Vol. 15, No. 1, 2020

scnat
swiss academy of sciences

swiss academies
factsheets

swiss-academies.ch

Variety is the source of life:
Agrobiodiversity benefits, challenges, and needs

For millennia, humankind's food security and resilience were ensured by thousands of cultivated plant species, dozens of domesticated animal species, and the wider biodiversity from which they derive. But with the expansion of industrial agriculture and globalized standardized food systems, this long-running agricultural biodiversity has fallen steeply. Today, just three plant species account for half of all plant-based food calories,[1] and only four animal species account for the vast majority of meat supplies.[2] Looking ahead, restoring *agrobiodiversity* – the richness of what we cultivate, breed, consume, and conserve in the wild – is crucial to ensure resilient food systems against the backdrop of climate change. In particular, we must safeguard the livelihoods of the "guardians of agrobiodiversity": approximately 500 million small farms across the world – particularly those in the global South.[3] This factsheet outlines causes and consequences of agrobiodiversity loss, areas of promise, and options for policy and research.

Bountiful sameness

Step into virtually any supermarket in the world today and the scene will be similar: aisles and refrigerators teeming with groceries from all over the globe. Yet the cornucopia of items on display may distract from a core reality: Most supermarket goods derive from a narrow selection of plants and animals compared to what nature provides and could be eaten – or is and has been eaten by diverse peoples and our ancestors since time immemorial. Consumers today are arguably sold a powerful illusion of diversity and choice. There are many shapes of bread and pasta on offer, but most are made from just a handful of plant species such as wheat. There are numerous kinds of milk, yoghurt, and cheese, but most come from a small number of livestock breeds. And ingredients like palm oil are added to everything from peanut butter to soap.

Agrobiodiversity

The underlying homogeneity of food marketed in the industrialized world – and increasingly everywhere else – is a symptom of deteriorating agricultural biodiversity, or *agrobiodiversity*, for short. The term refers collectively to the broad genetic spectrum of plants (varieties), animals (breeds), microorganisms, etc. domesticated and cultivated by humankind for consumption as food, medicine, shelter, clothing, etc. – as well as the wealth of farming *practices* and local *knowledge* used to produce them.

Agrobiodiversity emerged over the millennia in different key regions spread around the world, where separate human groups began to domesticate, cultivate, and breed different local plant varieties and animal species derived from the richness of flora and fauna existing in their ecosystems. For

Key terms

→ **Agrobiodiversity** encompasses "all components of biological diversity of relevance to food and agriculture, and all components of biological diversity that constitute the agricultural ecosystems, also named agro-ecosystems: the variety and variability of animals, plants and micro-organisms, at the genetic, species and ecosystem levels, which are necessary to sustain key functions of the agro-ecosystem, its structure and processes" (COP, CBD 2013).[14]

→ **Agroecology** refers to a scientific, technical, and social movement to preserve and restore local or regional agricultural self-reliance, conserve and regenerate natural resources, produce healthy foods with fewer inputs, empower small farmers and peasant organizations, and foster new, more sustainable and resilient food systems. It challenges "mainstream" policies oriented towards industrial agriculture, private agribusiness, commoditization, etc. while seeking to identify new political pathways for our food systems.[15]

→ **Sustainable food systems** are at the heart of UN Sustainable Development Goal 12 on responsible consumption and production, and are one of the six key "entry points" for action identified in the Global Sustainable Development Report 2019.[16] Food systems comprise all the stages involved in feeding humankind, from use of inputs (e.g. seeds, fertilizer) for crop growing to processing, packaging, transporting, retail, consumption, and food-waste management. Sustainable food systems must ensure fulfilment of the right to adequate food for all, reduce poverty and inequality, and maximize environmental performance and social-ecological resilience.[17]

example, evidence points to cultivation of wheat first emerging in the Middle East, maize in Central America, potatoes in South America, apples in Central Asia, and soybeans in East Asia. Over time, successive waves of managed selection, migration, colonization, and trade transplanted, mixed, and remixed these diverse agricultural crops and farming practices the world over – spreading them far beyond their original ecosystems.

In recent decades, however, studies show that agrobiodiversity has declined steeply.[4] Whereas historically about 7,000 plant species were cultivated for food, today only about 80 plant species make major contributions to food supplies at the global level.[5] In fact, half of all plant-based calories come from only three species – rice, maize, and wheat[6] – while 93% of global meat supplies come from just four animal species – pigs, poultry, cattle, and buffalo.[7] Indeed, humankind is farming and consuming ever fewer plant and animal species. To understand why this is a serious risk, it helps to review the many benefits of agrobiodiversity.

Why is agrobiodiversity vital?

Food security is ensured by agrobiodiversity. Cultivation and rearing of many different plant and animal species and varieties – in different ways and at different scales – helps to buffer overall agricultural production against key threats. These include weather extremes, pest outbreaks, plant diseases, market fluctuations or failures, logistical breakdown of seed provision due to conflict or natural hazards, as well as new uncertainties related to climate change. Where one kind of plant, animal, or farming practice falls prey to a particular threat, others may prove capable of withstanding, adapting, or thriving in response to it. In this way, preserving genetic and technical diversity at the field, landscape, and global levels serves as an insurance policy. It ensures that our food systems remain *adaptive* and *resilient* to shocks and changes.[8]

Health and medicinal benefits are equally important. Increasing evidence shows strong links between agricultural diversity, dietary diversity, and health outcomes.[9] Cultivating and consuming a wide range of local crops supplemented by wild-harvested species ensures a healthy diet, especially among poor rural families.[10] Moreover, dozens of effective remedies – from aspirin to new cancer drugs – derive in whole or in part from wild-harvested or cultivable plants. Many others likely remain to be discovered or adopted more broadly by medicine – possibly including major health breakthroughs.

Sustaining rich human culture and knowledge is also vital, particularly that of indigenous communities, peasants, and family farmers. Agrobiodiversity stems from numerous local contexts and a rich variety of non-materialist cultures, values, and experiences. It is part of humanity's shared social-ecological heritage and wisdom. This collective knowledge has enabled humankind to survive in wide-ranging – even extreme – environmental conditions. It is crucial to retain as we enter an uncertain climatic future.[11]

Protection of ecosystem services is a final core benefit. Agrobiodiverse areas – characterized by rich tapestries of human-managed crops, natural landscape features, and wild plants and animals – help to sustain the web of life. They contribute to regulation of water cycles, for example, and provide safe habitats for pollinators like bees, butterflies, and other fauna that fulfil irreplaceable, life-sustaining roles – also for modern agriculture.[12] Overall, farms abundant in agrobiodiversity underpin the provision of numerous other ecosystem services.[13]

Stark reality of declining agrobiodiversity

Despite these documented benefits of agrobiodiversity, evidence of its sharp decline continues to mount. Globally, the FAO estimates that 75% of crop diversity was lost in the 20th century. Country-level estimates vividly illustrate the downward trend: In China, for example, approximately 90% of 10,000 wheat varieties cultivated in 1940 were abandoned by 1970. In Mexico, about 80% of maize varieties were lost between 1930 and 1970. And in the US, around 80–95% of the varieties of apples, cabbage, field maize, pea, and tomato were given up between 1904 and 2000.[18]

Similar declines have occurred regarding animal diversity. In Europe and North America, for instance, Holstein-Friesian livestock breeds now comprise between 60% and 90% of all dairy cattle, respectively. Overall, a small handful of highly productive livestock breeds, suited to industrial production systems, are gradually replacing other diverse breeds world-

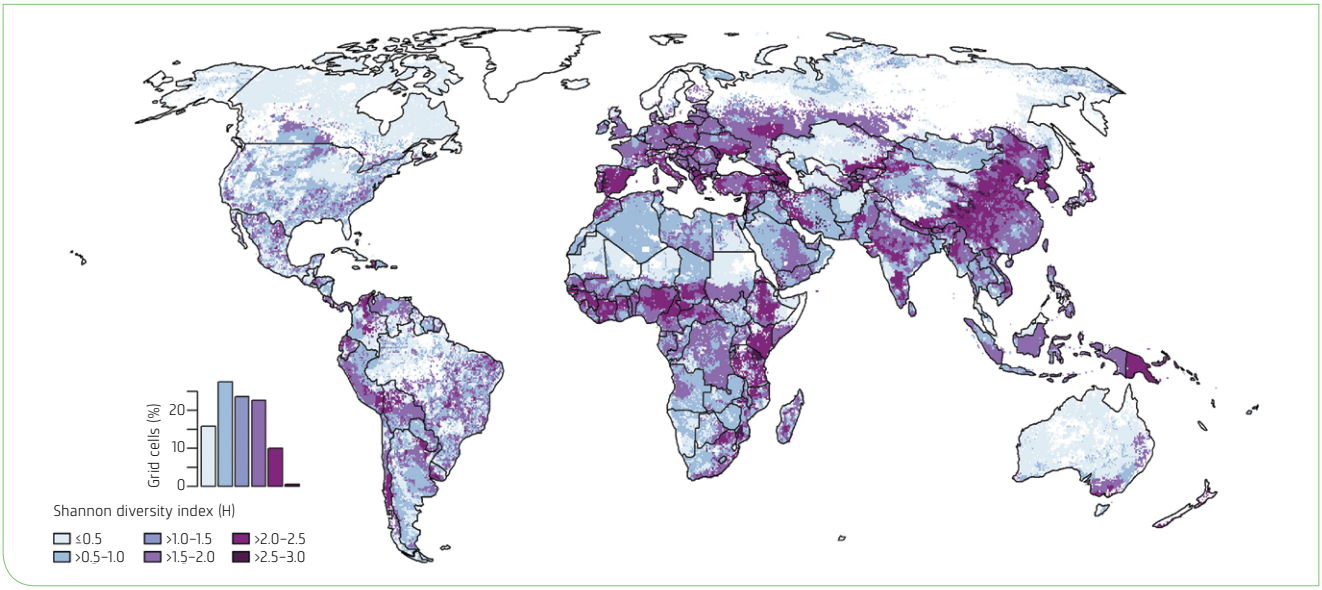

Figure 1. Global diversity of food commodities (as a proxy for agrobiodiversity). The higher the H-index, the higher the diversity. (Based on data from 2005; map source: Herrero et al. 2017)[36]

wide.[19] The FAO's Global Databank for Animal Genetic Resources for Food and Agriculture lists approximately 8,800 known livestock breeds. But about 7,740 of these are categorized as solely local breeds, meaning they are only found in one country. Further, over 590 local breeds are listed as extinct, while another 153 are classified as at risk of extinction.[20] Between 2001 and 2007, 62 breeds went extinct – a rate of almost one breed per month.[21]

Finally, there is growing concern about the remaining wild relatives of various crops, which play a critical role in plant breeding – especially to adapt to changing environmental conditions. Research shows that, unless action is taken to protect them, 16–22% of the wild relatives of peanut, potato, and cowpea plants could be gone by 2055, cutting their areas of distribution by 50% and leaving them significantly fragmented and vulnerable.[22] These and other *crop wild relatives* are an irreplaceable source of new plant varieties that could have highly valuable traits such as drought or disease resistance.

Drivers of loss

Land use change linked to massive expansion of globalized, highly commercialized industrial agriculture is the main overarching driver of declining agrobiodiversity. By adopting this model of industrial agriculture, numerous countries have transitioned to input-intensive production of a restricted number of plant species, breeds, and varieties, grown in vast monocultures.[23] Monoculture farming is strongly linked with large-scale animal agriculture, with 33% of global arable land used to produce feed (e.g. maize, soya) for livestock. Crop monocultures and industrial livestock farms are frequently implemented at the expense of vital forestland or formerly highly diverse agricultural landscapes. While livestock farming accounts for 77% of current agricultural land, animal-based food provides only about 17% of global food calories and 33% of global protein.[24] Such land use is highly inefficient: Beef production, for example, requires 20 times more land and emits 20 times more greenhouse gases per unit of edible protein than common plant-based protein sources.[25]

Enclosure of land and forest commons through land "grabbing" and concentration is another key driver. To date, foreign investors have taken control of 42 million hectares of land worldwide. Unconcluded land deals add another 18 million hectares to that total.[26] Most of these "land grabs" occur in agricultural or forest areas where small-scale farmers practise family and community-based agriculture.[27] The common-property systems these smallholders often maintain – featuring high levels of agrobiodiversity – are a prominent victim of large-scale land acquisitions.[28] The investors regularly shift land use towards monocultures, etc.

Replacement of local plant varieties and animal breeds with uniform, commercial ones also drives losses. When farmers abandon native landraces to cultivate new crop varieties or animal breeds, the traditional ones are lost. Since the "Green Revolution" of the 1950s, the spread of new, standardized plant varieties in the developing world has been dramatic. By 1990, they covered half of all wheat lands globally, for instance, and more than half of all rice lands.[29] This resulted in *large yield increases* of certain crops, but also in *major sacrifice of crop diversity*.

Corporatization and monopolization of food systems strongly fuels the decline of agrobiodiversity as well. This is especially evident in the growing concentration of ownership, production, and distribution of commercial seeds and other inputs (pesticides, fertilizer, etc.) in the hands of ever fewer transnational corporations – reinforced by an increasingly standardized and more centrally controlled "production model".[30] After the mergers of Dow and DuPont (2015), ChemChina and Syngenta (2016), and Bayer and Monsanto (2016), these big firms control at least 75% of the global market for agricultural inputs.[31] Similar levels of market concentration are found in the global trade, processing, and retail of agricultural commodities like grains.[32] Notably, Switzerland is home to headquarters of the biggest "fast moving consumer goods" company (Nestlé) as well as dominant global players in agricultural commodity trading (ADM, Dreyfus, Bunge, Cargill, Glencore) and in the development and sale of agrochemicals and

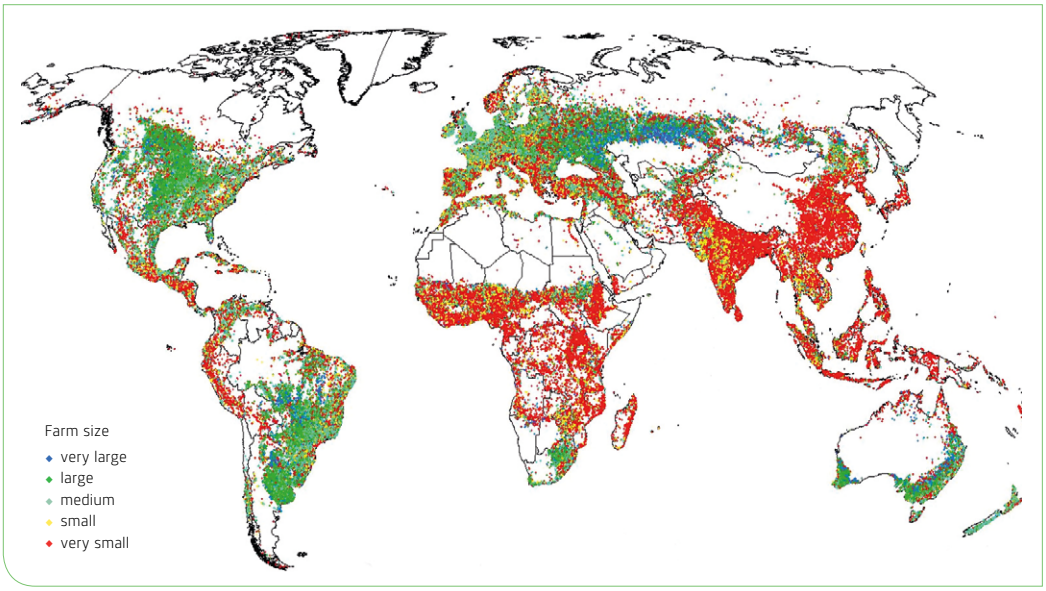

Figure 2. Global spatial distribution of dominant farm field sizes. (Based on data from 2011; map source: Lesiv et al. 2018)[37]

genetically modified seeds (Syngenta). The growing power of these conglomerate agribusinesses is crucial: Their business model depends on continuous expansion and consolidation of monoculture-based food systems that directly threaten agrobiodiversity.[33]

Guardians of remaining agrobiodiversity: Small and family farmers

Despite these troubling trends, dense areas of abundant agrobiodiversity still remain scattered around the world. This can be seen in a map showing the global distribution of food commodity diversity, which can be used as a proxy for agrobiodiversity (see Figure 1). Comparison with another map showing the global distribution of dominant farm sizes (see Figure 2) gives a critical insight: It appears to be the global community of *smallholders and medium-scale farmers* who are the primary *guardians of the world's remaining agrobiodiversity* in vital hotspots – and in many places and spaces between fast-spreading large-scale monocultures. For example, one recent study shows that the bulk of genetic diversity of 27 crop species – across five continents – continues to be maintained on smaller farms and at the community level, in the form of traditional crop varieties.[34] Another recent study shows that nutrients vital to human growth and development (e.g. calcium, protein, vitamins A and B12, zinc) are most likely to come from crops, livestock, and aquaculture on farms smaller than 50 hectares, especially in Africa and Asia.[35]

These smaller-scale farmers are typically less integrated into the commercialized global value chains of national and transnational agribusiness. By choice or necessity, they often continue to use local inputs, such as heirloom seeds for crops or manure for fertilizer. In Africa, for example, the informal seed sector remains the backbone of local agriculture. Review of a major dataset – comprising 9,660 observations in six African countries and covering 40 crops – showed that farmers obtain 90% of their seed from informal systems, with 51% deriving from local markets.[38] Based on open, autonomous farmer-to-farmer exchange, local adaptation, shared development, and reproducibility, these traditional seed sectors keep agrobiodiversity alive as part of a "cognitive-genetic" commons, as was done over the millennia.[39]

In addition, *common pool resource management* is a dominant feature of many of these smallholder farming systems. With few exceptions, common pool resource areas feature higher levels of agrobiodiversity than those of large private or state-owned agricultural operations.[40]

Importantly, these smallholders are not maintaining agrobiodiversity for its own sake. Rather, they are essential food producers, providing half of global food calories according to recent estimates.[41] And they produce this major share of food while occupying just 24–28% of all agricultural land globally.[42] They should not be seen as practitioners of outdated farming systems. Instead, they should be viewed as vital torchbearers for agroecological transitions to more sustainable food systems.[43]

Core challenge: Harmonizing policies to support agrobiodiverse food systems and farming practices

As the evidence shows, the fate of small- and medium-sized farms and the fate of global agrobiodiversity are intimately linked – as goes one, so goes the other. A major task for policymakers going forward is finding effective ways of supporting agrobiodiversity-friendly food systems, and the small farmers that sustain them.

The policy instruments that currently shape our food systems – from local to international governance levels – can be usefully divided into two categories: first, those that enable agrobiodiversity and smallholder farming systems by supporting the complexity of social-ecological food systems (Figure 3, bottom row); and, second, those that undermine agrobiodiversity by focusing narrowly on maximizing the profitability of individual commodity crops or livestock breeds (Figure 3, top row).

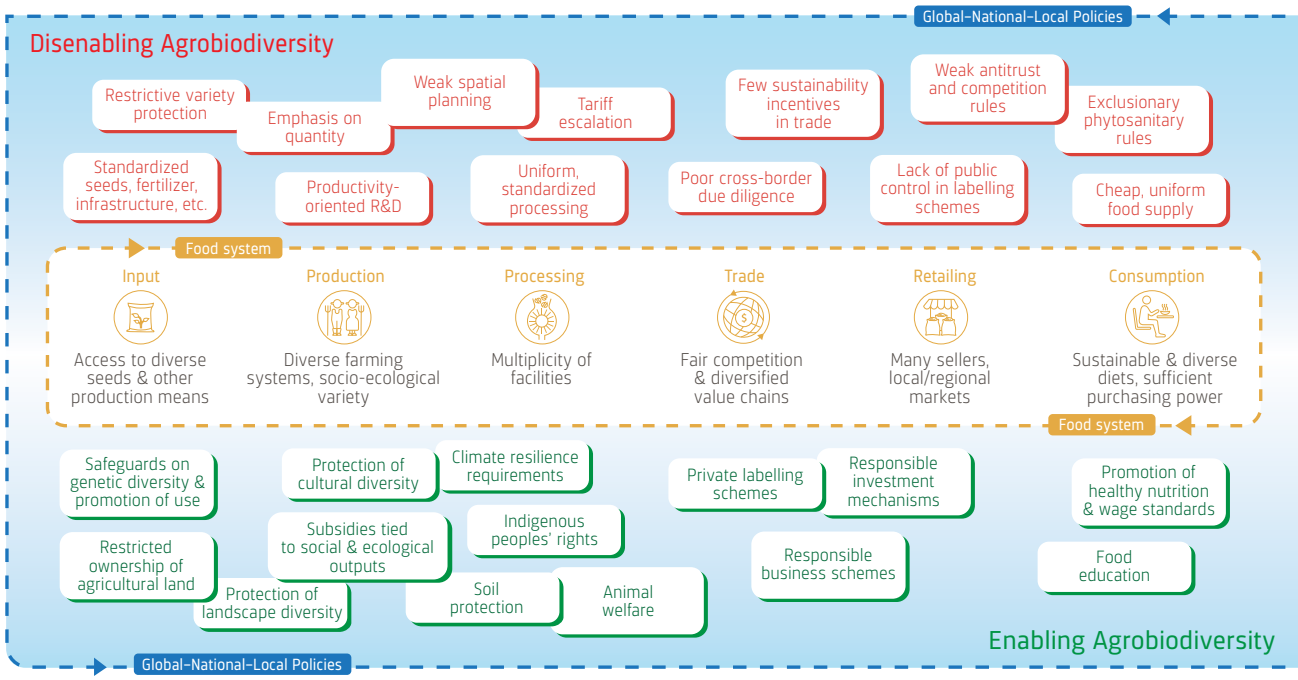

Figure 3. Policies enabling (bottom row) or undermining (top row) the conservation of agrobiodiversity as a cornerstone of sustainable food systems. (Source: authors' analysis)

To the fore of the debate are major agreements and other policy instruments that explicitly support agrobiodiversity. Key global-level instruments include the FAO's International Treaty on Plant Genetic Resources for Food and Agriculture (ITPGRFA), or "Seed Treaty", effective since 2004, and the Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization, effective since 2014. They particularly emphasize the importance of protecting diverse genetic varieties – not only by maintaining seed banks, but also by maintaining and encouraging *diversity of farming systems*. Art. 6 of the Seed Treaty stresses that "diversity is necessary to ensure *sustainable use* of these resources". Core global agreements also emphasize the importance of *diversity in food consumption*, such as the *right to adequate food* as enshrined in Art. 11 of the International Covenant on Economic, Social and Cultural Rights. At the national level, policies deriving from these wider agreements include, for instance, domestic subsidies for farmers who provide agrobiodiversity-based services, or public procurement schemes to promote consumption of agrobiodiverse products (e.g. via public-school meal programmes).

Less discussed, but arguably more consequential for agrobiodiversity, are the many food system-related policies that aim to increase the output, economic competitiveness, and standardization of agriculture. These "productivist" and market-oriented policies currently tend to undermine agrobiodiversity. At the national level, there are a range of policies and schemes in place that push for uniformity and market consolidation in every link of the value chain – whether *inputs* (e.g. proprietary seeds), *production* (e.g. monocultures), *processing* (e.g. centralized facilities in the global North), trade (e.g. vertical integration), *retailing* (e.g. chain supermarkets), or *consumption* (e.g. narrowing people's tastes). At the international level, this tendency is strengthened by current trade and investment frameworks that are not aligned with agrobiodiversity-related objectives and do not differentiate between production methods.[44] Anti-monopoly policies designed to promote market diversity are poorly enforced, narrowly price-focused, and neglect the unique needs for biological and technical diversity in food systems. Indeed, to restore and strengthen agrobiodiversity, policymakers must reform and better align these market-oriented policies.

Path forward to protect and restore agrobiodiversity

In order to fix this misalignment of policies, agrobiodiversity must be mainstreamed in all policies at every level of governance. Among experts, including the present authors, there is a growing consensus on the need to adopt a comprehensive approach to food systems in which the dominant uniformity paradigm of the 20th century is replaced with a new *diversity paradigm* for the 21st century.[45] The importance of applying a diversity lens to food systems has been emphasized, for example, by the Seed Treaty and the UN Declaration on the Rights of Peasants and other people working in rural areas, adopted by the UN General Assembly in December 2018.[46]

Several aspects are crucial to a new, more coherent, agrobiodiversity-enabling policy architecture. First, it must recognize the fundamental role of small- and medium-scale farmers as the guardians of global agrobiodiversity. Second, it must emphasize agrobiodiversity conservation and agroecology as integral to fostering and scaling up sustainable and resilient food systems. This means protecting and promoting agrobiodiversity in each stage of food systems – from input provision to consumption (see Figure 3, centre row). Third, it should strive to foster a thriving global *seed commons*, built on active use and sharing of diverse seeds as well as principles of interdependence, complexity, human community, and the links between diverse knowledge and diverse physical environments.[47]

Knowledge gaps and avenues for Swiss and global research

Based on a recent expert workshop on agrobiodiversity and review of existing evidence, several promising avenues have been identified for relevant Swiss and international research, in particular to inform policy:

Factors shaping conservation of agrobiodiversity among small-scale farmers

First, more research is needed on the factors – knowledge, practices, geography, actors, institutions, or policies – that help or hinder conservation of agrobiodiversity. What explains the observed agrobiodiversity hotspots? Research on the ground in these areas could inventory the knowledge and practices that make up this agrobiodiversity, such as cultural traditions, maintenance of commons, seed sharing, and alliances between small farmers, processors, traders, etc. Other analyses could examine its wider connections to (or disconnections from) external input providers, buyers or traders, consumers, etc. as well as its overall institutional embedding. How can smallholder-supported agrobiodiversity be reinforced, extended, sown, or restored elsewhere? Can it be complemented or enhanced with new insights from the field of agroecology, for example?

Role of Swiss businesses or financial activity in agrobiodiversity decline

Increased research is also needed on the various agrobiodiversity impacts of Switzerland-based private or public companies, pension funds, financial service providers, etc. Systems-level research could investigate their function in wider processes of market-based food system consolidation (e.g. monopolization, vertical integration). Sector-based studies could examine the specific effects of dominant players in particular industries. To what extent is Swiss finance involved in land deals that threaten agrobiodiverse smallholder systems, land commons, and forest commons? How are Switzerland-based agricultural input providers (seeds, pesticides, etc.) and other companies contributing to replacement of local seed varieties or expansion of monocultures? How could these harms be avoided or reversed?

Social and technological innovations to raise agrobiodiversity awareness and demand

Research should also focus on ways of enhancing societal appreciation for and access to agrobiodiverse goods, including more local crops, "forgotten" varieties, seasonal products, etc. This appears especially important against the backdrop of increasing urbanization, "defarmization", consumer alienation from food producers, and people's loss of cooking skills that support agrobiodiversity. Projects could develop, test, and/or evaluate agrobiodiversity-education programmes, certification and labelling schemes for agrobiodiverse foods, and "solidarity economy"-oriented networking of diverse small farmers, processors, retailers, and consumers – including use of new digital technologies (e.g. online hubs) to link these actors.

Development of policy-oriented innovations to aid agrobiodiversity transformations

Finally, research should focus on the subnational, national, and global policy changes needed to mainstream agrobiodiversity in food systems. Legal, political, and economic studies should identify areas where reforms are required to harmonize rights-based agreements and market mechanisms in favour of agrobiodiversity. What scope is available for reshaping agricultural subsidies worldwide on behalf of agrobiodiversity use and conservation? How might financial regulations, import/export rules, incentives, penalties, tariffs, or taxes be adapted in Switzerland to reduce the country's outsize ecological footprint – and harm to agrobiodiversity – in the global South?[48] How could trade, patent, and antitrust law be applied to restructure markets and food systems in favour of smaller-scale farms and businesses that maintain agrobiodiversity? The time is ripe for researchers to tackle these and other pressing policy questions.

SDGs: THE INTERNATIONAL SUSTAINABLE DEVELOPMENT GOALS OF THE UN
In this publication, the Swiss Academies of Arts and Sciences make a contribution to SDGs 2, 12, and 15

› sustainabledevelopment.un.org
› eda.admin.ch/agenda2030/en/home/agenda-2030/die-17-ziele-fuer-eine-nachhaltige-entwicklung.html

1 – 48 The list of references is available in the online version of this factsheet, at swiss-academies.ch/en/factsheets

IMPRINT

PUBLISHER
Swiss Academy of Sciences (SCNAT) • Commission for Research Partnerships with Developing Countries (KFPE) • Swiss Biodiversity Forum • House of Academies • Laupenstrasse 7 • P.O. Box • 3001 Bern • +41 31 306 93 49 • kfpe@scnat.ch

AUTHORS Stephan Rist (CDE) • Elisabeth Bürgi Bonanomi (CDE) • Markus Giger (CDE) • Cornelia Hett (CDE) • Bettina Scharrer (CDE) • Johanna Jacobi (CDE) • Anu Lannen (CDE)

PROJECT MANAGERS Jon-Andri Lys (KFPE) • Stephan Rist (CDE) • Jodok Guntern (Swiss Biodiversity Forum)

EDITOR Anu Lannen (CDE)

LAYOUT Simone Kummer (CDE)

This factsheet draws on findings from the literature references and on the results of an expert workshop held in September 2018, where scientific insights, gaps, and policy implications were discussed by 28 participants from academia, NGOs, public administration, and private organizations. It was managed by the Swiss Commission for Research Partnerships with Developing Countries (KFPE) and the Swiss Biodiversity Forum, in collaboration with the Centre for Development and Environment (CDE).

PHOTO Offering thanks to Pachamama: harvest festival in Colcha "K" community, Nor Lípez, Bolivia – Sabin Bieri (CDE)

swiss-academies.ch

ISSN (print): 2297-8283
ISSN (online): 2297-1831

DOI: 10.5281/zenodo.3568133

Cradle to Cradle™-certified and climate-neutrally printed by Vögeli AG in Langnau i. E.

CERTIFIED cradle to cradle GOLD

References

1 Frison EA, IPES Food [International Panel of Experts on Sustainable Food Systems] (2016) *From Uniformity to Diversity: A Paradigm Shift from Industrial Agriculture to Diversified Agroecological Systems*. Louvain-la-Neuve, Belgium: International Panel of Experts on Sustainable Food Systems. https://hdl.handle.net/10568/75659

2 FAO [Food and Agriculture Organization] (2019) *Animal Production and Health: Sources of Meat*. [Online] http://www.fao.org/ag/againfo/themes/en/meat/backgr_sources.html (accessed 26 August 2019)

3 Lowder SK, Skoet J, Raney T (2016) The number, size, and distribution of farms, smallholder farms, and family farms worldwide. *World Development* 87:16–29. https://doi.org/10.1016/j.worlddev.2015.10.041

4 IPBES [Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services] (2019) *Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Díaz S, Settele J, Brondizio ES, Ngo HT, Guèze M, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SHM, Chan KMA, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgley GF, Miloslavich P, Molnár Z, Obura D, Pfaff A, Polasky S, Purvis A, Razzaque J, Reyers B, Roy Chowdhury R, Shin YJ, Visseren-Hamakers IJ, Willis KJ, Zayas CN, editors. Bonn, Germany: IPBES secretariat. https://www.ipbes.net/sites/default/files/downloads/spm_unedited_advance_for_posting_htn.pdf

5 Romanelli C, Cooper D, Campbell-Lendrum D, Maiero M, Karesh WB, Hunter D, Golden CD (2015) *Connecting Global Priorities: Biodiversity and Human Health: A State of Knowledge Review*. Geneva, Switzerland: World Health Organisation/Secretariat of the UN Convention on Biological Diversity. https://hdl.handle.net/10568/67397

6 Frison EA, IPES Food (2016) *Op. cit.*

7 FAO [Food and Agriculture Organization] (2019) *Animal Production and Health: Sources of Meat*. [Online] http://www.fao.org/ag/againfo/themes/en/meat/backgr_sources.html (accessed 26 August 2019)

8 Lin BB (2011) Resilience in agriculture through crop diversification: adaptive management for environmental change. *BioScience* 61(3):183–193. https://doi.org/10.1525/bio.2011.61.3.4; Jacobi J, Mukhovi S, Llanque A, Augstburger H, Käser F, Pozo C, Ngutu Peter M, Delgado JMF, Kiteme BP, Rist S, Ifejika Speranza C (2018) Operationalizing food system resilience: An indicator-based assessment in agroindustrial, smallholder farming, and agroecological contexts in Bolivia and Kenya. *Land Use Policy* 79:433–446. https://doi.org/10.1016/j.landusepol.2018.08.044; Frison EA, Cherfas J, Hodgkin T (2011) Agricultural biodiversity is essential for a sustainable improvement in food and nutrition security. *Sustainability* 3(1):238–253. https://doi.org/10.3390/su3010238; Petersen U, Weigel HJ (2015) *Klimaresilienz durch Agrobiodiversität? Literaturstudie zum Zusammenhang zwischen Elementen der Agrobiodiversität und der Empfindlichkeit von landwirtschaftlichen Produktionssystemen gegenüber dem Klimawandel*. Braunschweig, Deutschland: Johann Heinrich von Thünen-Institut. https://literatur.thuenen.de/digbib_extern/dn054807.pdf

9 FAO [Food and Agriculture Organization] (2016) *Influencing Food Environments for Healthy Diets*. Rome, Italy: Food and Agriculture Organization. https://bit.ly/2MyUMMm

10 Fanzo J, Hunter D, Borelli T, Mattei M (2013) *Diversifying Food and Diets: Using Agricultural Biodiversity to Improve Nutrition and Health*. New York, NY, USA: Routledge. https://bit.ly/2zgl3p1

11 Morton LW (2019) Farmers' knowledge and adaptation to climate change to ensure food security. In: Yadav S, Redden R, Hatfield J, Ebert A, Hunter D, editors. *Food Security and Climate Change*: 449–470. Hoboken, NJ, USA, and Chichester, West Sussex, UK: Wiley-Blackwell. https://bit.ly/2NzTGzx

12 Duru M, Therond O, Martin G, Martin-Clouaire R, Magne MA, Justes E, Journet EP, Aubertot JN, Savary S, Bergez JE (2015) How to implement biodiversity-based agriculture to enhance ecosystem services: A review. *Agronomy for Sustainable Development* 35(4):1259–1281. https://link.springer.com/article/10.1007/s13593-015-0306-1

13 Augstburger H, Jacobi J, Schwilch G, Rist S (2018) Agroecosystem service capacity index: A methodological approach. *Landscape Online* 64:1-48. https://doi.org/10.3097/LO.201864

14 COP, CBD [Conference of the Parties, Convention on Biological Diversity] (2013) Decision V/5. *Agricultural Biological Diversity. Convention on Biological Diversity*: Montreal, QC, Canada: COP, CBD. https://www.cbd.int/decision/cop/default.shtml?id=7147; FAO [Food and Agriculture Organization]. 2005. *Building on Gender, Agrobiodiversity and Local Knowledge*. Rome, Italy: Food and Agriculture Organization. https://bit.ly/2ZmeNIb

15 Altieri MA, Toledo VM (2011) The agroecological revolution in Latin America: Rescuing nature, ensuring food sovereignty and empowering peasants. *Journal of Peasant Studies* 38(3):587–612. https://doi.org/10.1080/03066150.2011.582947

16 Independent Group of Scientists appointed by the Secretary-General (2019) *Global Sustainable Development Report 2019: The Future is Now – Science for Achieving Sustainable Development*. New York, USA: United Nations. https://sustainabledevelopment.un.org/content/documents/24797GSDR_report_2019.pdf

17 Tribaldos T, Jacobi J, Rist S (2018) Linking sustainable diets to the concept of food system sustainability. *Future of Food: Journal on Food, Agriculture and Society* 6(1):71–84. http://futureoffoodjournal.org/index.php/FOFJ/article/view/12

18 Secretariat of the Convention of Biological Diversity (2010) *Global Biodiversity Outlook 3*. Montreal, Canada: Secretariat of the Convention of Biological Diversity. https://bit.ly/2HiWVYb; https://www.cbd.int/gbo1/chap-01-07.shtml

19 Groeneveld LF, Lenstra JA, Eding H, Toro MA, Scherf B, Pilling D, Negrini R, Finlay EK, Jianlin H, Groeneveld E, Weigend S (2010) Genetic diversity in farm animals – a review. *Animal Genetics*. 41:6-31. https://doi.org/10.1111/j.1365-2052.2010.02038.x

20 FAO [Food and Agriculture Organization] (2019) The State of the World's Biodiversity for Food and Agriculture. Rome, Italy. *Food and Agriculture Organization*. Rome, Italy: Food and Agriculture Organization. http://www.fao.org/3/CA3129EN/ca3129en.pdf

21 FAO [Food and Agriculture Organization] (2007) *The State of the World's Animal Genetic Resources for Food and Agriculture*. Rome, Italy: Food and Agriculture Organization. http://www.fao.org/3/a1250e/a1250e.pdf

22 Thornton P, Cramer L, editors (2012) *Impacts of Climate Change on the Agricultural and Aquatic Systems and Natural Resources within the CGIAR's Mandate. CCAFS Working Paper 23*. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). https://cgspace.cgiar.org/handle/10568/21226

23 FAO [Food and Agriculture Organization]. (2010) *The Second Report on the State of the World's Plant Genetic Resources for Food and Agriculture*. Rome, Italy: FAO. http://www.fao.org/3/i1500e/i1500e00.htm

24 Roser M, Ritchie H (2013) Yields and land use in agriculture: Empirical view. *Our World in Data*. https://ourworldindata.org/yields-and-land-use-in-agriculture

25 Ranganathan J, Vennard D, Waite R, Dumas P, Lipinski B, Searchinger T, GLOBAGRI-WRR (2016) *Shifting Diets for a Sustainable Food Future*. Washington, DC, USA: World Resources Institute. https://www.wri.org/publication/shifting-diets; Ranganathan J, Waite R (2016) Sustainable Diets: What You Need to Know in 12 Charts. https://www.wri.org/blog/2016/04/sustainable-diets-what-you-need-know-12-charts

26 Land Matrix. *Global Observatory*. [Online] https://landmatrix.org/global/ (accessed 14 May 2019)

27 Messerli P, Giger M, Dwyer MB, Breu T, Eckert S (2014) The geography of large-scale land acquisitions: Analysing socio-ecological patterns of target contexts in the global South. *Applied Geography* 53:449–459. http://dx.doi.org/10.1016/j.apgeog.2014.07.005.

28 Dell'Angelo J, D'Odorico P, Rulli MC, Marchand P (2017) The tragedy of the grabbed commons: Coercion and dispossession in the global land rush. *World Development* 92:1–12. https://doi.org/10.1016/j.worlddev.2016.11.005; Timmermann C, Robaey Z (2016) Agrobiodiversity under different property regimes. *Journal of Agricultural and Environmental Ethics* 29(2):285–303. https://doi.org/10.1007/s10806-016-9602-2

29 Redfern SK, Azzu N, Binamira JS (2012) Rice in Southeast Asia: Facing risks and vulnerabilities to respond to climate change. *In:* Meybeck A, Lankoski J, Redfern S, Azzu N, editors. *Building Resilience for Adaption to Climate Change in the Agriculture Sector: Proceedings of a Joint FAO/OECD Workshop*. Rome, Italy: Food and Agriculture Organization. http://www.fao.org/3/a-i3084e.pdf#page=302

30 Clapp J (2018) Mega-mergers on the menu: Corporate concentration and the politics of sustainability in the global food system. *Global Environmental Politics* 18(2):12–33. https://doi.org/10.1162/glep_a_00454

31 Clapp J (2018) *Op. cit.*

32 IPES Food [International Panel of Experts on Sustainable Food Systems]. *Agribusiness*. [Online] http://www.ipes-food.org/topics/Agribusiness# (accessed 26 August 2019)

33 Clapp J., Isakson SR (2018) Risky returns: The implications of financialization in the food system. *Development and Change* 49(2):437–460. https://doi.org/10.1111/dech.12376

34 Jarvis DI, Brown AH, Cuong PH, Collado-Panduro L, Latournerie-Moreno L, Gyawali S, Tanto T, Sawadogo M, Mar I, Sadiki M, Hue NT (2008) A global perspective of the richness and evenness of traditional crop-variety diversity maintained by farming communities. *Proceedings of the National Academy of Sciences*. 105(14):5326–5331. https://www.pnas.org/content/105/14/5326.short

35 Herrero M, Thornton PK, Power B, Bogard JR, Remans R, Fritz S, Gerber JS, Nelson G, See L, Waha K, Watson RA (2017) Farming and the geography of nutrient production for human use: a transdisciplinary analysis. *The Lancet Planetary Health*. 1(1):e33-42. https://doi.org/10.1016/S2542-5196(17)30007-4

36 Herrero M, Thornton PK, Power B, Bogard JR, Remans R, Fritz S, Gerber JS, Nelson G, See L, Waha K, Watson RA (2017) *Op. cit.*

37 Lesiv M, Laso Bayas JC, See L, Duerauer M, Domian D, Durando N, Hazarika R, Kumar Sahariah P, et al. (2018) Estimating the Global Distribution of Field Size using Crowdsourcing. *Global Change Biology* 25(1):174–186 https://doi.org/10.1111/gcb.14492

38 McGuire S, Sperling L (2016) Seed systems smallholder farmers use. *Food Security* 8:179–195. DOI: https://link.springer.com/article/10.1007/s12571-015-0528-8

39 Herrero M, Thornton PK, Power B, Bogard JR, Remans R, Fritz S, Gerber JS, Nelson G, See L, Waha K, Watson RA (2017) *Op. cit.*

40 Augstburger H, Käser F, Rist S (2019) Assessing Food Systems and Their Impact on Common Pool Resources and Resilience. *Land* 8(4):71. https://doi.org/10.3390/land8040071; Timmermann C, Robaey Z (2016) *Op. cit.*

41 Ricciardi V, Ramankutty N, Mehrabi Z, Jarvis L, Chookolingo B (2018) How much of the world's food do smallholders produce? *Global Food Security* 17:64–72. https://doi.org/10.1016/j.gfs.2018.05.002; Herrero M, Thornton PK, Power B, Bogard JR, Remans R, Fritz S, Gerber JS, Nelson G, See L, Waha K, Watson RA (2017) Farming and the geography of nutrient production for human use: a transdisciplinary analysis. The *Lancet Planetary Health* 1(1):e33-42. https://doi.org/10.1016/S2542-5196(17)30007-4

42 Ricciardi V, Ramankutty N, Mehrabi Z, Jarvis L, Chookolingo B (2018) *Op. cit.*; Samberg LH, Gerber JS, Ramankutty N, Herrero M, West PC (2016) *Op. cit.*

43 Gliessman, S (2013) Agroecology and food system transformation. *Agroecology and Sustainable Food Systems* 37(1):1-2. https://www.tandfonline.com/doi/abs/10.1080/10440046.2012.734264; IPES Food [International Panel of Experts on Sustainable Food Systems] (2018) *Breaking Away from Industrial Food and Farming Systems: Seven Case Studies of Agroecological Transition*. Brussels, Belgium: International Panel of Experts on Sustainable Food Systems. http://www.ipes-food.org/_img/upload/files/CS2_web.pdf

44 Buergi Bonanomi E, Jacobi J, Scharrer B (2018) Food sustainability in Bolivia through fair food in Switzerland. How to improve food sustainability in both the north and the south through sustainable trade relations. *Latin American Journal of International Trade Law* 6(2). https://latam.unam.mx/wp-content/uploads/2017/01/V.-6-I.-2-2018-2.pdf

45 IPES Food [International Panel of Experts on Sustainable Food Systems] (2015) *The New Science of Sustainable Food Systems: Overcoming Barriers to Food System Reform*. Brussels, Belgium: International Panel of Experts on Sustainable Food Systems. http://www.ipes-food.org/_img/upload/files/NewScienceofSusFood.pdf

46 Claeys P. The rise of new rights for peasants (2018) From reliance on NGO intermediaries to direct representation. *Transnational Legal Theory* 9(3-4):386–399. https://doi.org/10.1080/20414005.2018.1563444

47 Girard F, Frison C, editors (2018) The Commons, Plant Breeding and Agricultural Research. New York, NY, USA. Routledge. https://bit.ly/2U5vQNF

48 FOEN [Federal Office for the Environment] (2018) *Environmental Footprints of Switzerland: Developments from 1996 to 2015*. Bern, Switzerland: Federal Office of the Environment. https://bit.ly/2oXClmX; Sachs J, Schmidt-Traub G, Kroll C, Lafortune G, Fuller G (2019) *Sustainable Development Report 2019*. New York, NY, USA: Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN). https://www.sustainabledevelopment.report/