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Integrating Agrobiodiversity Knowledge for a Sustainable Future

Karl S. Zimmerer, Stef de Haan, and Julia R. Lupp

Introduction

If humanity is to achieve sustainable food systems in the twenty-first century, it must confront, comprehend, and respond to myriad interactions that transpire over time and across multiple scales. This requires us not only to recognize the individual elements and actors involved, but to understand the mechanisms that operate within and between the resulting interactions, the significance of how they are linked, and the competing interests and systemic tensions that exist and continue to emerge.

To meet this challenge, research and activities into the processes that impact agrobiodiversity have grown in importance over the last few decades. Given the wide-ranging scope of work, integrating knowledge from the distinct disciplines and fields of expertise has proven difficult. This Ernst Strüngmann Forum was convened to advance this process.

Dedicated to the expansion of knowledge in basic science, the Ernst Strüngmann Forum invites experts to partner with it to address problem areas confronted in research. It creates dialogues between multiple experts that are best likened to intellectual retreats—carefully crafted forms of interaction that promote synergy between diverse areas of science. The resulting, extended discourse serves to identify knowledge gaps, to explore novel ways of conceptualizing pressing issues, and to delineate trajectories for future research.

The dialogue on agrobiodiversity began when Karl Zimmerer and Stef de Haan approached Julia Lupp to discuss the possibility of putting together a Forum "to develop a new integrated scientific framework for understanding and advancing the current and future roles of agrobiodiversity in land use and food systems of the twenty-first century" (Zimmerer and de Haan, unpublished). Together they developed the initial proposal for formal submission to

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the Forum's Scientific Advisory Board. After a process of review and approval, Conny Almekinders, Stephen Brush, Timothy Johns, and Yves Vigouroux joined Zimmerer, de Haan, and Lupp on the Program Advisory Committee to refine the proposal and expand the primary goals for the Forum:

- To examine the linkages among key areas in agrobiodiversity
- To consolidate and advance the multidisciplinary foundations of science and scholarship needed in agrobiodiversity
- To develop an integrated scientific framework that will guide future work on sustainable food systems amid global change

To achieve these goals, the Ernst Strüngmann Forum invited experts from agriculture, agronomy, plant and animal breeding, anthropology, ecology, food systems and nutrition, geography, plant and biological sciences including genetics, political science, law, and sociology to attend the 24th Ernst Strüngmann Forum on "Agrobiodiversity in the 21st Century: Foundations and Integration for Sustainability." Working groups addressed the following themes:

- Group 1: Evolutionary ecology of genetic components, crop and livestock functions, and agroecology
- Group 2: Governance, including cultural and policy frameworks, at different geospatial scales
- Group 3: Whole-system approach to human health, nutrition, and disease
- Group 4: Socioecological interactions amid global change

Specific topics were introduced in advance through invited papers, and questions were proposed by the committee to initiate discussion at the Forum. With both as a backdrop, each group identified additional areas of inquiry, prioritized topics, and generated a discussion agenda. Interactions within and between the groups enabled a cross-fertilization of perspectives and ideas. Throughout, consensus was neither forced nor did preexisting biases or ideas drive the process. Instead, existing viewpoints were challenged and knowledge gaps exposed. The expansive discussions that resulted have been captured in "reports" (see Chapters 2, 6, 9, and 14).

This introductory chapter summarizes the individual chapters contained in this volume as well as the key outcomes from the Forum. Of particular note is the development of an integrated scientific framework—the response to the third goal—that emerged from the discourse. This framework is presented below to provide a way of conceptualizing the complexities surrounding agrobiodiversity, to support the integration of further knowledge, and to guide future research, scholarship, policy, and practice. In conclusion, we reflect on what lies ahead and issue a call for collective action: If sustainable food systems are to be achieved, new ideas need to be set into motion, with the requisite sensitivity to diverse interests and systemic tensions, informed by an integrated knowledge base.

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The Dynamic Nature of Agrobiodiversity

Over the last century, crop genetic resources have declined significantly. In China, only 10% of the 10,000 varieties of wheat recorded in 1949 are now produced, and in the United States, more than 95% of the apple varieties known in 1900 are no longer harvested (Gepts 2006). Crop diversity plays an important role in food security amid a changeable environment and the urgent need for improved nutritional security, socioeconomic well-being, health, etc., and concerted action is needed immediately. Due to the diverse pressures that combine to cause loss or changes in range distribution, actions must be based on an integrated knowledge base that reflects the various actors and systems involved.

Broadly defined as the variation of crops and livestock in agriculture and food systems that result from and include heterogeneous (e.g., economic, ecological, institutional, sociocultural, and technological) factors, the concept of agrobiodiversity embodies dynamic processes between humans and nature on multiple organizational levels and spatial scales. It is simultaneously social and biological by nature, applicable to microbiomes, genes, species, habitats, and landscapes as well as to the historical, cultural, and social dimensions that frame the continuously evolving interactions between people and their environments. Utilizing a broad definition of agrobiodiversity enables us to integrate familiar biology, conservation, and ecology-centered meanings (e.g., CBD 2000; FAO 1999a; Jackson et al. 2007; Perrings et al. 2006) with sociocultural systems. It also presupposes the inclusion of new knowledge that may emerge as a result of pressures from globalization, global environmental change, or varied economic and sociocultural valuation. Implicit in this broad definition are three key areas.

The first refers to the *biodiversity* that is rooted in biology, genetics, and related fields of knowledge (e.g., taxonomy, conservation biology): organisms and communities (e.g., crops, vertebrates, trees, fish, insects, fungi, and other cultivated organisms) that pertain to domesticated and semidomesticated plants, wild biota used for food and health (Jacobsen et al. 2015; Reyes-García et al. 2006; Vandermeer et al. 1998), livestock, and the wild relatives of domesticates. This biodiversity must be understood across a spectrum of organismal groups and systems (Gepts et al. 2012), including

- alleles, genes, genomes, and microbiomes embedded in or constituting the actual domesticates and their wild relatives;
- crop and livestock varieties, landraces, breeds and or races that humans have historically selected and continue to create at the intraspecific level through traditional or modern practices;
- cultivated crop and livestock species that humans have domesticated through direct and indirect selection as well as the (un)conscious past and ongoing domestication of wild candidate flora and fauna; and

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- crop and livestock wild relative (sub)species, including primary, secondary, and tertiary gene pools.

The second pertains to *interactions within and among habitats* that affect biodiversity (e.g., fields, farms, ecosystems, landscapes) (FAO 1999a). Many of the biological elements of such interactions, termed "associated agrobiodiversity" by Vandermeer et al. (1998), are extremely important to the functionality of agrobiodiversity and involve

- beneficial and nonbeneficial (micro)organisms (e.g., insects, arachnids, bacteria, fungi, viruses, and nematodes) associated with domesticates and farming systems;
- wide-ranging environments that are developed and managed by humans as diverse food systems: fish-, fungi- and insect-raising schemes; forestry, crop, and livestock agroecosystems; and a broad spectrum of farming ranging from swidden cultivation with extensive wild plant collecting to modern greenhouse hydroponics; and
- agricultural, pastoral, and forestry landscapes that contain the abovementioned subsystems and traverse geographic spaces: from rural and peri-urban spaces to cities.

The third key area relates to the *human dimension of sociocultural relations* that affect and are integral to biological diversity in agriculture. This includes farm management, diverse belief and knowledge systems, cultural factors, collective processes such as seed exchange, and tourism associated with agricultural landscapes. Without these elements, biological and ecological subsystems of agrobiodiversity would not be able to exist or coevolve (Bellon et al. 2017; Brush 2000). In addition, variability in human resource management, skills, and knowledge is integral (Almekinders et al. 1995).

To support the integration of knowledge and areas of expertise, this volume embraces this broad definition of agrobiodiversity and holds that an inclusive view is imperative if diverse perspectives are to be incorporated to create greater understanding of the complexities inherent in agrobiodiversity. As knowledge is integrated, we should also be aware of the implicit use of knowledge systems as conceptual boundary objects. One example of a boundary object (Clark et al. 2016) would be the link created between the knowledge system of a particular group (e.g., scientists, resource management institutions, or NGOs) and the knowledge systems and practices of others (e.g., Indigenous, farmers, consumer groups). The objects and concepts that result from such connections constitute the "boundary" where communication occurs between different knowledge communities (Cash et al. 2003). The utilization of agrobiodiversity as a conceptual boundary object (Zimmerer 2015b) is thus relevant to the broad integration undertaken in this volume.

The individual chapters in this volume address wide-ranging issues related to environmental and socioeconomic changes, human nutrition, health, and

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governance, including policy, cultural, and economic practices. Below, the foci of the working groups are described, starting with the initial questions that were considered by the groups. An overview of the individual chapters follows, along with a summary of the key messages that emerged from the discussions.

Evolutionary Ecology, Agroecology, Conservation, and Cultural Interactions

- What are the complex genetic, evolutionary, and ecological interactions that underpin *in situ* conservation based on the continued cultivation of diversity in agroecosystems?
- How does the ongoing evolution of diversity, as practiced by individual farmers, function as an emergent adaptive mechanism in response to environmental change?
- What is the potential complementarity of *ex situ* and *in situ* approaches to genetic resources and how can this complementarity be strengthened?

Both natural and human factors cause agricultural systems to change. For millennia, humanity has relied on crops and biota that are semidomesticated and wild for the purposes of food, fiber, medicine, and fuel production. This reliance, in turn, has played a major role in shaping agrobiodiversity over time. Biotic and abiotic factors also impact agrobiodiversity, as do other organisms (e.g., pollinators, soil fauna, wild relatives). Understanding the interactions between crops and their wild relatives may reveal additional selection pressures at work across a range of ecosystems. Further, the phenotypic traits that crops express may help to clarify the ongoing process of crop evolution and domestication.

In their discussions, which aimed at understanding the genetic and functional dimensions of agrobiodiversity and associated knowledge, Kristin L. Mercer et al. (Chapter 2) stress that crop evolutionary agroecology must be viewed as a combined product of historical factors, local knowledge systems, and varied interactions with human society and associated biodiversity. Since each of these factors is affected by social and global change, the state of agrobiodiversity in any given environment must be considered to be in a state of flux. To gain a greater understanding of this complex, dynamic system, Mercer et al. propose research agendas to address the following areas:

- Quantify crop diversity and farmer knowledge that currently exist on the landscape to discern a baseline from which to understand future change.
- Increase understanding of the historical, evolutionary, and ecological factors that have led to current agrobiodiversity.
- Increase understanding of the drivers and effects of interactions between crops and their associated agrobiodiversity.

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- Clarify the role of *in situ* conservation in farmers' fields and explore how *ex situ* collections can be better linked to *in situ* use of agrobiodiversity.
- Generate a theory of agrobiodiversity and project trajectories of agrobiodiversity capable of responding to social and environmental change.

To extend our understanding of how agrobiodiversity has evolved, population genetics can assume an important role. As discussed by Yves Vigouroux et al. (Chapter 3), population genetics offers the possibility of high-resolution, precise data as well as a robust way of monitoring spatial and temporal changes in crop–livestock populations through its ability to delineate trajectories of allele frequencies within and between given populations. Vigouroux et al. recognize that additional dimensions (e.g., space, time, stress, drivers, conservation approaches, biosystematic scale) are needed as well, and emphasize the importance of utilizing an integrated, multidisciplinary approach. They suggest that advances in modeling and the use of genomic markers present novel opportunities to evaluate, test, and increase our understanding of agrobiodiversity.

In Chapter 4, Steven J. Vanek discusses how crop and varietal diversity impacts the functioning and resilience of agroecosystems. He assesses impacts from pollination services, pests and disease, soil biota and soil nutrient cycling, as well as abiotic stress resistance. Vanek highlights the distinction between production characteristics related to plant phenotypes (provisioning services of ecosystems) and functional traits that support ecosystem services (supporting services of ecosystems), including the tendency toward trade-offs and the need to reconcile these to achieve resilience. He describes how these production and supporting services are linked to broader social and economic contexts and ecosystem resilience, and lists a number of questions to direct future efforts.

In Chapter 5, Nora P. Castañeda-Álvarez et al. characterize the processes that inhibit crop diversity and may lead to genetic erosion in crop resources. To mitigate the risk of loss, they suggest that *in situ* and *ex situ* conservation can be used in complementary ways. To predict possible changes in agrobiodiversity in the future, spatial analysis can assist both approaches and inform conservation action. Data availability, completeness, and quality are needed to secure effective spatial analysis of crop diversity. Castañeda-Álvarez et al. emphasize the role that modeling can play in assessing future responses to human and environmental events (e.g., floods, drought, variable rainfalls, land-use changes). Ultimately, the challenge is to expand spatial analyses and turn patterns of crop diversity into models that can explain how crop diversity is affected (positively or negatively) by different drivers and change scenarios.

Key messages that emerged are summarized as follows:

- Integrating *ex situ* and *in situ* approaches will strengthen knowledge of global genetic resources conservation, but has not yet been realized. Baseline quantification and characterization of agrobiodiversity and farmer knowledge is needed at different scales to track systematically and understand trajectories of change (Chapter 3). Regular gap analysis,

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timeline comparison, registration of unique diversity in both systems, and gap filling (*in situ* to *ex situ*) or redeployment (*ex situ* to *in situ*) are among the mechanisms available to link approaches (Chapter 5).

- Ecosystem-, organism-, and trait-level functionalities and services from agrobiodiversity need to be more systematically documented, evaluated, and valued. These functionalities and services (e.g., ongoing evolution, adaptive capacity, nutrient provision, yield stability, pest and disease regulation, relationships to cultural management practices) need to be better understood in different contexts and at multiple scales (Chapters 2, 4, and 10).
- Trajectories of past and future social and environmental change require information from geospatial and temporal scales to be fully integrated. To make predictions, a wider range of modeling approaches needs to be implemented. The scientific advancement and expanding tools offered by genomics and microbiomics provide multiple ways to unravel evolutionary pathways in response to cultural, migratory, environment, and management interactions (including climate change). Advances in modeling population genetics enable the testing of original hypotheses about the drivers that shape crop and livestock biodiversity (Chapters 2 and 3).
- The importance of culture and ethnicity in understanding processes involving selection, ongoing *in situ* conservation, and biogeographic distribution requires significantly more attention in agrobiodiversity science. The codistribution between farmers' cultural and crop–livestock genetic diversity has been described at different scales. Various expressions of culture and ethnicity, including different food systems and trait preferences, are recognized as persistent drivers of smallholder agrobiodiversity management. Nevertheless, integrative ethnographic, gender, and consumer behavioral research that would enable an analysis of the social processes underlying agrobiodiversity selection, (de) diversification, and migration is sparse compared to solely biological enquiries (Chapters 2 and 3).

Global Change and Socioecological Interactions

- How do agrobiodiversity use and conservation link to globally significant trends of urbanization and migration characteristic of high-agrobiodiversity regions?
- How do use (conservation) and disuse (genetic erosion) of agrobiodiversity intersect with the intensification of land use and food systems?
- What is included in agrobiodiversity beyond seeds (e.g., cultural and knowledge systems, consumer interest, cultural identities)?
- What are the driving values and visions?
- What are the prospects for intentional agrobiodiversity?
- How do key institutions constrain/facilitate adaptation to change?

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In their discussions on socioecological interactions amid global change, Conny Almekinders et al. (Chapter 6) explore how agrobiodiversity has been used to improve human well-being under dynamic conditions by diverse groups and institutions. Their examination of different users (e.g., producers, consumers, and institutions) demonstrates how global change has impacted each group at the local level. In reviewing user responses, they found interesting instances where novel initiatives have been generated to link user groups and institutions, thus creating new collaborations and configurations diverse in nature, space, and scale. Such initiatives, Almekinders et al. propose, provide compelling evidence that socioecological interactions involved in agrobiodiversity can be positive and lead to increased human well-being amid global change. As efforts continue to resolve the many challenges posed by global change, this perspective holds promise that production and consumption can find complementary ways to interact.

In the conceptualization of interactions between climate and agrobiodiversity, it is important to recognize that different framings affect the types of questions addressed as well as the problem-solving approaches attempted. In Chapter 7, Jacob van Etten reviews how different scientific disciplines use distinct framings to explain these interactions and base their actions. Archaeological and environmental studies, for example, frame climate–agrobiodiversity interactions as part of a historical coevolutionary process, whereas agricultural and climate sciences focus more on genotype–environment interactions and diversification. Agrobiodiversity becomes critically important when agricultural development is framed as the central engine of economic growth to counteract loss due to climate change. Given the systemic nature, uncertainty, and intrinsic human values associated with climate change and agrobiodiversity management, van Etten stresses the need for integrated scientific approaches to address these complexities explicitly and to accommodate opposing sets of values.

In Chapter 8, Karl S. Zimmerer and Judith A. Carney review models and empirical studies that link demographic and spatial changes to socioecological interactions that involve agrobiodiversity at different spatial and temporal scales. Understanding the drivers of these global changes (e.g., human population changes, urbanization, economic and cultural globalization, spatial planning, food security, food sovereignty, historical, cultural, and social network considerations) is crucial as they shape agrobiodiversity outcomes. Zimmerer and Carney view engagement with policy communities as a high priority and recommend that researchers and organizations partner together to ensure that policy is informed by scientific analyses and scholarly understanding. They point out, however, that expanding the understandings of the varied processes involved in agrobiodiversity change will increase the complexity of research. Thus, they recommend that conceptual frameworks be developed to address this complexity and recommend promising areas for future research.

Key messages that emerged from this group are as follows:

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- Global agricultural intensification has not resulted in a full-fledged wipeout of agrobiodiversity, yet the continued, predominant focus of the "new Green Revolutions" on efficiency and uniformity has severely limited the utilization of agrobiodiversity. The extent of agrobiodiversity in the farms and foods of smallholder and Indigenous farmers is more resilient and consistently conserved than many scientists predicted several decades ago. Farmers around the world continue to manage landraces and traditional breeds. In many areas, partial displacement or complete replacement of agrobiodiversity production and consumption has occurred. Nonetheless, farmers have found the means to adjust and incorporate agrobiodiversity into intensified food systems. Still, new initiatives for agricultural intensification, exemplified by the so-called New Green Revolution, the Next Green Revolution, and the initiative known as Alliance for a Green Revolution in Africa, continue to rely on a limited number of crop species and a few widely adapted varieties (Chapters 6 and 8).
- The globalization of the food industry and trade has made global food supply chains increasingly uniform, leading to increasingly standardized diets in terms of species and varietal usage. The worldwide spread of a "standard globalized diet"—one that is highly industrialized and often subsidized—is making cheap food increasingly accessible at the expense of the cultivation and consumption of local and regional agrobiodiversity. This, in turn, has fueled major global movements and alternative food systems concerned with food, health, and nutritional awareness as well as organizations that recognize the essential role of agrobiodiversity, local food culture, and inclusive value chains. Researching the interactions of these systems is important (Chapter 8).
- As a major driver of global change, urbanization poses both challenges and opportunities for agrobiodiversity, its producers, and consumers. Most people reside and work in urban areas, and the majority of global gross domestic product is produced in these spaces. Research into future agrobiodiversity use and conservation related to urbanization is needed to understand the complex interactions that exist and the potentially positive impacts that might be derived from feedback loops (Chapters 6 and 8).
- Climate change is another major global driver, one expected to exert both negative and positive selection pressures on agrobiodiversity. Deleterious impacts of global climate change are predicted to occur where the natural habitats of crop wild relatives and crop agroecologies impede viable ecological range displacement. Impacts from extreme weather, crop pests, and disease pose additional threats. Local environmental knowledge systems may also erode amid a rapidly changing environment (Chapter 7). Positive impacts on agrobiodiversity are potentially rooted in the capacities of diverse cropping systems, seed

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networks, and cultivar management, although much research is still needed on actual socioecological adaptation and resilience capacities as well as vulnerability.

From Food and Human Diets to Nutrition, Health, and Disease

- What is the significance and role of agrobiodiversity in food-based approaches to assure nutrition security?
- What are the relations between agrobiodiversity and dietary diversity that support human well-being?
- How does agrobiodiversity interact with the main pillars of global food security: availability, access, stability, and utilization?
- What are the systemic and structural determinants of food preference, and how do they interact with cultural and social determinants?

In reviewing the complex relationships that exist between agrobiodiversity, food, and nutritional health, Anna Herforth et al. (Chapter 9) stress the need to move past the productionist paradigm, which has dominated agricultural and food policy since the middle of the twentieth century. Despite numerous adjustments being made, the productionist paradigm has been unable to improve global nutrition substantially or meet sustainable development goals: it is neither environmentally nor socially sustainable, and is thus unable to support economic sustainability. To promote nutritious, just, and sustainable food systems, Herforth et al. sketch out actions that support an alternative food narrative, where agrobiodiversity is viewed both as an essential element and key mechanism to the resolution of the world's food problems. They highlight the recent gains made as donors and policy makers adopt a more holistic view of food systems and practice in their attempts to balance nutrition security and the socioeconomic–environmental imprint of agriculture. They urge civil society organizations to give higher priority to farm and food systems that do not "mine" the earth, to restrict herbicide and agrichemical use, to push skills sharing and training that build on local knowledge, and to link agrobiodiversity to youth engagement, education, and revalued local identity. Further, they call for renewed public engagement, as change is needed at the consumer and food industry levels. Different messages are obviously required for different regions and social groups. Finally, Herforth et al. issue a direct appeal to the scientific community for clear, coherent, and evidence-based messages. Although the complexities involved in agrobiodiversity undoubtedly require ongoing research, they hold that enough is currently known to support the quest for sustainable, nutritious, and just food systems.

In Chapter 10, Andrew D. Jones et al. present key findings on the principal ways by which agrobiodiversity acts to influence human diet. Reviewing evidence of linkages between terrestrial agrobiodiversity (cultivated and wild harvested) and diet diversity and quality, they assess the research challenges

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that emerge when agrobiodiversity is linked to nutrition, and analyze diet diversity and quality indicators that would increase our understanding of these relationships. Jones et al. conclude with a set of policy recommendations directed toward global- and country-level policies, with the goal of producing more diverse foods and improving diet quality by mainstreaming biodiversity into overall development objectives.

Local choices about health (physical and mental) and food systems (production and consumption) do not occur in a void: they interact with and are affected by policies and economic trends that unfold across regional and global levels. Although evidence suggests that reduced agrobiodiversity is concomitant to dietary simplification and related health effects, complete understanding of this complex relationship is lacking. In Chapter 11, Victoria Reyes-García and Petra Benyei explore potential pathways at the local level (e.g., individuals, households, communities, or local landscapes) that link agrobiodiversity to physical (e.g., diet, nutrition) and mental health (e.g., how food culture and traditional agrobiodiversity management knowledge contribute to identity and self-esteem). They review social aspects related to the production and consumption of agrobiodiversity that promote health and well-being and contextualize how local solutions might fit into a broader political context. They stress the value of social support in attaining good physical and mental health, and argue that participation in social networks (e.g., seed exchanges or agrobiodiversity-based social networks) offers a range of supportive resources—emotional (e.g., nurturance), tangible (e.g., seeds), informational (e.g., advice), companionship (e.g., sense of belonging)—that relate back to physical and mental health.

Key messages that emerged are as follows:

- More of the same will result in more of the same: we must adjust our focus away from a small group of food species and varieties if we are to gain a broader understanding of agrobiodiversity as an integral part of true nutrition-sensitive agriculture. The consumption of cereals, starchy root crops, meat and dairy, oilseeds, and sugar has drastically increased during the last 50 years. Predominant crop and livestock sectors continue to receive most private and public investment, in terms of research and development. Offering a viable option and true alternative food narrative requires us to understand and use agrobiodiversity as a key to the world's current food system problems (Chapter 9).
- Understanding the impact of the full range of agrobiodiversity on diet diversity requires increased focus on intraspecific diversity, underutilized species, and wild foods. There are over 20,000 species of edible plants in the world yet fewer than twenty species now provide 90% of our food. Four staple crops—maize, potato, rice, and wheat—supply more than 60% of humanity's energy intake (FAO 2010b). Achieving healthy diets and diversified production requires (a) an expansion of

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"underutilized" species and varieties of crops and animal breeds, semi-domesticates, and wild plants and animals that are nutritionally dense and (b) increased use of fruits, vegetables, pseudograins, nuts, minor roots, and tubers, among others (Chapters 9 and 10).

- The complex relationships between agrobiodiversity, human physical and mental health, and human well-being are poorly understood and under-researched. Evidence is growing that the overall reduction of agrobiodiversity in agroecosystems and value chains is concomitant to dietary simplification and negative health effects (Chapter 9). Yet, beyond the links between species and dietary diversity, exploration of other pathways linking agrobiodiversity to health and well-being remains uncommon. Social aspects related to the production and consumption of agrobiodiversity, as well as effects on overall well-being, need to be investigated and promoted using new integrative knowledge systems (Chapter 11).
- Healthy diets require agrobiodiversity; increased consumer demand and agrobiodiversity use can potentially provide a major stimulus for conservation. One of the main autonomous drivers triggering agrobiodiversity use, and thereby conservation, involves diverse cuisines. Human health is also directly and indirectly influenced by environmental health for which richness in agrobiodiversity, in turn, is essential. Thus, the consumption of agrobiodiversity can have positive effects on conservation and environmental health. Regional and farmer cuisines, enabling food environments that promote diversity, food literacy and awareness, high-value niche markets, certification schemes, and designation of origin are among the multiple options to create positive feedback loops from diets to conservation (Chapter 15).

Governance, Including Policy, Cultural, and Economic Frameworks

- How does agrobiodiversity interact with the current legal, policy, and political economic frameworks for food and agriculture?
- Given increased attention over the past two-plus decades, what major lessons can be derived for agrobiodiversity governance?
- What are the characteristic perils and promises related to the predominant macro-level market-based approaches to agrobiodiversity conservation?
- What is meant by "governance" beyond conventional policy/frameworks, including the balance between ownership, stewardship, and access via the market?
- How do power dynamics influence the management of agrobiodiversity across scales and systems?
- What are the challenges and potential for governance in rapidly changing food systems?

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To date, the ability of Indigenous Peoples to determine governance of agrobiodiversity has not been fully recognized nor explicitly addressed in international policies or legislation. Gabriel Nemogá (Chapter 12) reviews the practices and politics of Indigenous Peoples relative to agrobiodiversity and proposes an inclusive, biocultural perspective of agrobiodiversity that accounts for the customs, worldviews, and rights of Indigenous Peoples. Nemogá discusses the epistemological and political barriers that currently exist and calls for a research agenda in support of a consistent policy for agrobiodiversity use and *in situ* conservation. He analyzes international and national policy and legal instruments that impact agrobiodiversity by Indigenous Peoples. Although the right of self-determination has been recognized on a global level for Indigenous Peoples, the contributions (past as well as present) and role that Indigenous Peoples play in agrobiodiversity governance have not been recognized at all levels of governance, global as well as domestic. Since the goal of overcoming hunger and malnutrition worldwide affects all peoples, Nemogá calls for proper recognition and protection of Indigenous Peoples, as their practice may contribute to robust approaches in agrobiodiversity governance.

Issues related to governance are often guided by estimates of countable and measurable objects: the number and diversity of heirloom seeds or landraces from a certain location, the frequency of seed exchange among actors, or the rates at which varieties disappear. Such variables provide information about conservation status at different scales as well as the dynamic, reciprocal roles and relationships that seeds and agrobiodiversity assume in local cultures and communities. In Chapter 13, Guntra A. Aistara explores the important cultural roles that seeds play in agrobiodiversity governance. She highlights how the practices, knowledge, and social networks through which farmers manage seeds are anchored in cultural memories and future visions of place. These places are further embedded in nested ecological, social, and political processes across scales. Aistara proposes that agrobiodiversity governance be studied as a set of nested but unequal relationships between people and their seeds, practices, and knowledge systems as well as to other people and species in their landscapes; also, within the broader politics of rural development and the cultural vision of place and landscape.

Furthering this discussion, Bert Visser et al. (Chapter 14) explore the multifaceted and highly dynamic realities of agrobiodiversity, which itself is the result of interactions between humans and nature, and is thus simultaneously both social and biological in nature. As carriers of major agrobiodiversity components, seeds are not mere material objects that exist outside of social relations; they are embedded sociobiological artifacts. Therefore, when addressing governance, we need to understand the limitations and political implications of the complementary and sometimes contradictory instrumental and relational perspectives. In many communities, agrobiodiversity constitutes a major part of the living environments of farmers and often plays a primary role in shaping both cultural identity and food systems. This situation is different in modern

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industrialized production systems, as farmers have become increasingly detached from the agrobiodiversity setting of their crops and animals. In addition, research and industry practices regarding the collection, taxonomic classification, and manipulation of seeds and plants has historically separated seeds and plants from the sociobiological context in which they were domesticated and the knowledge systems in which they functioned. This reality poses a dilemma. The multiple ways in which people relate to agrobiodiversity mirror myriad lifestyles, visions, cultures, and beliefs as well as the different social systems that help determine how resources are owned, exchanged, and distributed. These nuanced relationships reflect unique histories and ways of life, evoke unique questions, and necessitate a different type of research. To appreciate the potentialities of agrobiodiversity and the wealth of options for conservation and governance, the physical, biological, social, and cultural contexts must all be taken into account. Multiple worldviews must be managed and novel questions need to be raised and addressed. Researchers wishing to work with people with unique experience and value systems must not only be respectful of multiple and sometimes incompatible worldviews, they must be willing and able to represent competing worldviews as equally valid. Doing this will strengthen the unique plurality that historically gave rise to rich patterns of agrobiodiversity and promote relationship building and trust implicit in a highly multicultural, cosmopolitan world.

How have markets affected the governance of agrobiodiversity? In Chapter 15, Matthias Jäger et al. analyze the role of agricultural product markets in agrobiodiversity governance. The expansion of these markets globally over the past two decades has generally promoted the simplification of agricultural and food systems, thus reducing diversity within crop and animal species. Farmers who continue to conserve on-farm agrobiodiversity provide valuable public goods, in terms of food security and environmental sustainability. However, because the market does not compensate farmers for conserving high levels of agrobiodiversity, there is little incentive to maintain on-farm conservation practices. This could eventually precipitate the destruction of local food systems and general biodiversity loss. To enhance both agrobiodiversity conservation and income generation through market-based instruments, ways of valuing agrobiodiversity need to be developed that account for its true production cost and contributions to genetic resource usage. Jäger et al. propose that payments for agrobiodiversity conservation schemes and niche market development (e.g., differential marketing, labels, certification schemes, agrotourism) should happen in tandem: stronger activities in agrobiodiversity conservation need to emerge from private sector investment and government funds. These measures offer potential for the successful marketing of agrobiodiversity and its niche products through collective action. However, constraints and possible unintended consequences of market-based approaches to agrobiodiversity conservation must be taken into account.

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Key messages that emerged from this group include the following:

- Multiple systems to govern agrobiodiversity coexist and lessons can be derived from this multiplicity. Still, divergent systems are largely incompatible in terms of what is being governed and for whose benefit. Conflicting approaches based on different value systems and their rationales can be distinguished (e.g., stewardship versus ownership approaches). Access, control, and use of agrobiodiversity constitute major expressions of governance (Chapter 14). Future research is needed to understand the interplay of multiple parallel governance systems that vary in scale, object, actors, and purpose.
- Power dynamics involved in governance are crucial in the context of rapidly changing farming and food systems. Multiple power asymmetries affect agrobiodiversity governance as well as the control, access, use, and benefits to diverse actors. As intellectual property systems are costly institutions, the capacity of developing countries to develop and effectively use such systems can be limited. Indigenous Peoples and smallholders manage most of the world's *in situ* agrobiodiversity yet are rarely empowered on equal terms in negotiations. The analysis and self-reflection of power asymmetries, including scientific initiatives, is crucially needed to inform current and future agrobiodiversity governance avenues (Chapters 12–15).
- There are significant differences among modern and traditional peoples, or those outside the mainstream, that have important implications on how people experience, relate to, and seek governance options in agrobiodiversity. The multiple ways in which people relate to agrobiodiversity reveal myriad lifestyles, visions, cultures, and beliefs as well as social systems that determine how resources are owned, exchanged, and distributed. This does not merely translate into different views and experiences, but underlies subtle yet profound associations, unique place-based trajectories, and different ways of living that are vital to understand for the future viability of agrobiodiversity (Chapters 12–15).
- New and innovative models to govern agrobiodiversity have been emerging, often at local to national scales, led both by private and public initiatives to facilitate benefit sharing and farmers' rights. These governance initiatives need to be studied for potential replication and adaptation in different contexts (Chapters 14 and 15). It is important to research the diverse and often less visible initiatives that have emerged. Although a systematic analysis of piloted initiatives has been given priority, many private initiatives need to be evaluated in broader contexts of new corporate responses and potential social responsibility.

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Integrating Agrobiodiversity Knowledge: A New Framework

The complexities inherent to agrobiodiversity demand a way to envision and address the contributory elements, linkages, and dynamics that play out on multiple scales (temporal, spatial) and levels (individual, group, regional, global). Such a conceptual framework provides a way to recognize the immensity of the problem and can be used to identify unresolved areas or knowledge gaps as well as research and policy opportunities. It also supports the integration of information that will continue to emerge and can serve to unite wide-ranging actors and institutions to work in concert.

The development of this integrative framework was a motivating force behind the convening of this Forum. The following framing emerged from the discourse and is presented here to promote further work and dialogue within and between research communities, policy makers, and practitioners (see also Zimmerer and de Haan 2017):

- *Evolutionary Ecology and Biocultural Diversity*: This area refers to interactions involving genetics, genetic resources, agroecology, and plant science and addresses how ethnobiology, ethnicity, linguistics, and culture (e.g., use, tradition, practice) impact the ecological system. Emphasis is on comparative diversity, timeline measurements based on genetic markers, and the integration of spatial knowledge systems.
- *Global Change*: This area addresses how climate change, environmental factors (e.g., water, soil erosion, land degradation), and human behavior influence food systems. This includes the impact from socioeconomic drivers (e.g., urbanization, market integration, demographic changes, expansion of global industrial food systems, trade and food policy), processes of valuation and their results (e.g., loss of cultural knowledge systems), as well as socioecological interactions on numerous scales.
- *Food–Nutrition–Health Linkages*: This area focuses on impacts (positive and negative) of food biodiversity on the human diet and links the effects of food and related biota (e.g., microbiome) biodiversity to human health (physical and mental), disease, and well-being. It also addresses the dynamics of food choice (e.g., economic specialization, market-based purchasing power, social movements) and the knowledge needed from the environmental, social, nutritional, and health sciences to create effective policy.
- *Governance*: This area focuses on policy, cultural, and economic practices and involves institutions and legal agreements that span (a) mainstay approaches (e.g., the International Treaty on Plant Genetic Resources for Food and Agriculture, Convention on Biological Diversity, the Nagoya Protocol, and Second Global Plan of Action for Plant Genetic Resources for Food and Agriculture), (b) multiple access and benefit-sharing arrangements (e.g., market-based approaches, cultural movements), as

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well as (c) community/grassroots and Indigenous movements, civil society organizations, consumer groups, and the private sector.

Grouping the multiple aspects into these cornerstone areas enables us to visualize broad areas of concern, to identify the requisite expertise that may be needed to address challenges, and to highlight where potential connections and collaborations may be needed. Within each area, multiple relationships are possible on a variety of scales: (a) spatially, from molecule and gene levels to organism, field, community, landscape, region, country, and global systems as well as (b) temporally, from less than 1 year to over 10,000 years (Zimmerer and de Haan 2017:3). Currently, research in all four areas is being framed primarily at global or smaller spatial scales (e.g., organism, field, community). This lack of within-country, regional-scale research demonstrates an important gap that must be filled in all four areas.

Between areas, numerous relationships and interactions are also possible. This framework provides a way to recognize these connections, to access requisite knowledge sources that will help us grasp their significance, and to identify competing interests or systemic tensions that may emerge. It also offers a way to conceptualize the incredibly dynamic nature of agrobiodiversity and appreciate the multiple ways in which linkages form. Understanding the inherent intricacies of agrobiodiversity and integrating resultant knowledge is needed if we are to enhance our ability to develop research, policy, and practical strategies aimed at achieving sustainable food systems.

Looking Ahead

Nutritional and food security, the provision of ecosystem services, and the protection of cultural values are essential components for achieving sustainable food systems. Securing any one of these requires action on institutional and individual levels, as well as a hybrid information base derived from traditional and modern knowledge sources. All of this, of course, is influenced by the highly dynamic processes of global change, which reorganize and modify the conditions under which agrobiodiversity unfolds. Given these dynamics, humanity cannot afford to wait in its response. Collective action is required immediately, molded by priorities and valuation systems, to address a multitude of issues:

- How should agrobiodiversity ideally be used and conserved, by whom, and under what conditions?
- Can on-farm conservation be taken more seriously as a basis of future conservation and a linked, parallel system to gene banks?
- What is likely, or acceptable, to be lost? How can we track this? What might be added?
- What is the role of industrial agriculture versus family farming in future food systems and agrobiodiversity usage?

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- Can local market networks that incorporate agrobiodiversity remain or become viable businesses, accessible to different consumer segments?
- Will concentrated wholesale and hypermarket chains become the exclusive global model and what does this imply for agrobiodiversity?
- Is there room for increased emphasis of agricultural research on quality, nutritional, and sustainability traits that build on agrobiodiversity?

Profound choices and creative approaches will be required if production environments are to be generated that reflect economic and sociocultural values. Cross-country and societal comparisons of trade-offs offer important lessons to inform government-level reviews of food production (e.g., Fitzpatrick et al. 2017; GOS 2017; NAFRI 2016). Such studies can also provide insight to civil society organizations, the private sector, donor agencies, academia, and consumers as they seek to undertake actions to use, conserve, and valorize agrobiodiversity at multiple levels (e.g., grassroots implementation, financial and policy support for science and equitable benefit sharing, development of inclusive value chains, awareness raising, messaging within different food environments).

In addition to the various human dimensions discussed throughout this volume, many others demand attention. Demographic attrition, for example, is currently having a negative effect on the global farming workforce, compounded by the trend among young people to reject agriculture as a viable livelihood option. How can we anticipate and respond to impacts that will certainly follow, in terms of associated production modes, knowledge, and culture? Can farming be made to be more attractive to younger generations, perhaps through youth engagement and awareness programs? One possibility would be to incorporate principles of agrobiodiversity and intercultural approaches to learning into educational systems (e.g., through curricula development, digital technology). This challenge holds great potential for participatory approaches that would build on local expertise (e.g., teachers, parents, community elders) and knowledge sources.

Tailoring our response to the multitude of issues involved in creating sustainable food systems requires a new approach along with the requisite sensitivity to diverse interests and systemic tensions. Drawing from distinct disciplines and fields of expertise, this volume offers a framework which we hope will spur further discussion, guide future actions, and lend understanding to the myriad interactions involved in agrobiodiversity across multiple scales.

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