Beyond yield and toward sustainability: Using applied ecology to support biodiversity conservation and food production

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Several global assessment efforts indicate that greater action is required to halt biodiversity decline, ecosystem degradation and to increase food security (e.g. Intergovernmental Panel on Biodiversity and Ecosystem Service (IPBES) assessments; Food and Agriculture Organisation reports Tracking progress on food and agriculture-related SDG indicators 2023, the World Wide Fund Triple Challenge report and the Kunming-Montreal Global Biodiversity Framework). All report an urgent need to reduce and reverse land degradation as a means to increase food, fibre and water security and to ensure the management of agricultural production systems supports biodiversity conservation. This is further complicated by increased global demand for food production, expected to increase by 30-62% by 2050 (van Dijk et al. 2021). Greater effort and more difficult decisions will be needed to increase agricultural production in a sustainable manner. Agroecological research has an important role in supporting evidence-based land management to ensure food production is achieved whilst minimizing the impacts on biodiversity and its associated ecosystem processes and services.

Agroecosystems do not just provide food, feed, fuel and fiber~~fibre~~, but also supply, and are reliant on, a range of ecosystem processes and services. Understanding these connections is key to Environmental Social and Governance (ESG) sustainability reporting and obtaining the Sustainable Development Goals (SDG) goals of improved productivity whilst maintaining sustainability and ecosystem function (Blicharska et al. 2019). Industry stakeholders need to continue optimizing~~optimising~~ production metrics to be competitive in open markets. However, the impact of global change drivers (e.g. climate, land use change) and increasing awareness of the dependencies and risks associated with biodiversity loss upon corporate sustainability, are enacting greater motivation toward reporting against sustainability guidelines (e.g. Global Reporting Initiative standards). Yield, biomass and food quality metrics are driving GDP and other global indicators, but these metrics are underpinned by biodiversity and associated processes and services. This nexus between the often competing priorities of optimal production and sustainability requires greater knowledge of management decisions to enact more sustainable and transformative practice change and to better conserve biodiversity (Diaz et al. 2019). Demonstration of environmental, social and governance (ESG) performance against global standards is increasingly being recognised by the global economy's major players as the best route to future risk mitigation and financial performance. As global understanding deepens of the consequences of biodiversity loss upon the economy, the significance and urgency of the need to transition to a nature-focused reporting framework calls for bold corporate action.

These circumstances have motivated us to identify important steps we could take, as editors of *Journal of Applied Ecology,* to highlight some of the key knowledge gaps concerning the role of biodiversity and the ecology of food production systems and direct the scope of agroecological studies to reflect these knowledge gaps (i) The use of appropriate indicators to measure dependencies and impacts upon biodiversity; (ii) Methods to improve the management of resources to support the "health" of biodiversity within agroecosystems; (iii) Greater understanding of the ecosystem processes, and services generated and received across terrestrial and aquatic habitats.

The use of appropriate indicators to measure dependencies and impacts upon biodiversity

Agroecology is underpinned by knowledge of fundamental ecological mechanisms to improve agricultural production. However, many agronomic studies focus on how to improve agricultural production through traditional intensification of practices such as increasing pesticide, water and fertilizer~~fertiliser~~ use. A focus solely on management for optimal production, however, overlooks the myriad of interactions with above- and below-ground biodiversity across both natural and managed systems. For example, interactions between birds, bats and ants resulted in positive and negative impacts on cacao yield (Ocampo-Ariza et al. 2023), and landscape-level planning with varying intensities of forestry management can increase biodiversity gains within forestry systems (Moor et al. 2022). A greater number of studies that report agricultural productivity outcomes in unison with environmental (e.g. Marja et al. 2024), social, and economic indicators will more adequately support ESG and SDG progress reporting in relation to sustainable food systems and may help to balance and select optimal management practices.

It is well established that the diversification of farming systems to include biodiversity conservation and incorporate different species or genotypes of plants, fish, and livestock at multiple scales can improve biodiversity and associated ecosystem functions and services (e.g. He *et al*. 2023). Yet, a greater understanding of the interactions among services, taxa and/or systems can help identify management practices that optimize biodiversity conservation with little impact upon productivity.

Management of domesticated species underpins global food production, however, a greater focus on direct and indirect relationships to biodiversity or natural systems is becoming increasingly important to inform ecosystem management at broader scales.

In particular, studies of managed (e.g. honey bees), domestic (i.e. cattle) or cultivated taxa (crops) need to be presented in an ecologically-relevant context. Ideally, studies focusing on managed taxa need to include relationships with wild biodiversity and/or the surrounding environment of the system (i.e. positive or negative or neutral). These might include pollination or pest control services to crops by wild taxa, the contribution of soil, microbe or plant biodiversity to production metrics or those that measure variations in production in response to biodiversity management.

Further, many insights into mechanisms underpinning the relationship between biodiversity and ecosystem services have been gained from studies conducted in controlled environments such as mesocosms, glasshouses or experimental plots (Manning et al. 2019). Priorities include studies with application to the management of biodiversity, rather than the optimisation of a cultivated or managed taxon. While these types of studies are important to determine impacts to specific parameters and/or their interactions with other taxa, response to disturbances or global change drivers, ideally, such studies should be validated in open systems at the landscape scale or beyond to maximise their relevance for management.

Methods to improve the management of resources to support the “health” of biodiversity within agroecosystems

Although human health is understood as the physical, mental, and social well-being of an individual or population, the health of plants and animals has generally been understood as the absence of disease, small or declining populations. Integrated approaches that recognize the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent and are urgently needed (de la Riva et al. 2023). Studies that incorporate either the individual (disease, etc), the species (population size and status), the community (diversity, composition) and/or its functions would enable a broader appreciation of the important role of biodiversity in production systems (Cook et al. 2000; Parreño et al. 2022).

Often, organisms existing within agroecosystems have already passed through a strong selection filter, eliminating the most sensitive habitat specialists (Gallé et al. 2019). Those that remain are, therefore, adapted to using the resources embedded within a matrix of land use types and are generally able to utilize agricultural resource subsidies effectively. However, given the often transient availability of resources, a greater understanding of resource needs within these modified systems is required. Many studies report patterns of animal or plant diversity, or the response of biodiversity to human-mediated disturbance within agricultural systems, without implicitly relating the finding to better management of that biodiversity or system or tools to improve the health of that species or community. While long-term monitoring and surveys are one way to measure changes in population over time, a greater focus on improving population or community ‘health’ would ensure the focus shifts toward the resources needed to support the biodiversity in agroecosystems. A greater number of studies that improve our understanding of the connection between resource needs and their management to improve the functioning of the individual taxa, populations, communities or systems and/or land management practices to support conservation of biodiversity and their resource needs is an important next step. Understanding how to improve health in agricultural systems could be applied to other wild animals that use agricultural systems, such as predators, frugivores and herbivores. Any new methods reported must target improved management of systems to better conserve biodiversity, rather than to primarily aid researchers in data collection. Methodological advances that support our understanding of how to improve health in agricultural systems could include (i) more effective ways to measure, monitor change and manage and conserve biodiversity (e.g. multi-spectral drone imagery, passive acoustic recorders, and eDNA; Gibb et al. 2018, Taberlet et al. 2018; Darras et al. 2019; van Klink et al. 2022), (ii) studies that address social, ecological and/or economic stakeholder priorities in relation to topical issues (e.g. the challenges of reducing pesticide use in agroecosystems); (iii) tools to more effective manage above and below-ground ecosystem processes and functions at multiple trophic levels in agroecosystems (Soliveres et al. 2016). These studies would ideally demonstrate how the findings could be used to change existing recommendations for managing a particular land use, system or threat.

Greater understanding of the ecosystem processes, and services generated and received across terrestrial and aquatic habitats

While agricultural studies often focus on terrestrial landscapes, these systems can be tightly linked with marine and freshwater systems. Vegetated coastal marine habitats, specifically coral reefs, seagrasses, mangroves and tidal marshes, contain up to 50% of all the organic carbon buried in ocean sediments (Duarte et al. 2005). These habitats support coastal communities by providing food, jobs, recreation, clean environments and protection from storms. Understanding how agricultural production systems can be better managed to reduce impacts on aquatic ecosystem functions and services is still a significant knowledge gap (Sutherland et al. 2020).

A significant amount of food production comes from river and ocean systems, yet these environments have been degraded by human impact, including habitat conversion, overfishing, pollution, agricultural production and unsustainable development. Because the water and materials in most freshwater systems come from the catchment area, they also receive runoff that contains wastes, sediments, and pollutants from agricultural lands, which ultimately affect coastal and marine ecosystems. Excessive use of fertilisers and pesticides is listed among the major threats to freshwater biodiversity (Reid et al. 2018). Impacts upon aquatic ecosystems have a strong effect on global processes, as aquatic systems are responsible for processing carbon, cycling nutrients and supporting a disproportional amount of global biodiversity (Howard et al. 2017). For example, recent evidence indicates that streams and rivers, previously seen as sinks of carbon, can emit substantial amounts of CO2 and CH4 in agricultural catchments (Stanley et al. 2015; Blackburn and Stanley 2020). Thus, it is urgent that we understand the impacts of externalities and indirect spatial effects propagated through biotic and abiotic fluxes associated with agriculture upon aquatic environments.

Understanding the impacts of agriculture across land and water will enable improved management of ecosystem functions and services. Marine and freshwater aquaculture are growing quickly and have substantial effects on people and the environment as there are many potential carbon sources and sinks associated with operational (on-farm) activities in the bivalve, seaweed and fed finfish aquaculture sectors. Existing research has demonstrated that marine aquaculture can contribute to ecosystem service provisioning that extends beyond production of a resource, however, the extent and significance of these goods and services are not well understood (Sutherland et al. 2020).

Agroecological research in a new global context

While there are many challenges and impacts that face the research community, the role of researchers in contributing robust science to support more sustainable food production is becoming increasingly apparent (Enquist et al. 2017).

Many initiatives are in progress to measure and monitor global change relevant to agroecosystems (e.g. Global Reporting Initiative, United Nations Conferences of the Parties (COP), the "30 × 30" biodiversity framework, biodiversity offset and credit schemes etc.). These initiatives present exciting opportunities for the scientific community to engage with and contribute to policy, in particular, the need for robust evaluation and assessment. There is a need to develop, critique and validate the use of biodiversity indicators and accounting methods, to ensure that science and evidence are embedded within these new initiatives. In particular, new metrics that reflect the state of ecosystem processes, functions and services, are urgently needed.

Conclusion

In conclusion, practice change and transformation will need new tools and strategies to meet upcoming 2030 SDG goals and new global biodiversity standards. We hope that the pages of the Journal of Applied Ecology are used to further these fundamental goals. Rather than agricultural research with the sole aim of increasing output in the absence of biodiversity, we see the Journal of Applied Ecology serving as a conduit for globally relevant research at the interface of agriculture, ecology and biodiversity conservation, considering social and economic aspects for a sustainable future.

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