**GERC paper on priorities in the science area: Natural resources and food**
One of a series of rolling reviews carried out under the guidance of the
Royal Society's Global Environment Research Committee.

**Executive recommendations of GERC on the topic "Natural resources and food"**

GERC recognises a number of areas of science where conditions are now ripe for progress to be made, and recommends that NERC and other UK funding agencies should take note of these in deciding priorities for funding in the next few years. These address three types of natural resource (1) *non-renewable*, which have finite supply (e.g. minerals for fertilisers); (2) *renewable*, but which are poorly managed (e.g. fresh water, terrestrial and marine biodiversity, and soils); and (3) *poorly exploited*, but which are potentially of considerable value (e.g. mesopelagic fisheries, aquaculture, and broadening the genetic basis of food crops).

**Background and discussion**

Food systems are fundamentally underpinned by natural resources (NR): land, soil, water, terrestrial and marine biodiversity, minerals (essential nutrients for crops and animals) and fossil fuels. The use of these resources goes beyond primary food production, including, for instance, the use of fresh water for food processing; materials for food packaging; and biomass for cooking. While primary food production is a major driver of biodiversity loss, soil degradation, water depletion and greenhouse gas emissions, other food systems activities also affect the environment through water use, pollution and energy use.

A recent UNEP assessment noted that food system activities have led to 33% of soils being degraded, 20% aquifers being overexploited, 60% of biodiversity loss and 90% of living marine resources being unsustainably exploited. Further, 80% of minerals mined for agriculture are lost on the 'farm to fork' journey and food systems overall account for 30% of all fossil fuel use and contribute about 25% of all GHG emissions. Against this background, the GERC meeting identified three main areas of discussion:

## 1. Non-renewable NRs which have finite supply

Our ability to meet food demand with current technology depends largely on mined fertilizers, soils and fossil fuels. Key NRs for fertilizers include phosphate rock (P); potash salts and alternatives (K); geological sources for all trace nutrients; and methane for nitrogen fertilizer manufacture. The UK has world-leading mining innovation in but there is also a need to promote soil 'system' science to integrate blue sky mineralogy and blue sky biology to increase nutrient-use efficiency in production systems.

Soils can be considered 'non-renewable' if degradation is extreme. Erosion and compaction linked to common management approaches reduce the useful soil depth from the top and the bottom respectively, Contamination, nutrient depletion and loss of organic matter reduce quality and resilience. As restoration is very hard once a site reaches this condition, research on preventing such degradation is important, and involves social and political issues such as tenure arrangements, as well as soil management from a biophysical perspective.

Fossil fuels are used in almost all aspects of food systems, and enhanced research is needed on how to decarbonise food-related power generation and transport. UK science has capacity to increase Negative Emissions Technologies (NETs) in CCS and land based technologies (e.g. bioenergy, forestry, soil science, agriculture). But this needs a whole-system, comparative assessment of NETs, considering multiple impacts, environmental constraints, energy use and costs, and societal attitudes. Key is the interaction *via* land competition between food and biofuel production, urbanisation and industrial use, and land-based greenhouse gas removal technologies and practices.

## 2. Renewable NRs but which are poorly managed

Renewable NRs include fresh water, terrestrial and marine biodiversity (unless related to extinctions) and soils (unless irreversibly degraded). Many experience high levels of extraction and/or poor management.

Climate change is altering precipitation patterns, intensifying floods and increasing drought risk. Further, population growth, agriculture, industrialization and urbanization are degrading water systems (quality and quantity). Key areas for research include understanding the changing hydrological system across spatial and temporal levels, new modelling tools to capture the interconnected forces and their societal implications, the extrapolation of models to data sparse areas, and new monitoring systems to warn of critical environmental changes. The UK is a global leader, and has an excellent hydrological modelling community. Nevertheless, despite many assessments of future water security, uncertainty remains high. More physics-based approaches, incorporating land management and water quality, are needed. Some key areas include non-stationarity and data assimilation techniques for hydrological models needed to improve disaster warning globally, and to adapt to change, manage risk and ensure water futures.

Terrestrial biodiversity underpins agriculture by providing a wide range of services, e.g. natural pest control, pollination and soil conditioning by biota. The key question is how best to measure biodiversity and ecosystem services so as to support growers to make informed decisions. While much is known about the function of biodiversity at field level, further integration with the Earth Observation community could significantly help to assess its function at landscape level. In contrast, the genetic resources (GR) used in modern agriculture have been intentionally narrowed resulting in only a few crop varieties and breeds of livestock now being used, increasing their susceptibility to biotic and abiotic stress; native and crop germplasm collection is a priority. Potentially game-changing developments in biological and information science and technology (e.g. gene editing) are revolutionizing the way crop germplasm is managed and used. There is an opportunity to explore new mechanisms for coupling the use of 'big data' related to plant genomic and phenotypic diversity and ecological variation with physical genebank samples to predict breeding outcomes. Next-generation DNA-sequencing, deep phenotyping approaches, and informatics tools enable the comprehensive characterization of the genetic diversity of crops.

Soil underpins almost all terrestrial primary production, and the UK has a strong track-record in soil science. Key research areas include soil organic matter management (which serves multiple beneficial functions in nutrient and water supply, and carbon sequestration); nutrient and water management; scaling across spatial; and temporal levels; and understanding soil variability.

The marine environment also provides an important food source. Catches are falling globally, and climate change is expected to exacerbate winners and losers due to geographic changes in fish stocks. Restoration of key degraded marine resources (e.g. oyster beds) both benefits biodiversity and improves water quality, but restoration in the ocean in general is poorly researched. Linked to this there is major potential role for marine protected areas (MPAs) in fisheries and ecosystem management.

**3. NRs which are potentially of considerable value but which are poorly exploited**

Global marine capture fisheries have now passed peak catch although there is growing global demand for seafood. While there is the potential of mesopelagic fish as fisheries, aquaculture has the potential to make up the shortfall. But this needs feed which currently comes mainly from capture fisheries. A key area for research is the development of substitutes that replace or partially replace fish protein and oils in feedstocks. There is however significant risk of increasing disease of the cultured species, and an increasing threat of contamination of cultured species (especially shellfish) with human pathogens and biotoxins. Macroalgae is a potential source of food, biofuels, chemicals, fertilisers and nutraceuticals but capacity, environmental impacts and operational costs are largely unknown, and a regulatory framework is lacking.

There is a continued need to collect and curate terrestrial and marine genetic resources (GR) samples but with a shift from physical stocks to digital libraries. UK has frontier science skills in this area but is not approaching the topic in a co-ordinated and systematic way. Some key opportunities include: how to connect sequence variation to heritable phenotypic differences with a complex genetic basis; broadening the genetic basis of food crops; phenotyping at scale and linking to genotype; and the development of populations and the testing of breeding strategies maximising access to, and value of, GR in local collections. These do however need a policy framework to support their effective utilisation.

**Other factors**

The economics and logistics of the food supply chain, including wastage, physical and economic access to food, the nutritional and health-sustaining properties of foods, and the cultural acceptance of different food sources must be considered alongside sustainable use of natural resources. The UK has significant expertise in the necessary medical, social, economic and business, and humanities research to address these questions.

**The context for GERC reports**

The Royal Society's Global Environment Research Committee (GERC) is charged with advising the Royal Society, and interacting with research councils, the environmental science community and other bodies. To do this, it is undertaking a rolling series of reviews of areas of science within its remit. The areas it has identified are (in alphabetical order): Air quality, Biodiversity, Carbon and other biogeochemical cycles, Climate, Natural resources (including land use) and food, Oceans and polar science, Water. In each area, GERC uses its own expertise, and that of a small number of invited experts to consider the questions:

1. What are the hot research topics in this area at present?

2. What is the status of UK science within this area?

3. What are the most pressing research needs in the next 5-10 years?

4. Are there specific areas where UK science should be focussed to meet these needs?

5. How should priority topics be incorporated into multidisciplinary (funded across research councils) issues that Future Earth and its UK committee should consider?

This paper is the one resulting from the discussion about Natural resources and food, held in November 2016. In addition to contributions from its regular and co-opted members, the committee was advised in person by Professors Alan Jenkins (Centre for Ecology and Hydrology), David Raffaelli (U. York), Tina Barsby (National Institute for Agricultural Botany), Alex Rogers (U. Oxford), David Manning (U. Newcastle) and Pete Smith (U. Aberdeen). The resulting paper of course represents only a snapshot of issues, and is not a comprehensive survey of the science area. It does not represent the view of the Royal Society, but is merely one element of advice to the Royal Society Council. Exclusion of a topic from this document does not negate its importance, and many areas that are already under intense research are not highlighted here. However, we hope that this document will put a spotlight on some trends that will inform future activity by the Royal Society, Research Councils (and in future UKRI), and UK Future Earth.

Membership of GERC (including co-opted members) at the time this topic was discussed (November 2016) was: Professor Eric Wolff FRS (chair), Dr Helen Beadman (NERC), Professor Peter Cox, Professor Joanna Haigh FRS, Professor Gideon Henderson FRS, Professor David Hopkins, Dr John Ingram, Dr Sandy Knapp, Professor Corinne Le Quéré FRS Professor Yadvinder Mahli, Professor Paul Monks, Professor Martin Solan, Professor Chris Thomas FRS. Dr Scott Hosking acted as Secretary.