OPPORTUNITIES TO ADVANCE THE ROLE OF BBSRC IN BIODIVERSITY RESEARCH.

SUMMARY

Research relating to biodiversity is relevant across BBSRC's key research and innovation priorities, particularly at a molecular level and within the context of agricultural organisms and systems.

This report summarises the key findings of the BBSRC biodiversity expert working group. The purpose of the expert working group was to provide strategic advice to BBSRC on the role of bioscience in advancing research and innovation relating to addressing biodiversity challenges and opportunities.

The expert working group were presented with evidence on the role of biosciences in biodiversity from several different sources:

a. A survey was sent out to BBSRC's strategic partner universities and strategically funded institutes to ask them about their perspectives on biodiversity.
b. BBSRC organised two community workshops to ask for perspectives on biodiversity from a wider selection of the community.
c. An internal portfolio analysis on what BBSRC has funded on biodiversity since 2018 was conducted.

The report is being made available here to give more detail to the new area of investment and support page "BBSRC Biodiversity Research" which describes important areas of biodiversity research that guide BBSRC's strategy in this area and also includes some illustrative examples. We hope the information will be useful to the research community in understanding areas of the biodiversity research and innovation agenda in which bioscience can play a key role.

Introduction

Biodiversity is a broad concept with varying usage. Article two of the Convention on Biological Diversity[1] contains the following definition: “Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems.” Significant areas of biodiversity research lie within BBSRC’s remit, particularly at a molecular level and within the context of agricultural organisms and systems.

Research relating to biological diversity is relevant across BBSRC’s key research and innovation priorities. BBSRC has partnered with NERC, the main UKRI council to support biodiversity and nature-based research, on this topic historically. This is important as there are many interfaces between ‘managed’ systems in agriculture or aquaculture and the wider natural environment. Aspects of biodiversity research are also relevant to UKRI’s five cross-Council strategic themes[2], including Building a Green Future, a Secure and Resilient World, Better Health for Everyone and Tackling Infections. Many of the themes identified in this report should be explored in the wider context of cross-UKRI working.

We are living in a time of poor planetary health which includes extreme biodiversity loss. The UK is now one of the most nature-depleted countries on Earth[3]. Globally, many biodiverse areas are reported to be approaching tipping points or regime shifts, beyond which they will be unable to recover. This biodiversity loss is largely driven by human activity and its impacts on the environment, including agriculture and food production. Aligning well to BBSRC’s remit and priorities, central to the Global Biodiversity Framework is reducing and reversing key drivers of biodiversity loss while meeting the needs of people through sustainable practices.

The speed of biodiversity decline necessitates urgent and effective actions to halt further loss, actions that need to be informed by high quality research and innovation. Biodiversity loss has many drivers, including land use change, pollution and climate change, but it is not only an outcome of these threats. It is critical to recognise biodiversity loss is itself a crisis which will lead to loss of critical ecosystem services[4] on which humans depend. Beyond conservation of existing biodiversity, restoration of biodiversity through nature positive and agrobiodiverse systems is becoming increasingly recognised as a goal that would not only benefit nature but also have wider benefits such as strengthening resilience to climate change effects, improving resource usage, improving soil health, and contributing to long-term farm productivity.

Like climate change, there is urgency around the issue of biodiversity given the range of threats involved. This necessitates a search for better evidence, interventions, and solutions that will require interdisciplinary approaches. While bioscience will have a significant role to

[1] https://www.cbd.int/convention/articles?a=cbd-02
[2] https://www.ukri.org/who-we-are/our-vision-and-strategy/ukri-strategic-themes/
[3] TP25999-State-of-Nature-main-report_2023_FULL-DOC-v12.pdf (stateofnature.org.uk)
[4] UK National Ecosystem Assessment: Ecosystem Services

play, fostering partnerships with other fields (e.g. environmental, physical, economic, social and medical sciences) and stakeholders (e.g. industry, policy, end users) will be needed considering the complex nature of the challenge.

Key Findings and Opportunities

There are many new opportunities to progress knowledge by considering bioscience through the lens of biodiversity. **Biodiversity can be a solution to wider societal issues.** This was a point repeated by the working group and is embedded throughout our findings. **Research and innovation have the potential to unlock biodiversity with massive potential benefits** to sustainable agriculture, one health, climate change mitigation and adaptation, the green economy, and industrial biotechnology. It is essential that we protect our natural capital by embedding more sustainable practices into the economy as this will be central to maintaining the long-term economic well-being of the UK. Research is needed so policymakers and broader society can make nature-positive decisions that are evidence-based and that use the potential of our natural capital in sustainable ways.

- If we tackle the root causes and interactions causing biodiversity loss, such as pollution, climate change, land management and land use change, then the overall impacts of improved biodiversity should be a much more resilient ecosystem that positively impact other major challenges such as one health, food security, biosecurity, people's health and wellbeing, and national resilience.
- Genomic diversity is a source of next generation technology and future prosperity. With wider availability of rapid next generation sequencing and genetic tools, there is an opportunity to unlock innovations derived from biodiversity in many areas. There are still many chemical pathways and enzymes to be discovered which may feed innovation, e.g. in engineering biology, drug discovery, and sustainable alternatives to chemicals.

Emerging from this project the following themes were identified as opportunity areas for bioscience. These ranged from opportunities afforded by new technologies and approaches, key knowledge gaps, more integrated cross-disciplinary working, emerging needs at a policy level, and underpinning 'enablers' needed to help progress biodiversity research and impacts.

Frontiers of Knowledge

Targeted research into functional diversity

Targeted research into functional diversity will help address gaps in understanding that make it difficult to predict organismal responses to biotic and abiotic factors in a changing environment. There is need to gain greater understanding of potential long-term impacts of functional shifts and the evolutionary forces acting on these populations, as well as how these could be effectively managed. Within food production systems, important groups of organisms such as pests, pollinators, natural enemies, and microbiomes contribute not only to ecosystem health but also key ecosystem services, including those that underpin food production.

- As the number of available reference genomes for non-model species expands, we need to support greater understanding of genotype-phenotype relationships. This means recognising the functional measures of diversity linked to genetics in organisms and how these relate to the wider system. The types of traits linked to threats such as climate change are a particular priority to help build resilience, both to protect biodiversity and to ensure other needs such as food security continue to be met.
- Many newly discovered molecules and enzymes with structures interpreted from emerging tools such as AlphaFold are performing ecological processes *in situ* that should be understood. Understanding the *in situ* function will drive research on linking up structure to function which is key for many areas of synthetic biology.
- To achieve effective management of biodiversity, we need greater understanding of the limits of phenotypic plasticity and to understand why some species are more resilient to changes than others. For example, species that have successfully invaded new areas, especially ones that are struggling in their native environments, could provide novel insights.
- There is growing capability for monitoring of the abundance and roles of species, as well as intraspecies diversity, rather than just their presence/absence. Roles for underpinning processes such as epigenetics in the context of biodiversity need to be better understood to manage risks to populations.
- There is a key role to be played by biological collections in supporting biological discovery that is valuable to a wide range of researchers in academia and the commercial sector. Integration of modern molecular methods and better phenotypic characterisation of these resources will fully unlock their potential for the research and innovation community.

Expanding our understanding of life and underexplored biodiversity

Expanding our understanding of life and underexplored biodiversity will continue to yield valuable insights**.** We need a greater in-depth knowledge of a broader range of models relevant outside of biomedicine, particularly those important in a biodiversity and environmental context; for example, marine, soil, invertebrate, and microbial diversity. Mechanistic understanding is vital for identifying potential routes for intervention or understanding the underlying causes of effects on species. Such insights are becoming more feasible owing to growing genetic and genomic resources across species.

- Substantial progress has been made in both genomic resources and genetic tools in non-model species, with the research community now looking to exploit these to derive functional insights. Aims now should be to create a second tier of model organisms through which in depth understanding can be built that is more directly linked to biodiversity-related challenges. More general expansion of the availability of reference genomes and related resources is also of substantial value, with leading activity in this area already ongoing in the UK through the Darwin Tree of Life initiative. There is an opportunity to use modern methods to better understand the diversity contained within collections to optimise their usage.

- The transfer of understanding on physiological processes from model to non-model species should mean deeper understanding of organisms that have key roles in a biodiversity context, such as pollinators. This can be used to make more accurate predictions on understudied species adaptive responses to environmental stress. Improved 'lab to field' and 'field to lab' linkages in the study of biological systems will contribute to improved underlying theory and reliability in translating studies to practical use.
- It's vital that typically underexplored organisms are more widely studied to develop the deeper system understanding of biodiversity. Relevant examples include broad microbial diversity (including microorganisms that are sometimes labelled as 'biological dark matter' due to their difficulty to culture), marine diversity, soil, peatland, invertebrates, and the rhizosphere. There is intrinsic interest and potential for discovery in such studies, as well as key data to understand landscape and system function.

Addressing Critical Challenges

Biodiversity is a source of innovation and green solutions.

Biodiversity should not just be viewed from the perspective of guarding against loss, but its study can also be the source of solutions and innovations to key issues. With the advent of more rapid sequencing and genetic tools, there are new opportunities to harness diversity in a wide range of organisms through the advent of many engineering biology methods. There are many applications that can come from the understanding of fundamental molecular diversity and processes. Many biobased solutions offer greener and more sustainable alternatives that will provide direct benefit back to biodiversity; for example, through more sustainable agricultural approaches.

- Using knowledge gained from wider genetic biodiversity, many engineering biology innovations can be derived. These have included developing plastic degrading enzymes, biobased methods for water pollution clean-up, precision breeding crops and livestock, anti-microbial and drug discovery, or gene drives for disease management. However, the societal acceptability of engineering biology methods must be explored. If methods are not appropriately explained to the public, it is likely they will be considered unsafe and rejected. Some methods have potential knock-on impacts that need sociological study to recognise if people are accepting of some risks in these areas, such as the implications of gene-drives regarding containment.
- There are many innovations stemming from biodiversity to be targeted in the food systems sector: development of crops more resilient to pests, novel bio-control approaches to reduce pesticides, and lowering artificial N and P inputs which spill over into the environment. Harnessing soil, animal and plant microbiomes could potentially benefit biodiversity and help meet other goals such as food production and net zero, but this remains complex to achieve and the longer-term impacts in these instances need to be understood, e.g. of using synthetic modifiers. Many

biodiversity solutions can also contribute to key climate change targets, e.g. through improved carbon sequestration.

- There needs to be greater recognition of the potential bonuses to the economy from biodiversity research – there is a lot of potential untapped industry in using natural capital.

Improving food production systems is key to address biodiversity loss

Approximately 70%[5] of UK land is used for agriculture, so agriculture is a key opportunity to positively impact biodiversity and nature recovery through better management. As noted earlier, biodiversity itself holds promise in providing innovative solutions; for example, using plant diversity to develop crops that require lower inputs or are more pest resistant. Environmental and agricultural policies and practices need to be underpinned by higher quality and more robust evidence[6]. With the introduction of new agri-environment government support payment schemes, as well as private nature credit schemes, there is a growing need to use robust, consistent and accurate methods to inform agri-food actors how to improve biodiversity.

- BBSRC should continue to support research that enables transition to food production systems that address drivers of biodiversity degradation and support improvements in biodiversity. We must ensure that the scientific community works more effectively with stakeholders including farmers, agronomy companies, and policy makers to provide evidence and innovation that can support an agricultural transition and avoid wasted effort. Models of support, such as the 'multi actor approach'[7], for these collaborations need to support the roles of such stakeholders.
- The research community should work collaboratively with key stakeholders to develop nature positive, low-input crop and animal production systems that provide multiple benefits for nature, people, and the environment. This includes approaches to better integrate crops and farmed animals into mixed and agro-biodiverse systems (e.g. through silvopastures and multi-trophic aquaculture) as well as circular approaches that maximise co-benefits (e.g. smart use of manures and other organic amendments for soil fertility and utilising crop residues for feed). Novel crops, and cropping systems, should be developed that use knowledge from wild crop equivalents. We must accelerate the use of the genetic resources held in gene banks – amongst them there is potential knowledge to help build resilience to climate change, pests, and poor growing environments. There are several underutilised crops that need cultivation practices developed that would lead to biodiversity increases.

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[5] Hannah Ritchie and Max Roser (2019) - "Land Use" Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/land-use' [Online Resource]

[6] Natural England – Agri Environment Evidence Annual Report 2023 - NERR138 Agri-Env Evidence Annual Report 2023 - NERR138 (naturalengland.org.uk)

[7] Multi-actor projects – research and practice co-creating solutions | EU CAP Network (europa.eu)

Greater systems-level understanding of biodiversity and how it relates to wider challenges.

Biodiversity is intrinsically linked across a range of societal needs and challenges and systems level thinking is needed in a policy context. It is important to build accurate and high-quality models that can factor the complexity of agri-environment systems across a range of scales.

- There is an increasing recognition of the need for systems thinking for complex challenges and a vital need to consider biodiversity within this context. For bioscience, this would include understanding links between areas such as antimicrobial resistance, one health, and climate change, as well as understanding wider socioeconomic factors and how human behaviours might exacerbate disease or other ecological threats.
- Modelling complex, multiscale systems from molecular to landscape level requires a greater focus on biomathematics, computational data integration, and statistical methods within the research community. Building systems such as digital twins can help validate or refine theories relating to biodiversity and [agri-]ecosystems, as well as improving biodiversity monitoring and management within a wider systems context. These models can then be used for predicting future system changes, with and without interventions. There is an opportunity to develop a means of evaluating solutions as well as measuring what is happening in this context.
- There is a need to understand stable systems, what makes systems resilient, and what we can learn from this, as well as identifying key vulnerabilities. It's important to know whether functional elements of systems are being lost and what could be the consequences of this. *In silico* models must be effectively linked back to on the ground monitoring (calibrating and quality control of the models). In turn, there is an opportunity to facilitate greater understanding of the functional impacts of alterations to biodiversity and their subsequent effects. Bridging the gap between lab to field studies (and vice versa) could help unlock novel insights in this area, particularly at a functional level.

There is a growing need for improved evidence to support changes affecting biodiversity.

There are many drivers of change including climate change, pollution, reforms to policies and management practices in farming and land use more generally. It is important to understand the impacts of each on biodiversity and have robust evidence that underpins decision making, interventions and changes in practice.

- There needs to be more straightforward and facilitated access to agri-environment data for research purposes. Better use of data will provide insight into the effects of interventions to guide practice, particularly in relation to regenerative agriculture and emerging practices in this area. We urgently need appropriate ways to model whole systems to predict the outcomes that changes will lead to, which requires developing accurate metrics and integration of whole system data. Open data and dashboards

can help create positive feedback loops with the community, including farmers and policy makers.
- In response to a range of change drivers, there are many innovations being developed in the food systems sector and policy that promise to have positive impacts on biodiversity while reducing environmental threats. These provide many opportunities to study the effectiveness of interventions, ensure they don't have unintended effects elsewhere, and understand their suitability within and across a range of landscapes. Solutions and interventions being developed by the commercial sector are not necessarily fully understood or validated. This is particularly important for stakeholders such as landowners, local councils, and other organisations who are making decisions in the context of Biodiversity Net Gain (BNG) policies without reliable information on their relative efficacy.
- There should be recognition of the multi-dimensionality effects of interventions. The greater recognition of the importance of agroecology alongside productivity and yield means there is a timeliness for these capacities within the agri-community. Land use changes that are climate positive may be biodiversity negative, or we may unintentionally 'export' biodiversity loss overseas if changes in the UK increase pressures elsewhere. Therefore, embedding more systems thinking into research on agri-environment topics should be explored.

Key Future Enablers

Opportunities from novel technologies.

Developments in technologies means this is an area to focus on, as these present ways of rapidly advancing the field through new capabilities, delivering improved ways of working and unlocking deeper understanding.

- Throughout this project there was much recognition of how biodiversity research can be fundamentally changed by AI, with significant community interest in understanding this potential better. There are opportunities to look at much bigger and broader data sets; for example, interrogating multimodal datasets to identify underlying patterns and relationships that would be difficult to identify via conventional means. AI can also automate traditionally laborious manual analyses such as species identification and enable efficient management of streamed data from sensors, but some risks exist around robustness of AI outputs.
- Further developing sensor and remote sensing methods should mean detailed monitoring of landscapes across the system scale is possible. Integrated with AI this should mean richer automated monitoring enabling deeper insights and more targeted interventions and solutions. There are potential synergies between BBSRC, NERC, EPSRC and STFC communities in these areas, particularly in relation to key functional data that can be derived from these technologies.
- Genomics remains a key technology to understand biodiversity, from the perspective of reference genomes, wider use of genomic technologies for understanding within and between species diversity, and new genomic approaches such as use of eDNA

for species monitoring. There are nevertheless continuing challenges around interpreting genomic data and the genotype-phenotype relationship.

- Data integration was highlighted as an increasingly important challenge requiring interdisciplinary working and strong computational skills. There are challenges integrating new data types and data collection approaches with historic datasets to give agri-systems insights and inform changing practices.
- There are many opportunities for skills development with new technologies across career stages, and to build future capacity in this area within the research community. For example, genomics methods, quantitative genetics, AI and data science are key. Nevertheless, it is critical that the traditional skill sets, such as taxonomic skills, are equally valued especially as these skills are being lost. For example, automated monitoring techniques will rely on initial quality training data and must be continually validated and interpreted by experts in the underlying biology.

Collections, longitudinal datasets, and wider infrastructure are essential in supporting biological diversity.

We need to have better characterised collections and an understanding of what diversity they hold. There are challenges of how to do this at sufficient scale and in ways that are most useful for subsequent users, e.g. for plant and animal breeding or biotechnology.

- The UK has specific strengths in its collections and long-term studies and datasets. The Darwin Tree of Life (DToL) project, the Watkins collection, Rothamsted's insect surveys and North-Wyke farm Platform, Wytham Woods study site, the Natural History Museum and Kew Gardens are a few examples of world class collections, facilities, studies, and datasets. Resources which bring together data/ tissue/ organisms that are a stored representation of an element of biological diversity and can be used for further research are of particular interest to BBSRC's community. It is vital that these strengths are maintained and enriched in terms of characterisation of collections so that they can be effectively harnessed. Using new automated methods, digitisation of collections is more feasible than ever and this needs to support greater integration from different data types such as genomics, imaging, and other phenotypes to be valuable to a wide range of researchers in academia and the commercial sector. This is important if data from such resources are to be explored using AI, where algorithms need to be carefully developed cognisant of where the underlying data might bias performance. Many noted that new reference genomes are still a vital resource and that DToL has made significant progress in this area, but long-term funding will be needed to maintain this capability.
- Historic and archaeological collections have an important role to play in comparing the current state of systems to potentially less degraded, historical states. Further digitisation of these collections may make them more accessible[8]. Facilities and collections should have greater capacities to offer training. There are critical areas

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[8] During discussions on this project the DiSSCo project was funded from UKRI infrastructure fund - [Major research and innovation infrastructure investment announced – UKRI]

required for long term success in biodiversity research including -omics skills, statistical methods, use and training of AI and classical taxonomy skills.

- Biodiversity research will rely on quality data infrastructure. Its critical to ensure that data collected on biodiversity is usable, correctly stored, open and labelled. The data should also be standardised as per FAIR (Findable, Accessible, Interoperable, Reusable) principles if its value is to be maximised. Quality data will underly many biodiversity research breakthroughs and AI methods will only be as good as the data that underlies them.
- Long term studies have particular value in the context of biodiversity but funding models for such work are currently limited. Sustainability of infrastructures such as collections also remains a concern, limiting opportunities for innovation in what they can offer to the broad community. Many government departments hold relevant long term datasets that are invaluable for research purposes, but these are not always readily accessible to the research community, and sometimes the research community are not even aware of them. There is potential to take some lessons from other fields, such as the health data research UK initiative in medical sciences, to work in partnership and identify appropriate ways of opening up biodiversity and other relevant agri-environment data.

Cross-disciplinary networking and a global perspective is required.

There were several topics raised through the project that were more focussed on ‘ways of working’ and less on specific research goals. Critical to advancing the field is bringing together communities to accelerate application of new science, share knowledge, data and best practices. Biodiversity is also currently high on the political agenda for many countries, so it is useful to use this momentum to build suitable partnerships.

- There should be greater consideration for ways to consolidate and bring together people across the field. There are still lots of siloes and scope for more cross pollination in biodiversity research and innovation. It was noted that network funding is sometimes integrated into strategic programmes, but that longer term approaches to networking outside of specific programmes could be beneficial for community building. Nevertheless, targeted funding can create cohorts of researchers that come together even though they are working on different projects and play an important role in building capability.
- There should be more collaborative approaches across academia, industry and wider stakeholders. The commercial sector moves so fast it can be difficult for academia to keep up.
- There remains an opportunity to work collaboratively and develop international partnerships, noting previous initiatives in this area through GCRF and Newton have established capability in this area. It is important to support developing research capabilities in global biological diversity hotspots, especially in developing countries. Action in this area must be mindful of appropriate access and benefit sharing. The recent agreement from COP16 on digital sequence information shows a framework

of policy on how to share benefits of commercial profits gained from genetic resources[9].

- Researchers should be encouraged to take a multi-actor approach especially when various stakeholders may be affected by their research. Co-design with relevant stakeholders, including farmers, should be enabled when undertaking research in areas like sustainable agriculture where success relies on community uptake.
- There is a need to take a global system perspective of biodiversity. Biological diversity markets will shape national and international biological diversity action. We must ensure that pro biodiversity solutions are not just exporting the problem overseas through changes to UK based agricultural practices and productivity.

[9] Digital sequence information on genetic resources