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Perspective

# Urbanization and agrobiodiversity: Leveraging a key nexus for sustainable development

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## SUMMARY

**Expanding urbanization affects food biodiversity and broader agrobiodiversity, which are essential nutrition and ecosystem resources for sustainable development but are threatened globally. The increasingly influential nexus of urbanization-agrobiodiversity interactions has not been systematically researched. Here we design an interdisciplinary perspective to identify and understand the bidirectional interactions of agrobiodiversity in four major linkages: urban and peri-urban land use, urban food supply chains, urban food access, and urban food retailing. Agrobiodiversity is evident to varying degrees amid urbanization globally, rather than the previously assumed blanket incompatibility or unspecified partial compatibility. A proposed conceptual framework is used to hypothesize how these linkages create configurations of combined conditions that support agrobiodiversity amid expanding urbanization. These key conditions contain leverage points of the urbanization-agrobiodiversity nexus for policies to address nutrition insecurity and vital environmental functions. We conclude that the urbanization-agrobiodiversity nexus is a crucial new focus of interdisciplinary research to strengthen sustainable development and food systems.**

## INTRODUCTION

Urbanization profoundly influences the planet. More than one-half of humanity currently lives in urban areas, and by 2050 this figure is projected to grow to 68%, an estimated increase of 2.5 billion people from today.[1] Urbanization is a multi-dimensional process that includes demographic, biogeophysical, economic, cultural, and social changes that together are propelling global transformations. Expanding urbanization drives major changes in climate,[2,3] biodiversity,[4] land use,[5] and human diets.[6] Increasingly, the powerful links of urbanization to the production and consumption of food are recognized as crucial to sustainability of food systems.[7]

While the above impacts are well documented, little is known about how urbanization influences the biodiversity of food and agriculture (agrobiodiversity).[8] Agrobiodiversity is a broad umbrella term that encompasses multiple biota and levels, from genetic variation to agroecosystems, together with the allied human-environment interactions of food and agriculture (second row, Table 1). These are essential resources for sustainable ecological functions (e.g., nutrient and biotic-interaction regulations) of land use and evolutionary capacity (e.g., broad-based genetic resources and diversity-related adaptive capacity) of food production.[9,10] Food biodiversity is the edible subset of agrobiodiversity that meets the wide-ranging needs of human diets, nutrition, health, and well-being, as well as social and cultural needs (third row, Table 1).[11–13] Weakening this vital multi-functionality of agrobiodiversity thus threatens both the production and the consumption traits vital to food-system sustainability.

Cultivation and utilization of agrobiodiverse foods fell sharply in the 20th century, with 90% loss of rice varieties in China and wheat in Italy.[16,17] Agrobiodiversity loss has become geographically uneven. While slowing in certain places, including subareas of the United States,[18] global trends evidence the increased dietary predominance of 12 crops and 5 animal species as nearly three-quarters of worldwide food consumption and, especially, in the low-diversity diets of the poor.[14,19,20] The crucial importance of agrobiodiversity is increasingly recognized as needed for multi-functional adaptations to climate change, pests, and disease.[21–24] The urgency of the need to address these global changes calls for innovative new insight to leverage ways to reverse agrobiodiversity decline and threats to the sustainability of global food systems.

Urbanization is often interpreted as an exclusively negative impact on the production and consumption of agrobiodiversity. To be sure, powerful facets of urbanization, such as fast-food expansion, have driven expanding monocultures and weakened the utilization of agrobiodiversity.[15] Yet concrete examples of agrobiodiversity loss, such as the extinction-nearing decline of

**Table 1. Key terms and assumptions along with brief descriptions**

| Term | Brief description |
|---|---|
| Urbanization | High-density settlements of human populations, livelihood activities, and built-environment and land-use activities; concentrated flows of resources and supply chains; socioeconomic and sociocultural changes through employment, ideas, and lifestyles; and government and civil society institutions. |
| Agrobiodiversity | Umbrella term referring to biodiversity in food production and consumption as well as in food-producing agroecosystems.[8,9,1014] Key sustainability roles encompass both ecological and evolutionary services, including regulating carbon, nutrient, and water cycles; regulation; and examples of biotic components such as soil biota and pollinators, in addition to pest and disease management. Agrobiodiversity also supplies adaptive capacity in food-producing biota and landscapes. |
| Food biodiversity | Consumption component of agrobiodiversity[12] that functions in diverse diets and human food and nutrition security as well as health.[11,13] Food biodiversity derives from production biodiversity and thus is a subset of the realm of agrobiodiversity. Key sustainability roles of food biodiversity include human dietary diversity; micronutrient, fiber, and vitamins; and highly varied human-use and sociocultural functions. |
| Assumption of incompatibility with urbanization | "Higher incomes, urbanization, a growing population and changing dietary patterns are driving intensified demand for increased production of food … exacerbated by growing demand for more homogenous Western diets" (p. 3).[14] |
| Assumption of partial compatibility with urbanization | "…. urbanization [and associated shifts] … are reported to have … negative consequences for BFA [biodiversity in food and agriculture] …. However, such drivers are also reported to open opportunities to make food systems more sustainable, for example through the development of markets for biodiversity friendly products" (p. xxxviii).[15] |

unique potatoes in South America (*Solanum phureja*), are most directly the result of resource-change and national food-system drivers, rather than urbanization per se.[25,26] The above-mentioned concerns and evidence highlight the urgent need to examine the urbanization-agrobiodiversity nexus through the vigorous interdisciplinarity of a sustainability-centered scientific approach.

The impetus for examining agrobiodiversity in urbanization contexts stems from a range of policy analyses and program advocacy for food-and-environment sustainability and climate-change adaptive capacity,[15,27] for high-profile scientific reports (EAT-Lancet),[23] and as intended input for global initiatives.[28] These policy and program prioritizations of agrobiodiversity extend to its value in biodiversity and genetic resource conservation, and include the 2010 Aichi Biodiversity Targets of the UN Convention on Biological Diversity and the 2004 International Treaty for Plant Genetic Resources for Food and Agriculture.[9,10]

Taken together, the above sources point to the opportunity to examine the urbanization-agrobiodiversity nexus and its potential to strengthen sustainability by leveraging new scientific insights to guide future policies and programs across key policy spaces in the UN Sustainable Development Goals (SDGs; Figure 1). Promising applicability of the urbanization-agrobiodiversity nexus centers on the SDGs regarding food, nutrition, and biodiversity: End to Hunger (SDG 2), Sustainable Cities and Communities (SDG 11), and Life on Earth (SDG 15). These overlap Health and Responsible Production-Consumption (SDGs 3 and 12), as well as economic, social, and environmental sustainability, addressing urban poverty (SDGs 8, 10, and 13; see Figure 1).

Focus on the urbanization-agrobiodiversity nexus is further motivated by new urban policy and programs to enhance the biodiversity of food systems and agriculture as part of nutrition and health initiatives, such as the 2015 Milan Urban Food Policy Pact, which is currently adopted by 211 signatory cities worldwide. Similarly, the FAO's 2018 City Region Food System toolkit is designed for wide-ranging urban contexts and includes promoting agrobiodiversity in sustainable food systems.[29]

The goal of this perspective is to provide novel scientific insight by unpacking the major interactions comprising the urbanization-agrobiodiversity nexus and to outline a framework integrating these interactions. Resulting insights into the urbanization-agrobiodiversity nexus are intended to serve as leverage points for supportive policies. We begin by addressing the interdisciplinary challenge to identify major linkages between urbanization and agrobiodiversity. Synoptically reviewing the literature from diverse disciplines that include economics, geography, urban studies and planning, food systems, public health, sociology, anthropology, and development studies, as well as biodiversity, agrobiodiversity, agroecology, and land-use and resource sciences, this perspective makes use of the integrative concepts of food systems (production-to-consumption assemblages, including supply chains) and social-ecological linkages (bidirectional interactions of specific social and environmental processes). These concepts facilitate focus on bidirectional coupling whereby elements in the twin cornerstones of the urbanization-agrobiodiversity nexus mutually influence one another.

## UNDERSTANDING URBANIZATION-AGROBIODIVERSITY LINKS

To understand major linkages between urbanization and agrobiodiversity influencing the SDGs requires the brief overview of related knowledge prior to identifying principal interaction modes. It must treat both general agrobiodiversity and the

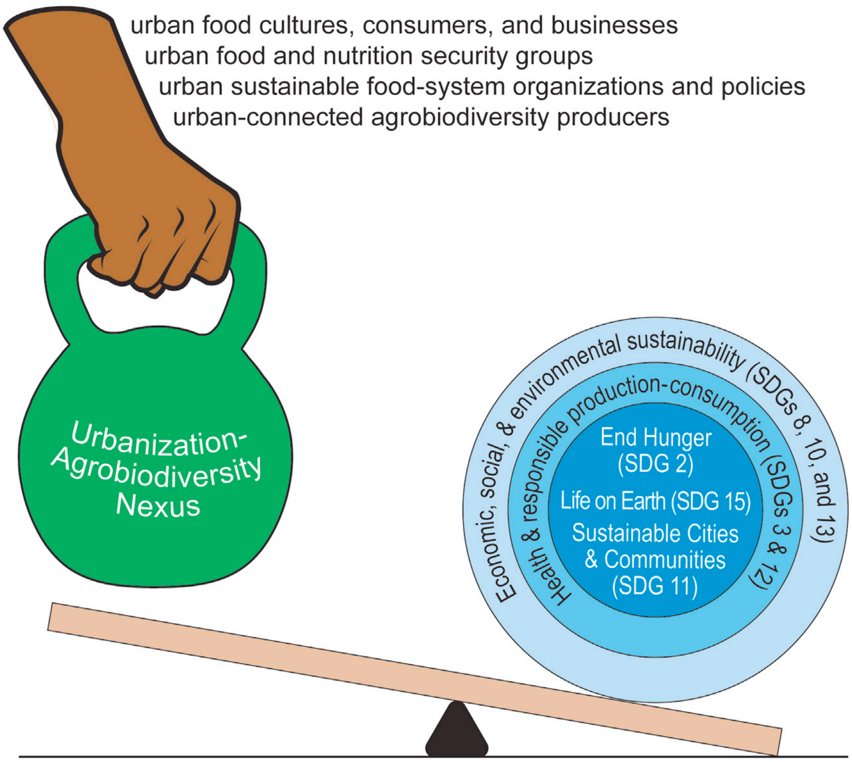


**Figure 1. The urbanization-agrobiodiversity nexus and sustainable development**
Policies advancing several major UN Sustainable Development Goals (SDGs) can be leveraged by new insight into the urbanization-agrobiodiversity nexus. These SDGs include End to Hunger (SDG 2), Sustainable Cities and Communities (SDG 11), and Life on Earth (SDG 15).

sub-component of food biodiversity (Table 1) in powerful, multi-prong linkages with urbanization.[7] Among city "foodprints,"[30] land-use change ranks the highest in case studies employing urban-metabolism methodology.[31,32] Variations in urban food-system impacts include the 8-fold range of the average distance of supply chains (food miles) among cities in India using multiple methods integrating city-level data sources.[33]

Neither agrobiodiversity nor its component food biodiversity has yet been a topic of urban food-system studies. Consequently, introducing the urbanization-agrobiodiversity nexus first features existing, general-level statements and then examines evidence to distinguish the specific contours of major, impactful interactions.

## Existing urbanization-agrobiodiversity assumptions

Two main general assertions linking urbanization and agrobiodiversity appear in the literature: (1) complete or near-full incompatibility or (2) partial compatibility (Table 1). Neither of this pair of urbanization-agrobiodiversity interpretations refers to specific mechanisms, but, rather, each depends on inferences reflecting the concept of the nutrition transition. Formulated using data synthesis, inference, and case studies in China and nationally representative data across world regions,[34,35] this concept encapsulates widespread shifts ("patterns") of diet and health in human societies. The concept's penultimate pattern of degenerative chronic disease is a contrast to its final pattern of greater dietary diversity, including whole grain, fruits, and vegetables.

One root of existing reasoning about urbanization's assumed incompatibility (fourth row, Table 1) traces to early emphasis of the nutrition transition on homogeneous diets.[34] By contrast, later nutrition-transition work highlights that "A range of factors (including *urbanization*, economic growth, technical change, and culture) drives all the changes [i.e., nutrition transitions]" (p. 292; our italics).[35] This later statement anticipates the existing assumption of partial urbanization-agrobiodiversity compatibility (fifth row, Table 1). Augmenting the factors in this quote, food supply chains that are both global and national are notable in nutrition transitions, driving homogeneous diets in the penultimate pattern and then greater dietary diversity in the final pattern.[35,36]

## Major urbanization-agrobiodiversity linkages

The challenge for this perspective is to move beyond broad-brush generalization by identifying main types of urbanization-agrobiodiversity linkages in the multitude of co-occurring interactions (Figure 2). As explained below, our perspective uncovers major urbanization-agrobiodiversity linkages that include food-producing urban and peri-urban land use, urban food chains, food access and foodways of urban populations influenced through socioeconomic capacity and sociocultural valuation, and food retail, infrastructure, institutions, and policy. These linkages are shown to occur across local, national, and international geographic scales. Work in Hanoi, Vietnam, is interspersed to provide examples of these linkages below.

Identification and understanding of these major urbanization-agrobiodiversity linkages are needed to move beyond the unexamined, myth-like assumption of blanket incompatibility and the anecdotal observation of partial compatibility.

## Urban and peri-urban land use

Urban expansion has replaced prime farmland, but displacement is similarly common and provides potential linkages to agrobiodiversity.[37,38] While impacts on agrobiodiversity are not a focus of these comprehensive studies, related research is relevant. The continued extensiveness of urban-fringe croplands has been estimated using remote sensing to cover 67.4 million hectares worldwide,[39] to provide capacity for dynamic food production in numerous cases,[40] and to offer promise for sustainable food systems.[41] Potential sustainability opportunities are illustrated by case studies of new peri-urban spaces containing high agrobiodiversity,[42–44] even in the world's largest cities.[45] Urban and peri-urban agrobiodiversity incorporates diverse species, varieties, and breeds of both local and non-local origins. This agrobiodiversity often contributes accessible foods that

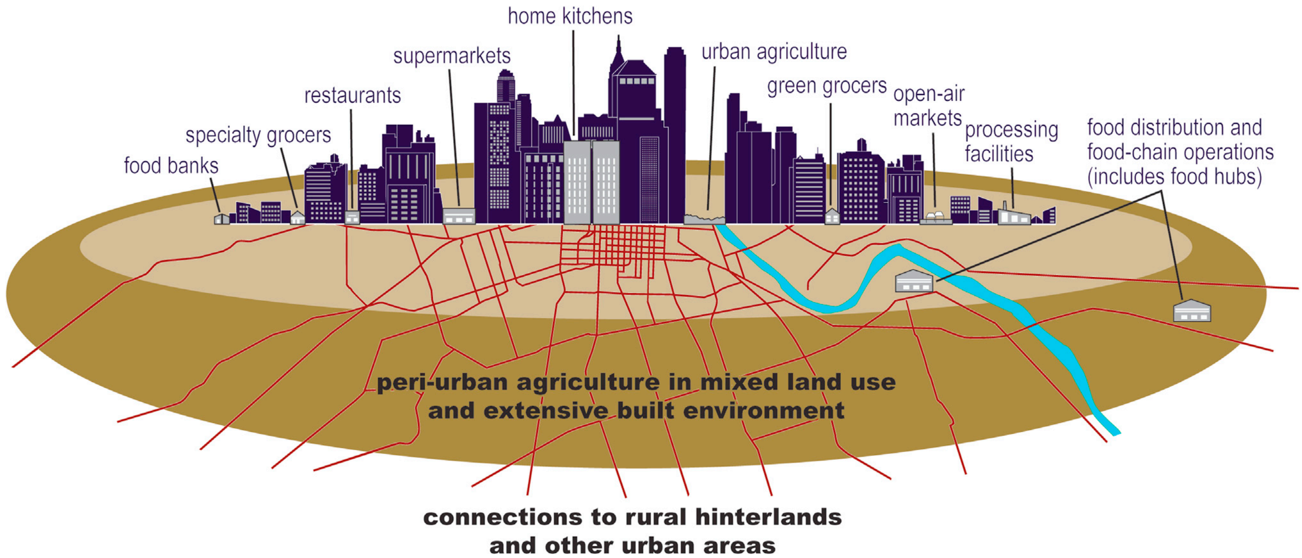


**Figure 2. Idealized cityscape and surroundings with agrobiodiversity networks**
Elements of idealized urban and peri-urban areas illustrate the networks and nodes through which food biodiversity can flow and the spaces where agrobiodiversity may be produced. Key networks include agrobiodiversity connections to rural production and the food-system connections to other cities.

are incorporated in the decisive benefits of urban and peri-urban farms and gardens to nutrition security in cities.[46]

While biodiversity is substantial in urban and peri-urban agriculture based on available studies,[47,48] models estimate this sectors' contribution to overall food production as highly varied among food types and partial overall, even in high-end scenarios. Examples include US metropolitan areas (many capable of local self-sufficiency in eggs and milk but 12% and 16% in fruits and vegetables)[49] and Sydney, Australia (15%–34% of overall food).[50] In Hanoi, government statistics showed combined urban and peri-urban agriculture providing 62%–83% of the vegetables and significant levels of pork and fish consumed in the city (Figure 3).[51] These studies highlight that urban food systems and influences on the urbanization-agrobiodiversity nexus comprise also linkages beyond urban and peri-urban agriculture per se.

## Urban food chains

Supply chains illustrate the complex influences of expanding urbanization on food biodiversity and broader agrobiodiversity in areas that extend well beyond urban and peri-urban spaces per se. For example, medium- and long-distance supply chains fueled by urbanization—including certain fresh fruits and vegetables—enhance the accessibility of food biodiversity and diet diversity, including among the urban poor.[18,19,52] In Hanoi, recent estimates of food biodiversity using household surveys show the importance of both local food chains and national and international sources.[53] These supply-chain studies of consumer-level food biodiversity have yet to assess related impacts on production-level agrobiodiversity (e.g., on-farm diversification).

Multi-scale variations in supply-chain agrobiodiversity, including production-level impacts, can be incorporated into such approaches as sustainable commoditization[54] and sustainable social-ecological food systems.[55,56] With upward of 80% of the food supply often produced domestically (estimated in a cross-regional comparison of countries in Africa, Asia, and Latin America),[57] national supply chains have been shown to drive increasingly standardized and biologically simplified crop and livestock raising,[19] as well as supporting pockets of diversified farming.[58] Even in countries where global food chains predominate nationally,[59] high levels of place-based agrobiodiversity are persisting.[8,60]

## Urban food access and foodways

Food access and cultural foodways, which are influenced by socioeconomic and sociocultural processes of urbanization, comprise a third axis in the urbanization-agrobiodiversity nexus. Food access is tied to food and nutrition insecurity, which in moderate and severe forms currently affects about a third of the global population, including many of the urban poor.[61,62] Their food and nutrition insecurity is typically associated with low dietary diversity. Conversely, high dietary diversity is widely adopted by urbanites with increased resources and food-purchasing capacity,[63] such as the "foodie" culture and population of food-conscious urbanites.[64] Urban processes, such as gentrification (the in-moving of wealthier populations that displace lower-income, often racialized populations), also affect food access[65] and presumably dietary diversity.

Diverse urban sociocultural groups influence agrobiodiversity through food access and foodways that influence food businesses.[66,67] These influences potentially encourage urban food diversification and can stimulate production-level agrobiodiversity in farms and gardens.[68] In Hanoi, cultural influences on agrobiodiversity use vary among the ethnic groups in and near the urban and peri-urban areas (Kinh, Hoa, Muong, and Tay ethnicities). In addition, established urban cuisine and new trends in Hanoi incorporate the valuation of diverse foods and farms. By contrast, the nutrition-insecure population of Hanoi is representative of the predicament of the urban poor globally, having

**Figure 3. Multi-species vegetable growing in urban agriculture**

Agrobiodiversity can be common at the levels of multiple food species as well as varieties in urban and peri-urban farming and gardening. This urban farm in Hanoi, Vietnam, shown in December 2019, relies on multiple vegetable species with agroecological techniques using low chemical inputs to provide safe, high-quality food. Multi-species farming enables year-round production. Photo credit: Karl S. Zimmerer.

reduced access to dietary diversity and food inputs, often reflecting less agrobiodiversity.[69]

### Urban food retail

Urban retailing and infrastructure are a fourth axis of the urbanization-agrobiodiversity nexus, showing both challenges and opportunities for accessible, healthy food to include agrobiodiversity.[70,71] While dizzying brand and packaging differences are obvious, empirical sampling-based research is illuminating quantitative food-biodiversity levels among retail types.[66] Food retail types reflect urbanization's mix of market-driven and governance-guided impacts on the food environment that shape access to and availability of biodiverse food. Moreover, urban planners have detailed the influence on retailing of food environment governance and infrastructure such as transportation, buildings, streets, and walkways.[70] Variations in urban food retailing, ranging from supermarkets to grocers, convenience or corner stores, and formal and informal urban open-air markets, as well as food delivery services, street vendors, restaurants, and other eateries, can lead to higher consumer-ready food biodiversity and potential links to production-level agrobiodiversity.[72–74] Overall, dietary diversity of the residents of Hanoi benefits from major inputs from the full spectrum of these retail types.[53]

### Urbanization-agrobiodiversity policies and stakeholders

National policies complementing city-based and multi-city initiatives are needed to enable urbanization processes favoring biodiversity in food and agriculture, often in combination with additional food-sustainability initiatives.[75] In the case of Vietnam, for example, food-safety governance and policy at national and urban levels are a focus for strengthening agrobiodiversity and sustainability.[76] International policy, including food trade policy, similarly exerts a key influence on agrobiodiversity.[76] Major social movements for food and seed sovereignty, such as Slow Food and Via Campesina, provide pro-agrobiodiversity policy support as well as vibrant, direct support networks in urban areas and food cultures. Additional policy support for agrobiodiversity may come from international initiatives, such as the UN's 2016 Habitat III, as these emphasize urban-rural linkages to drive sustainability.

Finally, coupled feedbacks are integral to urbanization-agrobiodiversity interactions. These include agrobiodiversity's role in urban ecosystem services[31,77,78] and food biodiversity's functions in human diets, nutrition, health, and well-being.[11,13,73] Such feedbacks illustrate the coupled, two-way directionality of the urbanization-agrobiodiversity nexus. It is a distinct complement to unidirectional views in which urbanization is seen as either influencing or being influenced by biodiversity,[4,78] and the latter refers to "wild," off-farm, or non-agricultural biodiversity.

Our focus on linkages in the urbanization-agrobiodiversity challenge is motivated by a need to address the widespread conditions of limited food biodiversity associated with urban poverty and food and nutrition insecurity. We view these conditions as stemming from political economic changes and pressures, including food globalization, trade, industrialization, and agricultural modernization, along with their webs of power, politics, and policies. Food- and nutrition-insecure populations in the Global South and North are often in need of additional dietary diversity—including several of the primary and secondary human foods estimated to exceed 5,000 plant species and 40 animal species[12,14]—since their diets contain increased predominance of inexpensive global staples.[19,69,79]

The challenge to enhance sustainable access to biodiversity in food and agriculture that is both adequate and desirable among poverty-affected urban populations requires recognizing their roles as stakeholders in each key linkage: land use in and near urban areas, urban food supply chains, urban food access and foodways of urban populations (reflecting socioeconomic capacity and sociocultural variation), and urban food retailing, infrastructure, institutions, and policy. Furthermore, these four key linkages of the urbanization-agrobiodiversity challenge are centrally relevant to each of the possible scenarios of sustainable food-system transitions associated with commodity, human rights, and common-good models.[80]

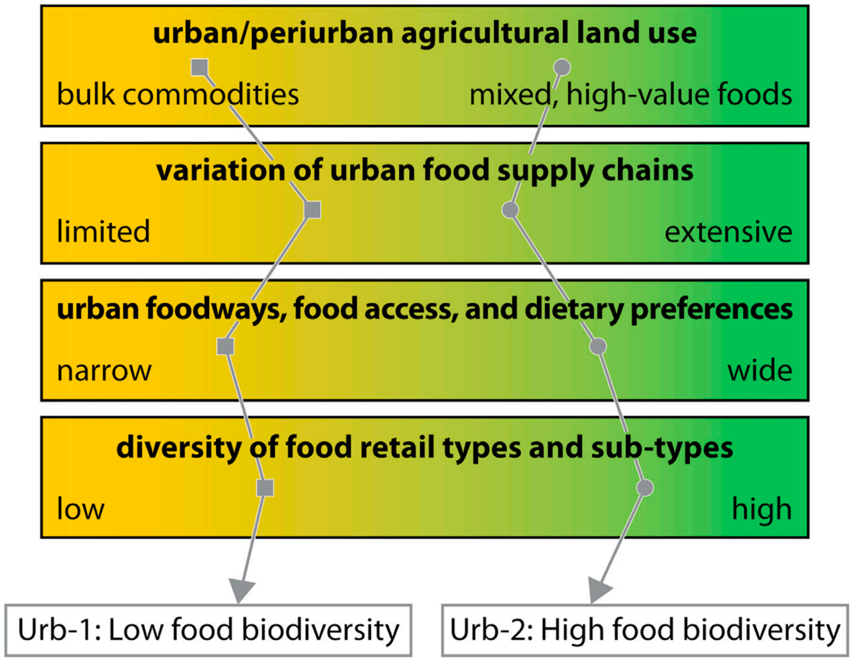


**Figure 4. Major urbanization-agrobiodiversity linkages and urbanization pathways**
Concept map of four major urbanization-agrobiodiversity linkages and a pair of urbanization pathways (Urb-1 and Urb-2). Pathway Urb-1 is characterized as urban and peri-urban land use producing predominantly bulk agricultural commodities with limited variation in food chains and foodways influencing preferences and low variation in food retailing practices. Pathway Urb-2 refers to urbanization involving land use based on high-value and diverse commodities, varied food chains with a broad base of food access and preferences, and varied food retail types and sub-types.

### Visualizing and interpreting urbanization-agrobiodiversity linkages

To offer a preliminary visualization of the major urbanization-agrobiodiversity linkages described above, Figure 4 displays each one in relation to a range of agrobiodiversity levels from lower (left) to higher (right). Distinct urbanization pathways (Urb-1 and Urb-2) suggest how combined characteristics of major linkages can lead to relatively low and high agrobiodiversity. Related, secondary, and less-direct linkages affecting agrobiodiversity include those of food-system processes that transform inputs (e.g., labor, land, water, and nutrients) into outputs, including both consumed food and food waste and resources. Examples of these kinds of food-system linkages occur in labor-intensive water resource use and wastewater recycling in high-agrobiodiversity peri-urban land use (e.g., Hanoi).[51]

Identifying urbanization linkages capable of differentiated, specific impacts on agrobiodiversity, as viewed in Figure 4, is therefore a vital step beyond existing general statements (Table 1). Such statements can unintentionally create the myth-like assumption of generalized incompatibility. We highlight that understanding major, multiple urbanization-agrobiodiversity linkages offers key insights for potential policy. Recognizing these linkages elucidates agrobiodiversity's role as dynamically emergent, rather than static, amid major global changes such as urbanization.[8]

## TOWARD AN URBANIZATION-AGROBIODIVERSITY FRAMEWORK

### Conceptual framework-building

To advance understanding and support of the urbanization-agrobiodiversity nexus we construct a new conceptual framework that builds directly on the above section. It focuses on four predominant urbanization linkages to agrobiodiversity: (1) food-producing land use in urban and peri-urban spaces, (2) urban food supply chains, (3) food access and foodways of urban populations, and (4) the diversity of urban food retail types and sub-types. The development of this conceptual framing can furnish process-specific focal points for urbanization-agrobiodiversity research, policies, and projects at the city, multi-city, national, and international levels.

We describe this framework by constructing a series of hypothesized statements focused on the key urbanization-agrobiodiversity relationships (hypotheses (H) 1–4, Table 2), the underlying assumptions, and the corresponding interdisciplinary research methods for further investigation. Formulation of these hypothesized relationships is motivated by the urgent need to foster supportive urbanization-agrobiodiversity linkages. Each urbanization-agrobiodiversity relationship can be useful to stakeholders in policy making, institutional governance, knowledge communities, business, citizen activism, and rights-based agendas to improve food environments. In addition, each hypothesized urbanization-agrobiodiversity relationship reflects wider political economy impacts on global food systems and is well suited to future research and policy analysis. H1–H4 are thus designed to stimulate research and policy initiatives at urban and local scales as well as national and international levels.

Figure 5 illustrates our conceptual framework and the integration of hypothesized urbanization-agrobiodiversity relationships. The individual linkages with urbanization—shown on the two axes and by the diameter and shading of the graph symbols—are integrated to hypothesize multi-dimensional spaces of concentrated agrobiodiversity (HA1–HA3). Each ellipsoid is associated with the integration of a hypothesized combination of distinct, urbanization-agrobiodiversity relationships.

### Urban and peri-urban land use

The x axis of the conceptual framework (Figure 5) illustrates the range of potential agrobiodiversity levels in urban and peri-urban land use. A spectrum of conditions is assumed in this first linkage (Table 2).[81] Lower values are distinguished by places where one or two bulk agricultural commodities are produced in crop

**Table 2. Hypothesized urbanization-agrobiodiversity linkages (UAL), assumptions, and methods**

| Hypothesized UAL | Assumed processes in the urbanization driver | Assumed agrobiodiversity impact | Methods |
|---|---|---|---|
| (1) Changes in food-producing land use in urban and peri-urban spaces | urban expansion includes physical and resource footprints as well as diversified farming | moderate to high agrobiodiversity in urban and peri-urban agriculture | land-use and resource change analysis integrated with agrobiodiversity science and agroecology applied to diversified farming |
| (2) Urban-directed food supply chains | urbanization drives distinct mixtures of food chains (national, international, local) | certain mixes of food chains result in higher agrobiodiversity | economics, policy, and food-systems analysis of supply chains combined with agrobiodiversity science and agroecology in source areas |
| (3) Food access and foodways of urban populations | urbanization drives demographic and cultural trends that include "foodies," immigrants, and other sub-populations | "foodie" and immigrant groups associated with notably higher food biodiversity | cultural, food-system, and sociological analysis of food practices combined with agrobiodiversity science; these approaches need to focus on access and quality of diverse diets of food- and nutrition-insecure populations |
| (4) Range of urban food retail types and sub-types | urbanization differences lead to distinct food retailing and to influences of surrounding infrastructure (e.g., transport accessibility of food markets) | mix of food market types (e.g., greengrocer prevalence) and infrastructure influences food biodiversity | economics and retail analysis through diverse approaches such as business and infrastructure assessment combined with agrobiodiversity science |

monocultures generally resembling the ecological homogenization of urban residential ecosystems.[82] High values near the opposite end of this spectrum assume diversified crop systems, such as both high-value and subsistence-level crop and animal raising in urban and peri-urban land use. These biodiverse food products can be consumed and marketed locally and regionally as well as through specialized value chains to distant markets.[48,81]

The principal orientation toward local consumption of many urban home and community gardens and farms can foster diversified land use,[83,84] as well as dietary, cultural, and other practices favoring agrobiodiversity.[85] These relations are empirical rather than naively presupposing the "local trap" assumption of inherently sustainable properties.[86]

The urban and peri-urban spaces of food thus potentially support important agrobiodiversity. Research synthesis shows that overall biodiversity levels tend to benefit urban and peri-urban agriculture, with agrobiodiversity variation dependent on contextual factors such as environmental, socioeconomic, and cultural geographic factors.[41,87] Agrobiodiversity in urban and peri-urban land use is a leverage point that can be incorporated in spatial demand-production analysis being used to strengthen policies for sustainable urban and regional food systems. Moreover, initiatives such as the City Region Food System approach suggest leveraging urban food biodiversity for food- and nutrition-insecure populations in planning sustainable development.[29,88]

## Urban food chains

The diameters of the graph symbols characterize the geographic parameter of food supply chains (short, medium, and long distance). Urban food chains reflect innovations such as the supermarket, cold storage, and processed-food transformations[89] and others in the "hidden middle" of food distribution and processing,[90] in addition to local food system initiatives.[48,81] Geographically distinct food chains, which include short or local, medium or national, and long distance, including international, are hypothesized to contribute relatively higher agrobiodiversity as reflected in HA1–HA3. Leveraging supply-chain linkages is increasingly a focus of academic and applied research to advance agri-food sustainability[54] and strengthen sustainable development.[91] Dozens of existing examples of supply-chain initiatives focusing on agri-food sustainability can be characterized as works in progress.[92] Several such initiatives are potentially well suited to incorporate both food biodiversity and production-level agrobiodiversity to foster broad-based sustainability.

As countries increasingly produce a small coterie of globally common crops,[19,77] the impacts of this standardization on biodiversity in food and agriculture are still unfolding. Impacts need to be estimated and compared between predominant national-level food supply versus local and global food chains.[53,54] This focus can help determine whether and how high levels of local and national agrobiodiversity can persist in a country such as Peru, where food imports exceed 50%,[93] yet spaces of local high agrobiodiversity persist.[8] Here the framework encompasses the complexities of multiple food chains and their interactions, thus again avoiding the "local trap" assumption of short food chains as inherently superior, singularly adequate, or stand-alone phenomena.

The supply-chain dimension urges consideration of leverage points in trade and food policy supporting agrobiodiversity and allied agroecological and social sustainability. For example, research is needed on the agrobiodiversity impacts of multiple food chains for quinoa and teff that add to dietary diversity in European and US cities but may reduce urban food biodiversity access of low-income consumers in producing countries and lessen overall agrobiodiversity.[94]

Domestic food chains are often overlooked as a key to leveraging in-country sustainability. In the United States, for example, consumers in San Francisco can be coupled to agrobiodiverse food producers in Montana via linked food chains.[58]

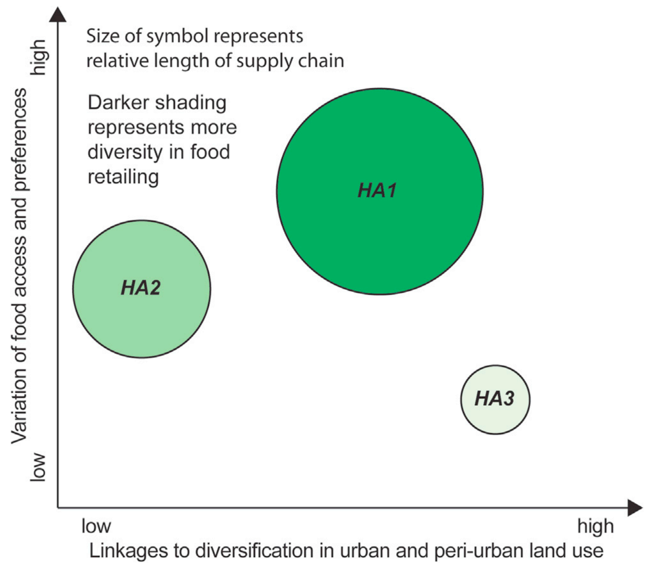


**Figure 5. Conceptual framework of urbanization-agrobiodiversity linkages**
This framework illustrates the integration of hypothesized spaces where distinct combinations of urbanization-agrobiodiversity links result in high-agrobiodiversity outcomes (HA1–HA3) corresponding to parameters on the two axes along with the size and shading of circle symbols (see text for details).

Policies promoting sustainability-enhancing agrobiodiversity of the national food supply—and going beyond sustainability assumed as strictly local—must be integrated with the realities of many countries relying on the health-benefitting, long-distance sourcing of seasonal fresh fruit and vegetables.[52] Other prospects for leveraging sustainability can benefit from the biodiversity of non-staple foods being supported through public- and private-sector investments that are attentive to the distribution of socio-economic benefits.[15,95] In sum, the full spectrum of urban-directed global, national, and regional-local food chains needs to be evaluated regarding biodiversity in food and agriculture.

### Urban food access and foodways

The y axis of Figure 5 displays hypothesized interactions of the food access and foodways among urban populations with edible biodiversity and, by extension, the agrobiodiversity of food-production spaces. Rapid urbanization influencing socioeconomic capacities, education and information factors (e.g., advertising), and sociocultural variation (e.g., identities) affects food practices and preferences in ways that shape food-biodiversity consumption. Certain urban groups, such as "foodies," may value diverse foods (Table 2) that hypothetically are associated with relatively high agrobiodiversity (HA1). A second hypothesized high-agrobiodiversity concentration entails the food of socioculturally varied communities (HA2; Table 2). For example, immigrant communities and populations with varied cultural foodways exert wide-ranging food preferences that can favor higher agrobiodiversity.[96] Policies to assist poorer, food-insecure urban populations can be leveraged to ensure food access incorporating biodiversity without requiring high income levels (e.g., 2015 Milan Urban Food Policy Pact, 2019 Food Policy for Canada).[97]

### Urban food retail

Urban retailing exerts hypothesized impacts shown by symbol shading in Figure 5. For instance, a sample of 446 produce items among retailers in Lansing, Michigan, was used to classify and illustrate the roles of five retail types contributing to this diversity (supermarket, grocer, convenience store, ethnic food specialist, and organic grocer).[66] These results reflect how cities are associated with distinct food-retailer portfolios.[65] This hypothesis assumes that the variation in retailing types and sub-types influences food biodiversity, with local retail networks, such as farmers' markets, providing relatively high food biodiversity (HA3; Table 2). It reflects how retail food biodiversity bears an open-ended relation to on-farm agrobiodiversity that requires empirical research rather than simplistic assumptions.

The variation in food retailing reflects factors in the built environment, infrastructure, and governance, such as the design of transportation (including pedestrian accessibility),[98] buildings, streets, and walkways. These are vital factors in enhancing the urban food environment, facilitating healthy and diverse eating.[70,99] Policies can leverage the influences of retail types and sub-types supporting urban food biodiversity and, by extension, the agrobiodiversity and sustainability of linked production environments.

### New technologies and research methods

New technologies promise research insights into the urbanization-agrobiodiversity nexus, as well as into policy and broad public applications. Recognizing widespread reductions in agrobiodiversity through the bias of dominant technological trajectories to date is as vital as investigating potentially complex new technological impacts (e.g., conservation tillage). Certain new technologies can add valuable research methods. For instance, spatial data offer unprecedented availability of information on land use. Similarly, the capacity to trace food supply chains is mushrooming through blockchain and internet of things (IoT)-enabled technologies.[100] These technologies create the potential for accessible information that can trace and compare food biodiversity through food systems from production to consumption. Purchases of retail items identified by the Universal Product Code (UPC)[101] can be geo-tagged for estimating food biodiversity.

Food data gathered through crowdsourcing and web-scraping techniques are also potentially promising as integrative approaches involving food biodiversity and geographic information corresponding to urban spaces. Cities themselves and partnering institutions will play key roles in advancing these approaches. For example, realizing the need to support and monitor the food retail and supply-chain linkages of urban centers and surrounding areas, the FAO has promoted the City Region Food Systems toolkit, which includes agrobiodiversity in general and food biodiversity specifically.[29,88] A prospective evaluation and monitoring tool, termed the Agrobiodiversity Index,[14] is designed for other stakeholder clients, although its usefulness might be adapted for urban areas and sectors such as consumers, businesses, policy makers, food activists, and others.

Finally, our conceptual framework counsels that testing and leveraging hypothesized relationships will now require developing and applying measures of urbanization and corresponding

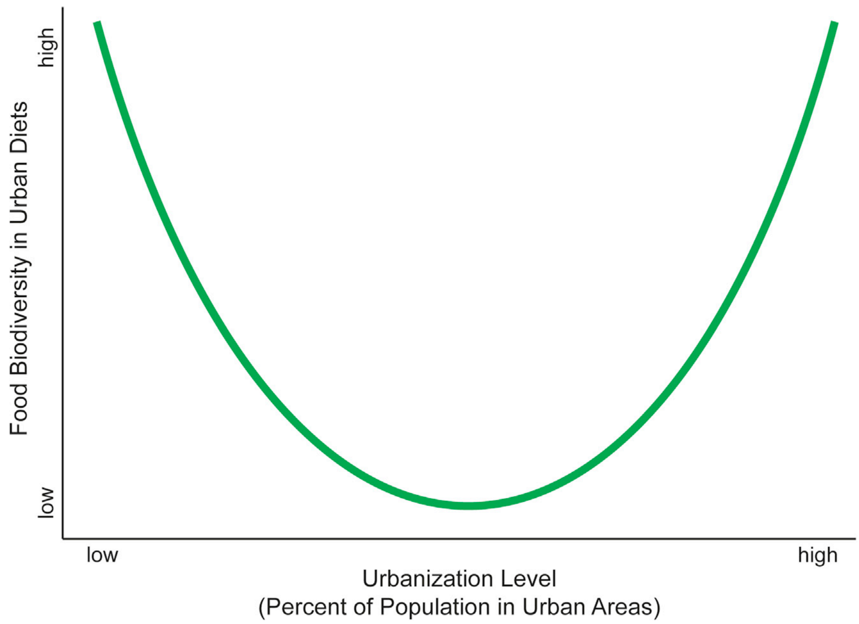


**Figure 6. Hypothesized relationship of food biodiversity to urbanization**
The U-shaped urbanization-food biodiversity curve hypothesizes the correspondence of food biodiversity (frequency in diets; y axis) to degrees of urbanization (percentage urban population; x axis) and anticipates similarity to the Environmental Kuznets Curve.

agrobiodiversity. This next advance is among the crucial steps that we envision as vital to future research, synopsized in the next section.

## URBANIZATION, AGROBIODIVERSITY, SUSTAINABLE DEVELOPMENT

### Insight and implications

Novel insight and broader implications of this perspective on the urbanization-agrobiodiversity nexus can leverage new policies for sustainability with particular emphasis on sustainable development. Our interdisciplinary integration of urbanization, agrobiodiversity, economics, food-system, and land-use analysis highlights a triad of broad implications that summarize general claims and guide new research.

First, the conceptual framework of major linkages of the urbanization-agrobiodiversity nexus is broadly formulated and integrative, yet sufficiently specific to elucidate a new perspective. It highlights that agrobiodiversity levels vary depending on the conditions of each linkage. Second, the framework of four linkages provides a perspective on combined urbanization processes associated with agrobiodiversity variation that can help to eclipse the myth-type assumption of blanket-type incompatibility as well as the impressionistic notion of partial compatibility. A third broad implication is that urbanization creates dynamic, ongoing interactions with agrobiodiversity—including emergent agrobiodiversity relations in current urban food systems—rather than serving as a uniformly destructive force.

### Broad urbanization-agrobiodiversity synthesis

A further broad implication takes the form of a meta-level synthesis hypothesizing the correspondence, shown in Figure 6, of food biodiversity (frequency in diets; y axis) to degrees of urbanization (percentage urban population; x axis). Higher food biodiversity and the potential for a broad spectrum of agrobiodiversity benefits are hypothesized to occur among populations that are both less- and more-urbanized. This broader implication suggests the potential role of a U-shape urbanization-food biodiversity curve anticipating similarity to the Environmental Kuznets Curve.[102]

The left side of the U-shaped curve in Figure 6 is anticipated to consist of biodiversity in urban food inputs produced largely in regional and local landscapes.[103] Reduced food-biodiversity frequency is marked by simplified diets that comprise the well of the U-shaped curve presumed to reflect low-agrobiodiversity, cheap-food commoditization.[54] Raising this inflection point can be leveraged by strengthening food biodiversity among the urban poor as food- and nutrition-insecure populations.[69] The curve's right side would reflect the increased frequency of food biodiversity (sourced nationally, globally, and locally) representing improved access and product differentiation.[52] This broader implication is intended to suggest a potential national or regional model that can then be adjusted for key contextual factors such as urban populations and sub-populations.[102]

This further implication conveys a time-based dimension where sustainable development policies can aim to "flatten the curve upward" as regards urbanization interactions with biodiversity in food and agriculture. Local food sourcing typically becomes less important in mid-stage urbanization and then potentially resumes as cities gain larger groups of middle- and high-income populations with demand for diet diversity corresponding to rising incomes. As cities grow larger (usually correlated with the national urban share), supply chains lengthen. Transport-adapted and shelf-stable products start to dominate. Moreover, local production is no longer sufficient to feed the now-larger city, while consumer demand is concentrated on bulk cheap food. This trajectory, which has been well documented for seafood commoditization,[54] poses a broad implication well suited to further examination.

### Immediate next research steps

Future research steps on the hypothesized urbanization-agrobiodiversity relationships—in both the detailed formulations of the previous section on hypothesized high-agrobiodiversity spaces (HA1–HA3; Figure 4) and the potential broad implications of the U-shaped curve—will require the development of methods to measure urbanization and agrobiodiversity levels. Multidimensional measures must incorporate demographic household structure, urban form, food access, production, and agricultural land. Similarly, estimating techniques will need to distinguish food biodiversity and ecosystem-level agrobiodiversity across multiple functional, taxonomic, and spatial levels as well as spatial scales. Agrobiodiversity, food-system, and agroecology specialists are increasingly creating relevant estimates that will be useful in this research.[10,12,14,79,104,105]

These next research steps will enable the construction of estimated agrobiodiversity levels (including the food biodiversity component) that correlate with specific typologies of urban areas and neighborhoods and of urbanization linkages to rural spaces. These steps can focus research on individual urbanization-agrobiodiversity linkages, such as specified above, as well as combined linkages characteristic of individual cities or city types.

Developing research methods and designing further conceptual advances in the urbanization-agrobiodiversity nexus will require expansive interdisciplinary collaborations. Based on our collaborative activities to date, we anticipate that fields such as urban, food-system, and land-use studies and planning; economics; geography; policy analysis; and public health will need to identify the diverse interactions and leverage points of urbanization-agrobiodiversity dynamics. Biodiversity, agroecological, nutrition, and health sciences will be required to assess the actual variation in foods as well as this biodiversity's functioning. Case studies, comparative designs, and data synthesis can be geared to distinct spatial units and conditions with corresponding estimates of food biodiversity or other components of agrobiodiversity.

### Broader next steps

Promising next steps extend beyond the themes noted above. Specific examples include additional urbanization-agrobiodiversity linkages, detailed within-linkage dynamics, and examination of how each linkage corresponds to planning and policy for food-system sustainability and sustainable development. For instance, the change and variation in the food-trade partners of an urban area and its food supply chains have been found to determine the level of urban food resilience.[105] This additional linkage with urbanization could potentially affect both immediate food biodiversity and the agrobiodiversity of supply-chain-linked production spaces.

Finally, this perspective highlights that numerous related next steps are already being undertaken by urban food access, food quality, and food-rights-supporting groups and organizations advancing food and nutrition security; agrobiodiversity producers and food-chain entrepreneurs; and allied practitioners, policy makers, activists, innovators, and businesses. Our research and analysis are motivated by understanding and learning how to strengthen their activities where the urbanization-agrobiodiversity nexus can be leveraged to promote sustainable development. These individuals and groups are primary innovators with whom researchers will need to collaborate and partner in future projects. Such broad-span, highly interdisciplinary teams connect researchers with diverse stakeholder, practitioner, and policy groups, and thus can powerfully engage the urbanization-agrobiodiversity nexus to strengthen food-system sustainability and sustainable development.

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## AUTHOR CONTRIBUTIONS

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## DECLARATION OF INTERESTS

The authors declare no competing interests.

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