Technologies for ecological research – Insights from the Royal Society Global Environmental Research Committee

This paper represents the output from a discussion on the use of technologies in the field of ecology at the Royal Society Global Environmental Research Committee (GERC) meeting held in November 2020 (see box on page 3 for context). It seeks to highlight technologies for ecological research of interest to researchers, funders and government.

Executive summary

GERC has highlighted a number of technology related opportunities that could provide significant advances in areas of community and ecosystem ecology, including on species interactions and behaviour, species and ecosystem responses, species movement and habitat use, and spatial and temporal dynamics of species.

Key priority areas for research or investment are:

1. The development of technologies capable of monitoring response variables beyond environmental properties, such as species interactions, behaviours and the multi-dimensional tracking of their movements.
2. Repurposing low-tech devices that can offer immediate, reliable and scalable solutions for large scale and/or long-term observations. There are opportunities to redeploy technologies used in one domain that could offer novel insight in other domains. There is an urgent need to understand which technologies are available and how they can be repurposed.
3. Establishing smart research environments in ecologically significant locations across ecosystems, including scalable citizen science, partnership opportunities and open data access.

Cross-cutting challenges include:

A. Identifying research areas in which the UK can become a world leader, by linking the usage of technologies with the growth of technological hubs for development and commercialisation.

B. Generating innovative technological solutions in response to specific ecological research needs and challenges rather than being technology led.

C. The need for a mechanism to marry technological expertise with ecological insight.

Introduction

The use of technologies in the field of ecology is widespread, with the UK playing a leading role in the development and use of a variety of sensors and platforms on land and in the ocean. However, the capabilities of many technologies are currently confined to sub-disciplines within the field, to specific habitats and species, or niche areas of research that are not widely known or appreciated. There are opportunities to repurpose technologies used in one domain to offer novel insights in other domains. In addition, large-scale deployments of multiple low-tech devices offer services that differ from those provided by the development of fewer or single high-tech technologies and therefore deserve adequate attention. Moreover, much of the research experience in recent years has emphasised a need to continually improve the accuracy, reliability and durability of existing technology.

The aim of this discussion meeting was to explore the wide variety of technologies that are available and offer great promise in the field of ecology, and to emphasise areas where reimagined technological knowledge or novel technological applications might lead to significant advances in ecological research, such as on species responses to climate change and the redistribution of biodiversity.

Areas for the use of technology in ecology

The GERC discussion identified four key areas for the use of technology in the field of ecology (listed in no particular order):

1. A new era of spatio-temporal ecology

Decades of ecological research have mainly relied on point observations in time or space when ecological processes occur over multiple spatial and temporal scales. For example, remote sensing from satellites and aircrafts revolutionized the study of spatial ecology at large scales, but the resolution was insufficient to capture many ecological processes and species interactions at landscape scale. Detection of community dynamics at the scale at which they happen requires high resolution techniques, such as laser scanning and structure from motion photogrammetry, that can be upscaled from four dimensional digital models[i] . By using these techniques, the ecological spatial domain can be viewed as a continuum, replacing previous methods that separated habitats or the surface from the subsurface.

Machine learning can help identify ecological features of interest within the footprint of a focused area and/or across the broader scale[ii]. Releasing the constraint of scale dependence presents a new opportunity to interrogate ecosystems at the temporal and spatial scales at which they operate and removes the need to compartmentalize the environment into arbitrarily defined habitats.

2. Continuous observation capability

Low powered computers and/or microcontrollers coupled with on-site power generation (e.g. solar-batteries, bio-batteries) can operate continuously in remote locations and communities, allowing rare or unanticipated events to be captured and data collection to take place when access is infrequent or otherwise restricted (e.g. breeding periods, high altitude/deep ocean, seasons, night/day). Similar transformative capacity can be achieved spatially using large-scale deployments of many low-tech devices (eg *Warblr,* a smartphone app for birdsong recognition) rather than focussing on the development of high-tech devices.

Servicing long term replicated networks can be infrequent (less than annually), but deliver high returns in data capture and analysis (eg as in the NSF funded NEON network). High volume data streams are already being produced in ecology, and the holistic analysis of data streams using artificial intelligence allows new inferences to be made about entire assemblages rather than individual species. Importantly, these techniques can also provide fuzzy observations with meaningful probabilities that extend observations beyond the requirement for confirmed sightings. As many low-tech devices are small, placement can be achieved using drones or other autonomous vehicles, removing or reducing the requirement for costly expeditions and they offer a way to build capacity and support projects in remote or otherwise ill-equipped locations.

3. Open source, open standards and increasing accessibility

Combining new technologies with existing technologies and reimagining how, when and where technology is deployed can lead to new insights and a step change in technological capability. The internet and widespread use of smart phones make professional practices, previously only available after years of training, accessible to a much wider audience through simple-to-use interfaces. *Google Earth*, for example, revolutionises the way we view and interact with the world. In the same way, instructional videos, open-source communities (*RaspberryPi#Ecology, Wildlabs.net*) and online discussion boards (*Naturebytes*) provide problem-orientated advice and solutions, including task specific technical know-how, code, field tests and standards.

There are also global networks designed to partner technologists with ecologists, such as *TechnEcology* (Deakin, USA) and the *Conservation Technology Working Group* of the Society for Conservation Biology. These new types of interactions considerably accelerate capability and, with the right support and investment, have potential to revolutionise the field of ecology.[iii] Next steps include the need for a mechanism to set out acceptable technological requirements, criteria and standards, ensuring that the science produced is consistent and of high-quality.

4. Smart ecological research environments

The integration of multiple emerging technologies, including bio-batteries, low-power and long-range telemetry, internet-enabled devices, swarm intelligence, machine learning, 3D printing, and low-power computers[iv], provide a transformative opportunity for studying species and environments. It is now possible to connect multiple devices together wirelessly, share and log information, and collect additional event triggered data based on set criteria, even in remote locations that lack a source of power.

Although the establishment of smart ecological networks can be readily imagined, the necessary multidisciplinary collaborations between ecologists and technologists from academia and the private sector are comparatively rare and have been difficult to achieve within single research grants. There is an opportunity for the UK to become a hub for the identification, development and implementation of new and emerging technologies and set global standards in the use of smart ecological research environments. Exciting developments in tracking/telemetry are already feeding into global conservation efforts, including the identification of previously unknown species behaviours, their migratory routes, and breeding and feeding grounds.

The context for Global Environmental Research Committee reports

The Royal Society's Global Environmental Research Committee (GERC) is charged with advising the Royal Society, and interacting with research councils, the environmental science community and other relevant bodies. To do this, it is undertaking a rolling series of reviews of areas of science within its remit. Areas it has identified include: air quality, biodiversity, carbon and other biogeochemical cycles, climate, natural resources (including land use) and food, oceans, polar science, and water. In each area, GERC uses its own expertise, and that of a number of invited experts.

This paper results from the discussion on technology use in ecology, organised by Professor Martin Solan and Dr Maria Dornelas and held in November 2020 via videoconference. In addition to contributions from its regular and ex-officio members, the committee was advised by Dr Lars Boehme (University of St. Andrews), Dr Matthew Frost (Marine Biological Association, Plymouth), Dr Julian Leyland (University of Southampton), Dr Ilya MacLean (University of Exeter), Dr Dan Stowell (Queen Mary University of London).

This paper does not seek to represent the views of the Royal Society or to produce a comprehensive overview of technology used in ecology, but instead to highlight some specific areas of potential interest to researchers, funders and government. The absence of a topic from this document does not negate its importance, and many areas that are already under intense research are not highlighted here.

Membership of GERC (including ex-officio members) at the time this topic was discussed (December 2020) was: Dr Maria Dornelas, Professor Peter Smith FRS (Chair), Professor Martin Solan, Professor Louise Heathwaite, Professor Roy M. Harrison, Professor Harry Bryden, Professor Gabi Hegerl FRS, Dr Tim Newbold, Professor John Croxall, Prof Kate Heal, Dr Sarah Webb, Professor Pierre Friedlingstein, Professor Alessandro Tagliabue, Professor Mike Bentley, Dr Kirsti Ashworth. Helene Margue, Senior Policy Advisor, acted as GERC Secretary.

---

[i] D'Urban Jackson T, et al. (2020) Three-dimensional digital mapping of ecosystems: a new era in spatial ecology. Proc. R. Soc. B 287: 20192383 (doi: 10.1098/rspb.2019.2383)

[ii] Yamada et al. (2020) Learning features from georeferenced seafloor imagery with location guided autoencoders. Journal of Field Robotics 38, 52-67. (doi: 10.1002/rob.21961)

[iii] Berger-Tal O, Lahoz-Monfort JJ. (2018) Conservation technology: The next generation. Conservation Letters 11:e12458. (doi: 10.1111/conl.12458)

[iv] Allan BM, et al. (2018). Futurecasting ecological research: the rise of technoecology. Ecosphere 9(5):e02163.10.1002/ecs2.2163 (doi: 10.1002/ecs2.2163)