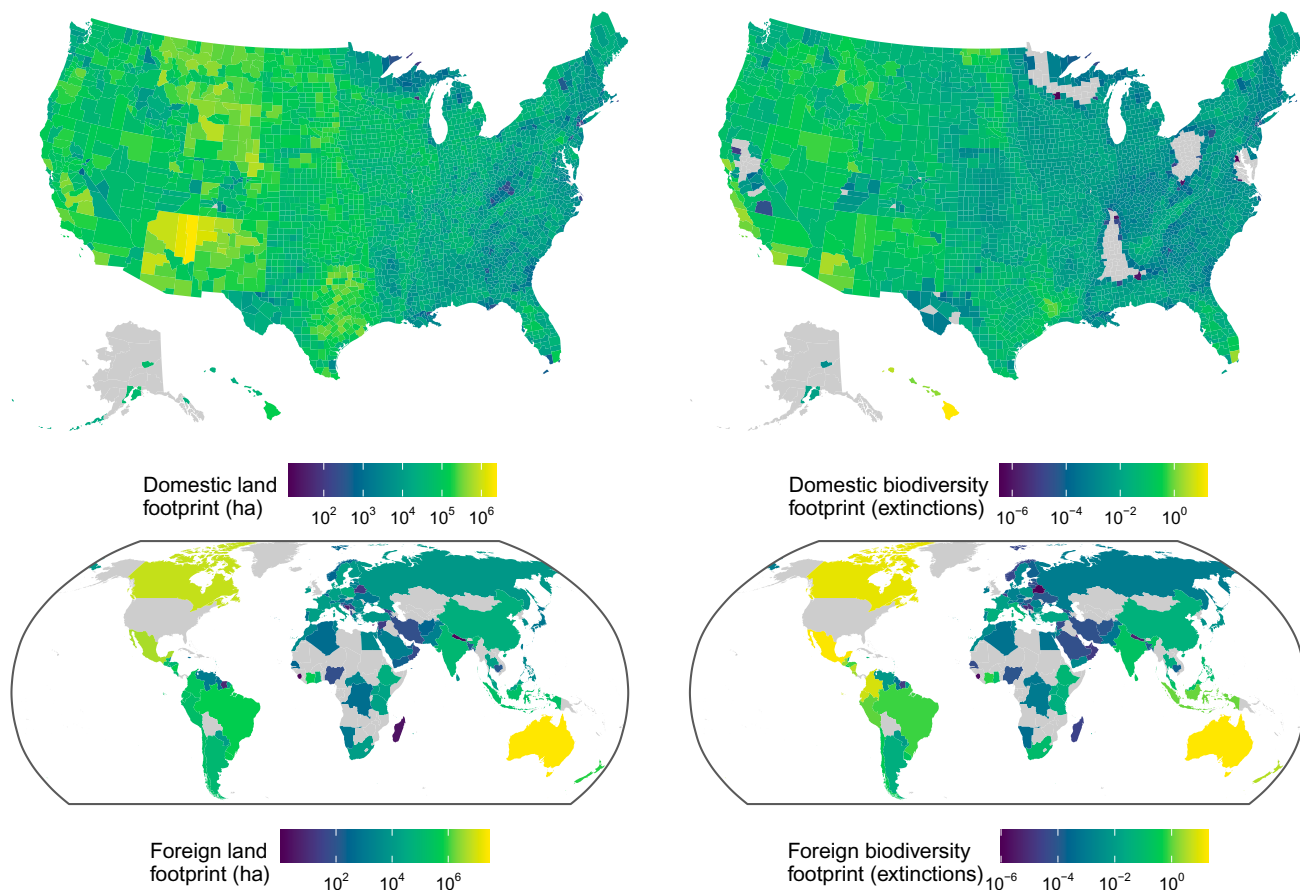


Fig. 2. (Left) Baseline land and (Right) biodiversity footprints, both (Upper) domestic by county and (Lower) foreign by food-exporting country, of food consumption in the United States in 2012. Counties and countries shaded in gray have a negligible contribution to US land or global biodiversity threat footprints resulting from food consumption. Ha refers to hectares.

when combining the Mediterranean-style diet with waste reduction (+9.1%). The highest reductions to the biodiversity threat could be achieved by combining 50% waste reduction with the Planetary Health (−43.6%) or vegetarian (−44.3%) diets (Fig. 3).

Although there would be a net biodiversity benefit of the Planetary Health and vegetarian diets for most counties, counties in California (e.g., San Diego, Napa, Sonoma), Florida (e.g., Miami-Dade), and Hawaii (e.g., Hawaii, Maui) that produce large amounts of fruit crops would see an increased threat to their biodiversity under all alternative diet scenarios (Fig. 4 and *SI Appendix*, Figs. S24–S26 and Table S3), although this increase could be largely offset by waste reduction.

We invite readers to view our results interactively at <https://qread.shinyapps.io/biodiversity-farm2fork>.

Discussion

In this study, we have modeled the biodiversity threat of land use due to food consumption in the United States. We found that domestically produced beef and dairy and some fruit crops imported from foreign countries have the highest embodied biodiversity threats and that the relative share of biodiversity threat imported from outside US borders is twice as high as the relative proportion of virtual foreign land imports. Cutting food waste by 50% has the potential to significantly reduce the threat to global biodiversity from US food consumption, nearly as much as the reduction associated with diet shifts for foods

other than beef and dairy. Food waste reduction would offset the increased biodiversity threat of the USDA-recommended US-style diet and enhance the already substantial biodiversity benefits of the Planetary Health and USDA-recommended vegetarian diets. Combining the halving of food waste with the adoption of the Planetary Health or vegetarian diet would reduce the biodiversity footprint of US food consumption by roughly half.

Feasibility of Sustainability Interventions. Both food waste reduction and diet shifts are critical to achieve sustainability but cannot be implemented without considering potential unintended consequences. First, diets are strongly culturally determined; a one-size-fits-all planetary diet may not be appropriate for all people (28). Furthermore, there are economic disincentives—while increasing sustainability benefits everyone, our analysis shows that economic winners and losers would be unevenly distributed geographically. In particular, decreasing demand for livestock would cause economic harm to regions with high livestock production. In contrast, fruit-producing regions would benefit economically due to increased demand for fruit, with attendant increased pressure on local biodiversity. Another consideration is that massive-scale sustainability interventions are expensive to implement and would have large-scale effects on agricultural markets and prices. Some estimates have been made of the cost of food waste reduction interventions at the national scale (29, 30), but there have been few proposals regarding how exactly to attain large-scale diet shifts (8, 31).

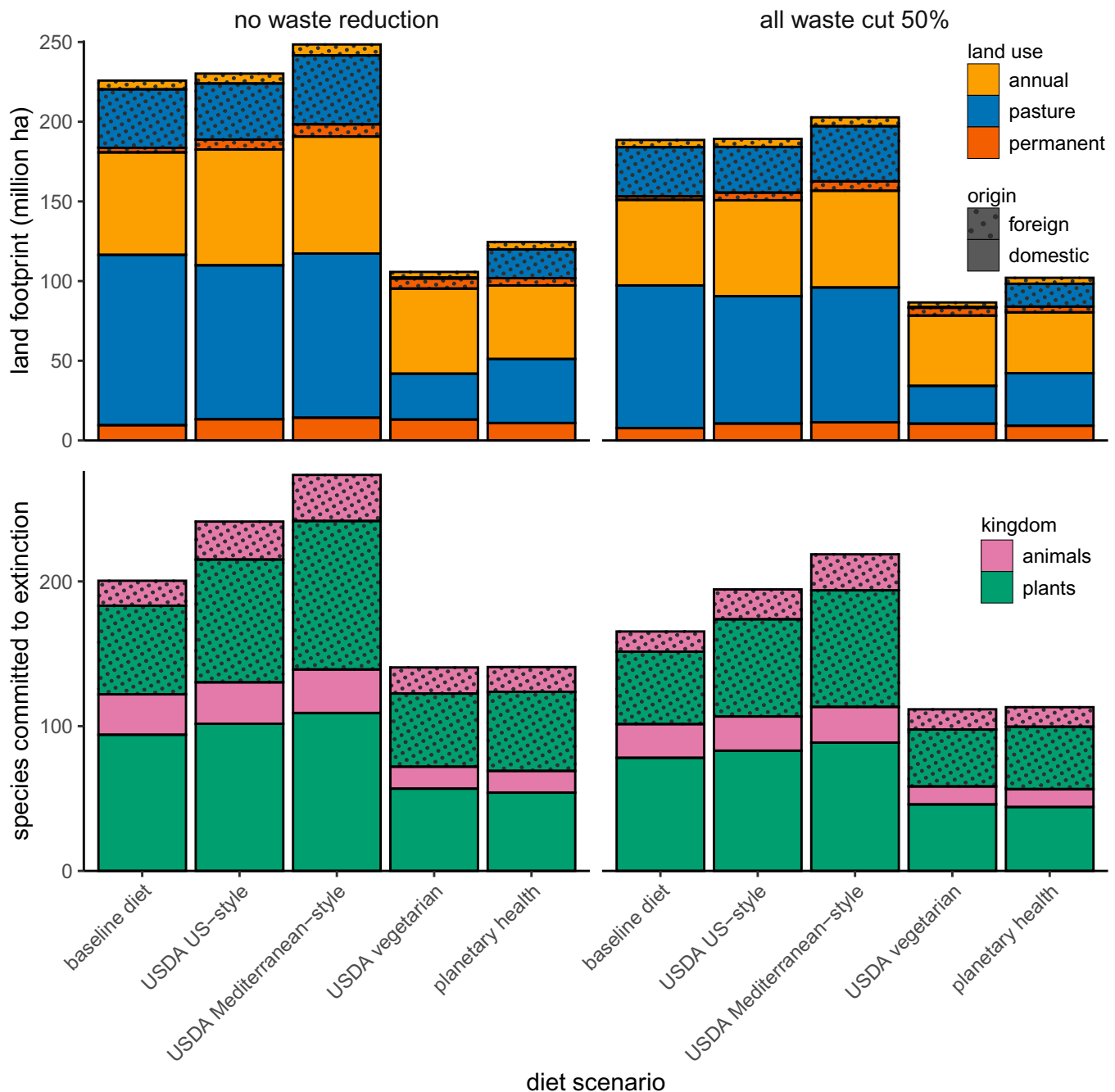


Fig. 3. (Top) Modeled total land footprint and (Bottom) biodiversity footprint of US food consumption across all combinations of diet shift and food waste reduction scenarios. In Top, the color of the bar shading represents the agricultural land use type. In Bottom, biodiversity threat is in units of species committed to extinction, and the color of the bar shading represents the kingdom of the threatened species. Footprints due to foreign agricultural land use have a dotted pattern superimposed. Ha refers to hectares.

We are unlikely to achieve significant diet shifts without either gradual cultural changes or potentially unpopular measures such as taxing meat, either directly through an excise or sales tax on purchases, or indirectly via a carbon tax (32). Finally, our work, along with a previous study (19), suggests that it is difficult to simultaneously minimize environmental impact and maximize nutritional quality; the lower-footprint healthy vegetarian and Planetary Health diets consist of foods that tend to be higher in carbohydrates and lower in protein than the other diets. Our high-resolution biodiversity footprint analysis reveals that although diet shifts are commonly promoted as a sustainability solution, they have the potential to increase local ecological impacts in areas of high biodiversity. Food waste reduction,

which helps mitigate this unwanted trade-off by reducing extinction threat across all ecoregions and avoids any potential trade-offs with nutritional quality, should therefore be part of any long-term sustainability plan.

Although our approach assumes that interventions occur instantaneously, in reality, implementing sustainability actions at such a scale would be a slow, incremental process. In addition, the capacity of formerly agricultural land to support biodiversity would recover over a discrete period, rather than instantaneously as we assume here. This consideration emphasizes the need for sustainability interventions to be implemented as fast as possible to start the clock on recovery, especially given that climate change and other anthropogenic

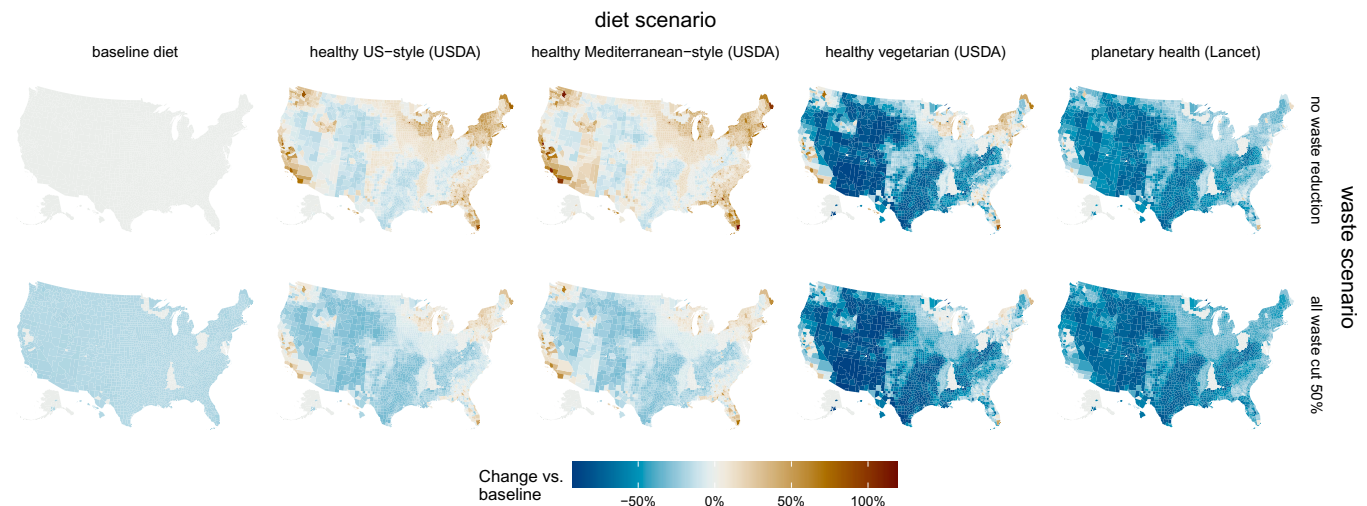


Fig. 4. Modeled change relative to baseline in biodiversity threat footprint due to agricultural production used to satisfy US food demand for each county in the United States across all combinations of diet shift and food waste reduction scenarios. Counties are shaded blue if the number of species committed to extinction due to land use in that county would decline relative to the baseline case, and brown if it would increase.

threats may interact with land use change over time to further decrease the land's capacity to support biodiversity (33). Furthermore, we assumed that production would increase or decrease proportionally in response to changes in consumption, without changing its spatial distribution. However, it is possible that production would shift to other regions of the United States, causing changes to biodiversity threat levels beyond what we predict here. In addition, it is possible that production would not drop in response to decreased domestic demand; instead, producers might export their goods to other countries. As a result, the biodiversity threat reductions we predict for alternative demand scenarios could be viewed as optimistic unless the demand for goods with high biodiversity footprints in export markets also decreases.

Implications for Land Conservation. Here, we estimated food production's impacts on biodiversity from land conversion and land use. This estimate shows the potential benefits of a "land-sparing" approach, in which the impacts of agricultural production are minimized by farming the smallest possible land area intensively. However, there are many other ways in which food production can affect natural communities. While the land-sparing paradigm has been controversial (34), conserving natural habitats and restoring agricultural land can produce ecosystem services with greater value than extractive agricultural use across a wide range of contexts (35). Integrating conservation practices into agriculture, i.e., "land sharing," may have similar benefits (36), reducing pressure on biodiversity without necessarily reducing the land footprint. Furthermore, there is not a clear dichotomy between agricultural and natural land; in fact, much cropland lies within protected area boundaries globally (37). The countryside species-area relationship that we use to model potential biodiversity loss is flexible enough to account for positive impacts of regenerative and land-sharing agricultural practices on individual taxonomic groups (16). However, doing so would require additional parameters from studies measuring the biodiversity impacts of those practices at multiple scales (38, 39). On the other hand, better predictions of the impacts of a land-sparing approach would require additional measurements of the biodiversity impacts of sustainable agricultural intensification (32, 40).

The results of our analysis can inform conservation prioritization for the goal of conserving 30% of land in the United States by 2030 by identifying ecoregions with the highest biodiversity threats due to food consumption and where land conservation efforts would have the maximum benefit for reducing extinction threats. For example, we estimate that shifts to the USDA-recommended healthy US-style or healthy Mediterranean-style diets would require expanding the already large biodiversity footprint of dairy cattle production. This idea further underscores the importance of food waste reduction to reduce pressure on land due to cattle production, which is a major contributor to the overall biodiversity threat embodied in the American diet and would potentially increase if consumption patterns change to conform more closely to some healthy recommended diets. To increase the amount of conserved land in the United States, food waste reduction and shifts to sustainable diets are both needed to reduce pressure on the land and reduce the opportunity cost of setting aside productive agricultural land (6). Our work could inform a targeted spatial prioritization of conservation land in conjunction with demand-side actions.

Spatial Resolution of Land and Biodiversity Footprints. Our approach enables the biodiversity footprint of agricultural production to be allocated spatially (41). We used spatially disaggregated land and biodiversity characterization factors to quantify impacts based on the overlap of agricultural land use and ecoregions at the county scale, which acknowledges that biodiversity impacts from a given areal extent of agricultural production will vary geographically. In the future, it may be possible to spatially disaggregate the biodiversity footprint on the consumption side as well as the production side. This process would require incorporating spatially explicit input-output transaction matrices constructed from data such as intracountry shipments of agricultural goods, e.g., the Freight Analysis Framework (42, 43). However, estimating the consumption footprint of individual regions in the United States would also require data on flows of food among counties, accounting for the transformation of raw agricultural products into food and the multiple steps of transportation that food products in the United States undergo as they travel from farm to fork (44). Expanded dietary recall studies with adequate sample sizes to

generate regional estimates would also be helpful to spatially resolve food consumption patterns.

The work presented here is a useful first step for agenda-setting and messaging for conservation organizations. Previously, they were limited to making statements such as “The expansion and intensification of agricultural activity is imperiling... 62% of [species] listed as threatened or near-threatened” (ref. 45, p. 144) and “Drivers linked to food production cause 70% of terrestrial biodiversity loss” (ref. 46, p. 61). A recent report estimated that biodiversity impacts contribute more than \$450 billion to the “true cost of food” in the United States (47). Complementing this effort, our work provides further information on biodiversity threats to tailor the message to the specific audience, based on their individual dietary and food waste behaviors.

Conclusion. In this study, we show the potential biodiversity benefits of the widespread adoption of alternative diets and of food waste reduction. Our results suggest potential unintended consequences of promoted healthy diets for the environment and biodiversity. Reducing the consumption of one food group requires increasing the consumption of another, which may simply transfer embodied biodiversity threats to another region. Diet shifts and food waste reduction are both commonly promoted as sustainability solutions. Because implementing large-scale food waste reduction initiatives may face less resistance and have fewer unintended consequences, it may be more practical to push for food waste reduction.

Many populations of animals and plants are currently trapped in an extinction death spiral—humans have so modified and reduced their natural habitat that too little remains to sustain a stable population size (7). It may be possible to rescue some species from this fate by reducing agriculture’s footprint and restoring agricultural land so that it can sustain larger natural populations. Together, diet shifts and food waste reduction can help us achieve that crucial goal.

Materials and Methods

The objective of this study was to estimate the land and global biodiversity impacts of changes in food consumption in each county of the United States (*SI Appendix, Fig. S1*). To model the land-use and biodiversity footprint of food consumption in the United States, and how the footprint would change under scenarios of food waste reduction and shifts to recommended sustainable diets, we adopted a spatially explicit environmentally extended input-output (EEIO) approach. We used publicly available data provided by the US government and other sources (*SI Appendix, Table S8*). We chose 2012 as our baseline year because it is the most recent year for which the US Bureau of Economic Analysis has released input-output tables (matrices of transactions between industries) at the highest level of industry disaggregation (48); furthermore, few or no nationwide food waste reduction initiatives had been implemented at that time. Our overall approach was to define the baseline scenario, construct alternative scenarios for food waste reduction and diet shifts, and estimate the potential effects of these sustainability interventions on biodiversity.

Baseline Land and Biodiversity Footprints. We estimated the amount and spatial distribution of global land required to produce all food consumed in the United States in 2012, and the biodiversity threats associated with the use of that land to produce food, using the following approach. First, we input the total US personal consumption expenditure into the USEEIO version 2.0 input-output model (49) to determine how much production of 10 primary agricultural goods (*SI Appendix, Table S9*) was needed to satisfy final consumer demand for food. We used data from the US Census of Agriculture (50) to find the monetary value of all agricultural goods produced in each county and the amount of cropland and pastureland used to produce those goods, then summed the monetary and land values to find the total footprint. We used production and trade data from the Food and Agriculture Organization of the United Nations statistical database,

FAOSTAT (51), to estimate the land use embodied in food imported from foreign countries into the United States. Next, we proportionally divided the embodied land from each exporting political region (county or foreign country) among the Nature Conservancy ecoregions (52) (*SI Appendix, Figs. S2 and S3*) within it. We did not consider the impact of changes in wild-caught seafood consumption; we assumed that wild fisheries are at or near their maximum potential output and have no capacity to increase production. For scenarios with greater total demand for fish and other aquatic foods than the baseline scenario, we assigned all excess demand above baseline to aquaculture rather than wild fisheries (53). Finally, we multiplied the land use values by biodiversity characterization factors (15), which represent the expected number of global extinctions in each taxonomic group per square meter of natural land converted to cropland or pastureland in each ecoregion. This resulted in modeled estimates of the total biodiversity threat associated with food consumption in the United States, in units of potential global species extinctions, and the counties and foreign countries where the threats are located.

Scenario Analysis. We predicted how much the baseline land use and biodiversity threat would change under a factorial combination of diet and waste scenarios. We used four different alternative diets in addition to the baseline diet; differences in the types of food consumed under each diet underlie the ultimate differences in biodiversity threat among scenarios. We compared the baseline US diet with the four alternative proposed diets: the Planetary Health diet proposed by the EAT-Lancet commission (54) and the three healthy diets promoted by the USDA/DHHS 2020–2025 Dietary Guidelines (55): healthy US-style, healthy Mediterranean-style, and healthy vegetarian diets. While all alternative diets deliver balanced, healthy nutrition, the Planetary Health diet explicitly considers sustainability and minimizing the land footprint; in contrast, the diets recommended by the USDA are only required to consider individual health. As a result, the calories allocated to different food groups differ among diets (Fig. 1). The daily allowance of meat on the Planetary Health diet is much lower than current average meat consumption. Dairy products, added fats (any fat added during processing or cooking, such as cooking oils), and added sugars are also allocated fewer calories than currently consumed; in contrast, fruits, grains, nuts, and vegetables are allocated more calories. While all three of the USDA-recommended diets allow less meat and added fats than the current average American eats daily, they compensate for these allowances with a substantially increased dairy consumption, in addition to increases in fruits, grains, and vegetables.

For the food waste reduction scenarios, we simulated a 50% reduction of avoidable food waste (not including inedible parts) across the entire food supply chain, following the United Nations’ sustainable development goal of halving food waste by 2030 (22). Here we use the term food waste to encompass food intended for human consumption but not consumed for whatever reason: both food lost during production, processing, and distribution, and food wasted by consumers and businesses. We used the baseline food waste rates and diet composition data from the USDA’s loss-adjusted food availability data (56) to estimate the amount of food lost as a proportion of final consumption between farm and fork (processing, retail, and consumer losses) in each food demand category in the EEIO model.

We derived counterfactual consumption change factors for each food in each scenario crossing waste reduction with diet shifts, from which we obtained production change factors for each primary agricultural good. Using these factors, we repeated the land and biodiversity footprint calculations for each of the alternative scenarios. The relative differences in land footprints among diet scenarios were qualitatively similar to previous estimates (20; *SI Appendix, Appendix 4*). Although our biodiversity footprint estimates tended to be higher than previous estimates (6, 26) due to methodological differences in how the characterization factors we used are calculated, the relative differences among scenarios were similar (6). The biodiversity threat reduction relative to the baseline scenario was calculated assuming that land taken out of agricultural production can immediately support the same number of species as previously undisturbed land (no hysteresis and no time lag to full recovery). Therefore, it is more appropriate to consider the alternative scenarios as counterfactual cases rather than a simulation of a process occurring over time.

Data Availability. Data have been deposited in Figshare (https://figshare.com/articles/dataset/Data_from_Biodiversity_effects_of_food_system_sustainability_actions_from_farm_to_fork/14892087). Code to reproduce the analyses

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