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Biodiversity Loss and Its Impact on Dietary Land Diversity and Nutritional Status: A Comprehensive Review

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Abstract

Habitat destruction, climate change, overexploitation, and agricultural intensification contribute to the current predicament in global food systems: loss of biodiversity means fewer plant and animal species to be utilized. This study examines and synthesizes the available literature in PubMed and Scopus on how losses in biodiversity adversely affect people's diets and nutritional status, especially in the case of malnutrition and missing key micronutrients in certain demographic cohorts. Principal factors are the loss of agrobiodiversity and wild foods, especially fish and other foraged plants, and shifts in diet toward nutritionally poor mono-staple foods. Land-use change and environmental degradation through the agricultural expansion of the built environment over 70% of terrestrial habitats, deforestation, and loss of soil biodiversity and ecosystem services disrupt other fundamental underlying factors of food quality. Multiple studies demonstrate that greater biodiversity within foods, as measured by greater Dietary Species Richness (DSR), correlates with better diet and improved health, especially with lower all-cause mortality. In LMICs, for example, declining agrobiodiversity correlates to increased micronutrient deficiency, anemia, and stunting. Of the nine crops that dominate global production of 66% of total food produced, biodiversity loss poses problematic risks. Investigating losses of wild-caught species in Amazonian fisheries suggests compensatory dynamics may heighten supplies of certain nutrients, such as omega-3 fatty acids, in the short term, but cause greater long-term supply instability in iron and zinc. Environmental scope analysis suggests that land degradation shrinks soil microbial diversity by 50–75%. It consequently reduces the iron and zinc contents of staple cereal crops' micronutrients by 20–40%. Review articles highlighting food biodiversity inform that over 2 billion people whose diets are centered on wild foods are supplied with greater nutrients, but current patterns evidently increase malnutrition risk. Strategies to mitigate the negative impacts include the promotion of neglected but underutilized species, sustainable food production, and greater policy integration around health, agriculture, and conservation.

Keywords: Agricultural, biodiversity, climate change, overexploitation, sustainable food

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INTRODUCTION

Biodiversity loss at unprecedented rates, with over one million species threatened with extinction, negatively impacts food security and human nutrition in all its dimensions, including healthy dietary diversity [1]. The main driver is land-use change and, in particular, agriculture, which has been converting 38% of the global terrestrial surface for its use, while fragmenting and degrading the ecosystems that sustain food production. The diversity of the diet, which varies in richness and evenness of the different species of plants and animals consumed, is positively related to the adequacy of the diet in terms of micronutrients, which is attributable to the complementary supply of several vitamins and minerals and other bioactive compounds found in varied food sources [2, 3]. The documented decline of nutrition status in countries with low and middle income, where there is over-reliance on staple foods such as rice and maize while nutrient-dense wild greens, fruits, and fish are avoided, illustrates the consequences of declining food production biodiversity. The impacts of environmental degradation and loss of biodiversity are compounded as soil biodiversity loss and consequent reduction in nutrient cycling is estimated to lead to a 30–60% loss of the efficient cycling of nutrients for up to 30% of the soil, while deforestation removes wild foods that are known sources of up to 30–93% of the dietary energy of deforested communities. Through land conversion and intensive agriculture, food systems are responsible for 70% of terrestrial biodiversity loss. There is a self-reinforcing cycle where simplified diets lead to more rapid habitat degradation, which in turn leads to the loss of edible and even wild biodiversity within food production systems [4–8]. Smallholder land tenure insecurity and gaps in environmental policy, particularly regarding biodiversity and nutrition, exacerbate these disconnections, as smallholder farmers, in particular, lack the incentives for the conservation of diverse agroecosystems. This paper will review the available literature on these themes in PubMed and Scopus. This includes the potential mechanisms, empirical impacts, the most impacted vulnerable populations, and the most targeted composite measures.

It focuses on more recent reviews from the past five years discussing biodiversity metrics, such as Dietary Species Richness (DSR), Nutritional Functional Diversity (NFD), and the Shannon Diversity Index (SHDI), as they relate to diet quality measures (e.g., Mean Adequacy Ratio (MAR)). The environmental consideration incorporates frameworks on land management, soil health, and ecosystem services to more fully evaluate the biodiversity–nutrition pathways [9–12].

Mechanisms of Biodiversity Loss

Dietary food loss due to climate change and habitat fragmentation from deforestation and urbanization alters access to seasonal edibles and wild food sources [1]. Land transformation from agriculture represents the most extensive change to the environment, as cropland and pastures take up around 50% of the earth's habitable space and cause irreparable damage to the biodiversity of tropical forests and grasslands. There is also an over-dominance of monoculture in agriculture as numerous diets are over 50% composed of cereals which are, in turn, accompanied by the neglect of various nutrient-rich pulses, roots, and leaves. Nutritional loss through the diversity of crops is also altered by the loss of functional diversity due to the overapplication of tillage and industrial agricultural chemicals, which further export and erode 15% of rich trace micronutrients and erosion nutrient systems. Exhaustive underdevelopment depletes wild aquatic stocks and completes the loss of large and migratory species before the depletion of dominant smaller species and nutrient depletion from the capturing of highly migratory species. Environmental degradation through the construction and pollution of habitat systems within intercontinental river basins and the destruction of aquatic ecosystems results in the loss of protein, critical omega-3, and animal-rich sustenance through fish species depletion of 60% and essential industrial protein. Genetic erosion depletes micronutrients in food and crops as modern varieties of wheat are recorded to retain 20–50% less zinc and iron. Reduced nutrient dissimilarity across species in a diet also results in functional diversity decline. These processes further homogenize diets pandemically. Loss of biodiversity has feedback systems: loss of biodiversity decreases ecosystem resilience and makes food systems increasingly vulnerable to climate change; this, in turn, worsens land degradation and accelerates species extinction [11–13].

Impacts on Dietary Diversity

Biodiversity losses reduce DSR in LMICs from over 20 to less than 10 species/day, which restricts food options. Scoping reviews indicate positive correlations suggesting that each species contributes a 0.03–0.10 MAR increase (0–1 scaled). Compared to other regions in Europe, DSR is high (median 68 species/year), which anchors better compliance to Mediterranean diet/healthy Eating Indexes. The greater the landscape's agri-intensification, the less varied its land and the more natural compartment patches (50–70%) lost to cultivated/managed ecosystems which collapse ecosystems and wild food plants. Wild food is important, amplifying ubiquitous proteins/omega-3s for 800,000 people [14]. Amazon fisheries face 50% species loss and diet failure risk for zinc/iron provision. 200 million people reliant on inland fisheries also face a clear paradox – for wild food lost. Neglected, underutilized plants (e.g., moringa, amaranth) enhance dietary variety. A 50–70% increase in species richness occurs while in crop production. The trend is due to land abandonment and likely to be reversed by environmental restoration [17, 18] in Table 1.

Consequences for Nutritional Status

Biodiversity loss is tied to increased micronutrient gaps, as monoculture zones produce much less diverse and less nutritious diets. Furthermore, diets low in DSR in the Solomon Islands signal low quality and unhealthiness as they contain low micronutrient levels; DSR associates with increased body fat. Of the 2 billion people still dependent on wild foods, the loss of EPA and DHA, especially critical to child growth, is of increasing concern. Land degradation directly affects the soil biodiversity impact on nutritional levels. For example, the iron and zinc content of the crops on such degraded soils falls, as shown by soils in Madagascar, sub-Saharan Africa, and other regions with over 40% of the population zinc deficient. Mortality strains DSR, as a 10-species DSR increase/year is associated with a cut in all-cause mortality HR 0.90 and cancer mortality HR 0.93. The HR 0.94 is attributed to cancers of the GI, to a large extent, but there are other mostly non-cancer vital statistics with largely depressed levels of mortality. Contaminants of degraded land, such as persistent heavy metals and other drugs, deteriorate the nutrients of foods and thereby exacerbate the impact of such foods on stunting and anemia. In areas with low biodiversity and erosion, stunting, and anemia rise, as seen in India during the pulse crops decline with iron deficit. Nutrient-dense crop yields also drop as climate changes, further exacerbating the situation. In regions with >50% forest loss, there are 30–50% higher child stunting rates. This is due to changes in land use and also reduction in ecosystem services, forming increased spatial inequalities as seen with the 30–50% loss of forests [19–25].

Vulnerable Populations and Regional Variations

In Table 2, African, and Asian smallholders are losing access to wild greens and fish, which has resulted in a sharp rise in hidden hunger. Indigenous people of Ecuador and the Solomon Islands consume a staggering 119 and 87 species respectively, but are increasingly facing cultural homogenization. The urban poor are also moving toward diets high in ultra-processed foods and low nutritional diversity. This is problematic as women and children are often the most affected by it, and in the case of the Peruvian Amazon, the loss of fish sources is particularly detrimental due to the prevention of anemia. Vulnerable groups are impacted by land tenure insecurity the most. For instance, smallholders without land rights are estimated to greatly reduce agrobiodiversity by 25–40% as a result of land tenure insecurity. People within high-income countries are blessed with contrasting lifestyles; for instance, in Europe they profit from imports but also push for the destruction of the tropics as a result of overconsumption. There are many environmental justice factors to highlight. For instance, the high-income countries' biofuel and livestock feed mechanism, which they tend to defend as an environmental protection mechanism, is a direct attack on the agricultural systems in LMICs. This results in forced loss of plant species and malnutrition. However, it is worth noting that with the Planetary Health Diets, it is possible to reduce the biodiversity impact by almost 50% and improve through waste-cutting initiatives [29–31].

Table 1. Food biodiversity metrics and associations with diet quality [15–18].

Metric	Description	Association with MAR/NRF	Population/Example
DSR	Unique species count	β=0.10 (strongest)	LMICs, n=6226; +1 species → +3% adequacy
NFD	Nutritional dendrogram ratio	β=0.06; OR=11.26 high MDS	Italy, n=7948
SHDI/SDI	Evenness-weighted richness	Hill-SHDI: β=13.7% MAR	5 LMICs, women
Hill Numbers	Unified effective species	Q4 vs Q1: +12-14% MAR	Cross-country

Interventions and Policy Recommendations

Encourage biodiversity in agriculture by supporting initiatives such as quinoa or teff cultivation; implement and promote initiatives regarding seed banks. Champion and promote programs that support dietary consumption of various food types (equity in biodiversity). Reduce food waste by 50% in order to support food biodiversity. Integrate nutrition and biodiversity policies (e.g., WHO). Soil restorative conservation practices increase biodiversity by 30–50% within 5–10 years as well as crop micronutrient density. Managing fisheries for their nutrients (e.g., phosphorus) has multiple benefits. Urban foraging and local farmers' markets support access. Educational initiatives regarding wild food (foraged) plants increase community resilience. Integrating environmental policies that prioritize land use (i.e., protect 30% of land allocated for agriculture) allows for sustained biodiversity of wild food. Controversies regarding land sharing and land sparing for agriculture concluded that biodiversity-friendly practices within protected area landscapes support both nutrition and biodiversity conservation [32–35].

DISCUSSION

The interrelation of biodiversity sustaining diverse diets and nutrition through functional complementarity is corroborated by clear evidence. In Table 3, considering land and its environment, biodiversity loss in soils decreases the availability of nutrients by 25–40%. Meanwhile, land degradation removes wild food habitats which buffer seasonal food shortages. Biomass compensation can buffer nutrients, but not always; when heightening, the risks are greater. Feedback loops in the environment heighten interrelated impacts: loss of biodiversity leads to lower ecosystem resilience, then greater loss of biodiversity through climate impacts and land degradation. This in turn leads to greater ecosystem loss and less climate resilience, which eventually leads to more land degradation. Extant longitudinal datasets are few and primarily from high-income settings. Gaps are left to future research: harmonization of metrics (DSR is preferred); modeling of the climate, biodiversity, and nutrition interlinkages. The use of land and its environment calls for interdisciplinary approaches which merge remote sensing for land cover change, soil microbiome analysis, and nutritional biomarkers for causative pathways. Systems approaches are required to transform food systems, aligning agriculture, health, and conservation. This involves land governance reforms to secure smallholder tenure, which motivates biodiversity conservation in agriculture. Environmental policies should mainstream nutrition in biodiversity targets and land-use planning and, therefore, should be aimed to conserve and purposefully use the land [35–38].

Table 2. Nutrient Supply Changes with Biodiversity Loss (Trait-Based Modeling, Amazon Fisheries) [26–30].

Nutrient	No Compensation (%Δ at 50% Loss)	Random Compensation (%Δ)	Trophic Compensation (%Δ)	Risk Increase
Protein	-88	Stable	Stable to -40%	Moderate
Iron/Zn	-88	-10 to -20	-20 to -50	High
Omega-3 (ALA/EPA/DHA)	-88	+20 to +50	+10 to +30	Low
Calcium	-88	Stable	Stable	High

Table 3. Strategies to mitigate impacts [31–35].

Strategy	Biodiversity Benefit	Nutrition Outcome	Examples
Diet Shifts (Planetary Health)	-44% footprint	+ Micronutrient MAR	Reduce beef/dairy, add plants
Waste Reduction (50%)	Offsets diet threats	Maintains supplies	US food system
Underutilized Plants	+ Species richness	+ Fe/Zn/Vit A	Moringa in Africa
Metrics in Monitoring	Standardize DSR/NFD	Track adequacy	LMIC guidelines

CONCLUSION

Biodiversity loss threatens dietary diversity and nutritional status and should trigger immediate action. Environmental degradation and land-use change are primary drivers. From an agricultural perspective, land-use change causes the degradation of 70% of all terrestrial ecosystems. Meanwhile, the loss of soil biodiversity is reducing nutrient levels of crops by 20–40%. Nutrient-rich, resilient diets are produced by diverse ecosystems, and their erosion leaves billions of people malnourished. Multiple reviews use NMDS/NFD as proxies for quality, and with loss of biodiversity, iron, and zinc gaps are more likely, even if omega-3s are gained. Public health must recognize the need for policy and practice of sustainable and protected agricultural practices, and conservation of wild and underutilized food species. Nutritionally, biodiversity loss can be addressed with conservation agriculture, agroforestry, and protected area networks. The erosion of biodiversity and improvement of malnutrition are directly correlated. Valuing biodiversity will improve the nutritional outlook of societies as global changes occur. From regional food security frameworks, a balance between health and the planet can be achieved if conservation is incorporated. The promise of diverse agroecosystems will avoid a range of crises, especially in LMICs. The need to integrate land governance and environmental policy will define whether food systems can sustainably nourish 10 billion by 2050. Securing land rights, restoring degraded ecosystems, and mainstreaming nutrition will determine the outcome.

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