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EXECUTIVE SUMMARY

1. This report presents the results produced by an open call issued as part of NERC’s ‘Environmental Evidence for the Future’ (EEF) initiative. The aim of the call was to gather, from a wide range of stakeholders, views on key knowledge gaps and evidence needs that should be addressed in order to underpin and enable the development of robust, effective UK environmental policy in the future.

2. The call followed a series of four regional workshops that (i) prioritised the different ‘drivers of change’ set out in the UK National Ecosystem Assessment (NEA) Technical Report and (ii) used these drivers to produce a total of 65 ‘100-word challenges’ in the environmental field that arise from the UK’s decision to leave the EU.

3. A bespoke web-based tool allowed those responding to the call to highlight the knowledge gaps and evidence needs that, in their opinion, should be addressed in order to allow the 100-word challenges to be tackled successfully. In addition, Government Departments submitted written responses directly to NERC.

4. A total of 30 individuals and organisations submitted responses, and a further 34 respondents provided input anonymously, via the web-based tool. The anonymous responses were all considered to be genuine and legitimate (i.e. they included no inflammatory, extraneous or off-topic opinions) and so were included in the subsequent analysis by the EEF team.

5. All of the 186 separate responses received (by the respondents to the challenges i.e. multiple responses per respondent) were grouped according to the drivers of change (or clusters of similar drivers) they related to. (Note: The majority of respondents considered that the knowledge gaps and evidence needs they highlighted were UK-wide, or UK-wide including the UK’s Overseas Territories.) This process also provided the basis for the identification of 10 interlinked ‘research themes’.

6. Overwhelmingly, respondents to the call indicated the need for new research in all of these research theme areas. Many statements also indicated that there was a need to undertake a synthesis of existing knowledge and combine data from different disciplines, especially in terms of integrating social science and natural science datasets so that the full socio-ecological system could be considered. Only three statements indicated that no new primary research was needed and that only implementation of existing knowledge was required.

7. The following graphic summarises the process described above. It outlines: (a) the prioritisation of drivers of change, which resulted in the generation of the 100-word challenges; (b) the wide consultation that was undertaken, involving both the use of the bespoke web-based tool and the collection of direct responses; (c) the grouping of the responses received and their use to identify research themes; and (d) the research themes identified.
Based on the responses received as a result of the call, the overall conclusions reached for each of the 10 research themes were as follows:

- **Land and Marine Use**

Here, drivers of change and the resulting 100-word challenges focused on the production and use of natural resources from the terrestrial and marine environments. 43% of the responses relevant to this research theme related to drivers that focused on the holistic need to consider the use of land and marine resources in terms of competing demands, environmental policy and food security. 22% of responses focused on the concepts of natural capital and ecosystem services as a framework to provide knowledge on management options, regional planning and policy formation with regard to land and marine use.

Respondents recommended that donors should fund research to further the use of the natural capital and ecosystem service frameworks and integrate these studies with analysis of existing and future policies. The use of integrated spatially explicit models was also recommended as a means to assimilate knowledge across diverse disciplines, in order to consider the full socio-ecological-coupled system when developing policy.

- **Climate Change**

This research theme focused on global climate change, considering many aspects ranging from extreme events (e.g. flooding, invasions of alien species and pests) to adaption and mitigation measures and the need for better forecasting. Respondents stressed the need for long-term data not only to identify temporal trends in environmental change but also to capture extreme events and allow the development of mechanistic understanding – thus improving models for forecasting and studies of
policy scenarios. Respondents also called for research with sufficient depth and longevity to allow a holistic understanding of ecosystem processes and human drivers.

- **Economics of Resource Use**

  This research theme focused on the influence of economic driving forces on environmental issues – for example, the influence of market forces on products from the terrestrial and marine environments, or the economic influence of recreation and tourism on the environment (with a particular focus on the UK’s Overseas Territories). The need to understand the multifaceted influence of natural resource use on the environment in the UK, in its Overseas Territories and globally was considered a high-priority area for future research. Natural capital accounting was an approach viewed by many as practical and useful, but respondents noted that it required more research in order to ensure the robust evidence required to inform policy.

- **Soils**

  This research theme addressed several key unknowns relating to soils, including soil diversity, quality and health. Respondents recognised the fundamentally important role of soil in the environment as it affects many elements relating to environmental policy. They recommended a diverse range of research topics that collectively would enhance policy-makers' knowledge. There was consensus that soils should be considered more explicitly within research programmes (e.g. programmes focused on climate change or land use), as should the influence of policy on soil form and function.

- **Biodiversity**

  This research theme combines 100-word challenges centring on invasive alien species, pests and diseases, and on the decline of species. The key research gaps highlighted by respondents with respect to the spread of pests and alien species focused on understanding ecological networks and the role of humans in dispersal processes. Similarly, a key research gap was identified relating to the role of humans in degrading ecosystems and the subsequent effects of this on biodiversity survival. Respondents reported that the knowledge obtained from research projects that utilised tools and models in the field of ecological networks would provide policymakers with more robust evidence capable of aiding development of policy to protect humans from pests and diseases and to enable biodiversity to survive in an increasingly human-dominated landscape.

- **Environmental Policy**

  This research theme focused on the knowledge required so that UK administrations can deliver new environmental regulations post-Brexit. The key research gaps suggested by respondents focused on a need for greater analysis of the effects of current policy and for scenario planning. In particular, inter-sectoral effects were highlighted as a neglected area. Respondents called for more consultation with a wider range of stakeholders when considering the likely impact of policy change.
Human Health

This research theme centred on two drivers of change: the use of antibiotics and the risk of chemical contamination of the environment; and the opportunities that the natural environment presents for human health. Evidence needs reported by respondents focused on the requirement for interdisciplinary studies that would enable a holistic view of human health and the environment. The concept of ecosystem services was highlighted as a means to provide evidence to encourage integration of knowledge and inform policy-makers. More research on nature-based solutions was called for – respondents suggested that more knowledge of such an approach could inform policy-makers on measures and instruments to mitigate the effects of chemical pollution (especially in the aquatic environment) and could directly benefit human health in the urban environment.

Technology

This research theme considered new technology designed to monitor the environment, boost production and digitally gather information and link it together (i.e. the Internet of Things). Respondents urged that future research should especially focus on sensors and the linking of sensors to provide long-term monitoring of the environment, in order to enhance the ability of policy-makers and public sector agencies to build cheap, effective compliance monitoring as well as to provide an evidence base for new policy.

Circular Economy

This research theme focused on care for the environment in relation to, for example, waste disposal and recycling. Here, the majority of respondents highlighted a need for evidence centred on the production, utilisation and recycling of waste, and urged the inclusion of all sectors of society in the development of innovative, sustainable solutions.

International Focus

This research theme revolved around issues relating to the need to consider international collaboration, transboundary relationships and the role of UK scientists in solving global environmental problems. Respondents focused on the need to consider such cross-border issues as food security and air pollution in a global context – supporting the view that global consensus is the most effective route to environmental protection.

Overall, there was a strong call for interdisciplinary research, with respondents often explicitly calling on donors to fund such work (e.g. involving non-science organisations in project design). Funding streams to encourage collation and analysis of datasets from diverse disciplines (e.g. the re-purposing of datasets) were recommended in order to address knowledge gaps in the environmental science evidence base and inform future policy and practice.
1. THE ‘ENVIRONMENTAL EVIDENCE FOR THE FUTURE’ INITIATIVE

The EEF initiative aims to work in close collaboration with UK Government Departments and regulatory agencies to define key cross-departmental evidence challenges arising – and decisions required – as a result of the UK’s decision to leave the EU. Naturally, these challenges relate closely to the European environmental policy frameworks under which those departments and agencies are currently working. The challenges also have the potential to be addressed via the UK’s environmental research landscape and community. The ambition is therefore to develop a programme of activity that will prioritise and address knowledge gaps in the UK’s environmental science evidence base in order to inform UK policy and practice after Brexit.

As part of the EEF initiative, a series of four UK-wide workshops were held in August and September 2017 – in Scotland, Wales, Northern Ireland and England (encompassing perspectives from the UK’s Overseas Territories). Primarily with the policy and practice community but also including leading academic, business and third-sector voices, the workshops set out to define future challenges connected with the gathering of environmental evidence, in the light of the UK’s upcoming departure from the EU. In total, around 120 individuals from around 70 different organisations took part.

The workshops followed a ‘futures’ approach, utilising pre-defined ‘drivers of change’ taken from the NEA and adapted/updated in the light of recent geopolitical developments. These were prioritised by workshop attendees according to ‘importance to/impact on UK environmental policy’ and ‘certainty/uncertainty of outcome’. For the highest-priority drivers, statements on challenges/opportunities were articulated. In total, across the four workshops, 65 ‘100-word challenges’ were developed. The summary reports from the workshops (containing these 100-word challenges) are available on the NERC website.

This report details the results of an open call for evidence relating to the challenges identified at these four workshops. Over a consultation period that lasted from 3rd November to 5th December 2017, views about knowledge gaps and evidence needs in these areas were gathered using a bespoke web-based tool alongside direct input provided by a range of UK Government Departments and agencies.
2. INVITATION TO RESPOND TO THE CALL FOR EVIDENCE

A strategy for the dissemination of the call for evidence was agreed with the EEF Advisory Board at a meeting held on 12th October 2017. It was agreed that the call would be open from 3rd November to 5th December 2017. A mixed-method approach to publicise the call was adopted using CEH, National Oceanography Centre and NERC communication channels as well as personal contacts of the EEF Coordination Group, the NERC Executive Group and members of the EEF Advisory Group.

All the people who had agreed to attend the regional workshops were, via email, personally invited to respond to the call. In addition, a generic email invitation was sent to 29 organisations or groups and all six NERC research centres. Rachael Creed from the Government Office for Science also distributed the invitation to the National Academies of Sciences, Engineering and Medicine. The call for evidence was widely advertised via social media, including Twitter and LinkedIn, and a blog on the CEH website.

Communication channels were contacted three times: when the call was opened; mid-way through the period when the call was open; and a few days before the deadline.

Some of the contacted organisations advertised the call for evidence by publishing the letter of invitation on their website; for example, the Future Earth Global Research Project iLEAPS Others provided a fuller explanation of the EEF initiative and invited their members to contribute views on knowledge gaps and evidence needs; for example, the Landscape Institute.
3. **A BESPOKE TOOL TO CAPTURE RESPONSES**

CEH created a bespoke web-based tool to capture responses to the call for evidence. The tool was improved with input from the NERC Executive Group and also incorporated feedback received from the EEF Advisory Group on 12th October 2017.

The tool was developed using the Drupal Content Management System (CMS). A form page was created for collecting the 100-word challenges text and tagged using the following keywords: ‘Theme’, ‘Topic’, ‘Workshop’. The allocation of themes and topics was carried out by the NERC Executive Group. A form was created for the user input side (‘Responses’, linked to the 100-word challenges). Challenges could have many Responses. Results were then outputted using a ‘View’ page for the Coordination Group to collect and process.

The tool contained all 65 100-word challenges pinpointed via the workshops. Respondents were asked to identify challenges where they felt there was a need for evidence (see Figure 1 below) and were then provided with a series of search options to allow investigation by theme, topic or workshop. All of the challenges could also be searched via key terms using the normal search function (i.e. ‘Ctrl’ key plus ‘F’ key); for example, ‘soils’ or ‘human health’.

When respondents chose to write a response (see Figure 2 below), they were asked to answer three questions:

- What was/were the key knowledge gap/gaps which, if addressed, could provide evidence to address this challenge?
- Could this/these gap/gaps be filled using existing research/knowledge/evidence or was new primary research required?
- What were the key capabilities, data and skills needed in order to address this/these research gap/gaps?

The geographic scope of the knowledge gap or evidence need was captured by asking respondents to tick one or more of the following options:

- UK-wide
- Scotland
- England
- Wales
- Northern Ireland
- Overseas Territories.

Respondents were also invited to provide their name and institution, although this was not mandatory. However, it was mandatory to identify the nature of their organisation or role from a dropdown menu of the following six options:

- Academic
- Business/industry
- Civil society organisation/NGO (Non-Governmental Organisation)
- Government
- Public sector agency
- Other public sector.
In addition to responses gathered using the bespoke web-based tool, some Government Departments preferred to submit a single response for the whole organisation. These responses were collected via the NERC Executive Group and then combined with the information gathered via the web-based tool.
Figure 1. Screenshot from the bespoke web-based tool. The search menu on the left allowed responders to investigate the ‘100-word challenges’ identified by the four regional workshops either by theme, by topic or by the workshop where the challenge was created.
Figure 2. Screenshot from the bespoke web-based tool showing how information was collected on: (i) knowledge gaps and evidence needs; (ii) whether or not new primary research was required to address the identified gap/need; (iii) the skills, data and capabilities required to address the identified gap/need; and (iv) the geographic focus of the gap/need.
4. ANALYSIS OF RESPONSES: THE PROCESS

All responses were collated and grouped according to which of the 100-word challenges they related to, as well as the drivers of change (or the 21 driver ‘clusters’ identified by workshop participants) that inspired them. The Coordination Group then further grouped the responses into 10 research themes. This phase of the project is summarised as step (c) in Figure 3 below.

![Figure 3](image)

**Figure 3.** Graphical summary of NERC’s ‘Environmental Evidence for the Future’ initiative: (a) prioritisation of ‘drivers of change’ resulted in 65 ‘100-word challenges’; (b) a wide consultation was undertaken involving both the use of a bespoke web-based tool and direct text contributions from respondents; (c) responses were grouped according to the relevant ‘driver of change’ or cluster of such drivers, and ‘research themes’ were identified; (d) this process produced 10 broad ‘research themes’.

The rationale behind the formation of the 10 research themes was to group responses that answered similar societal challenges (e.g. the ‘Land and Marine Use’ research theme) or considered interlinked issues (e.g. the ‘Biodiversity’ research theme, which clustered responses on evidence needs relating to species decline, alien species, pests and diseases).

Several respondents highlighted evidence needs that were directly relevant to more than one 100-word challenge, copying and pasting text in order to do this. Others simply mentioned that the evidence need they were highlighting was also relevant to another challenge; these responses were double-coded under more than one research theme, as appropriate, with a member of the NERC Executive Team checking the coding. Three responses were coded to each of the ‘Climate Change’, ‘Environmental Policy’ and ‘International Focus’ research themes; four responses were added to the ‘Human Health’ and ‘Soils’ research themes; five responses were added to the ‘Land and Marine Use’ research theme; and seven responses were added to the ‘Technology’ research theme.
Each response was also coded in a consistent manner in terms of its answers to the three questions set out in Section 3 above. To code the responses accurately, both the response and the challenge text were read together. This was because, in many cases, research gaps were identified by the respondent in the space specifying the challenge to which the respondent noted that they agreed or disagreed. In addition, respondents did not always reply to the three questions discretely; frequently, they placed information relating to all three questions in their response to the first question. Therefore the analysis team members needed to read the challenge and the responses to all three questions prior to coding the responses.

An iterative analysis approach was adopted where the leader of the Coordinating Group read all the responses and, from these, derived categories of evidence needs, knowledge gaps and required data/skills/capabilities (see Tables 1-3 below). These were then discussed with two other team members and a final set of categories was agreed. This team then iteratively coded each response for presence or absence with respect to each of the categories. In this way, responses could be coded into multiple categories; as noted above, some responses mentioned multiple evidence needs, knowledge gaps and data/skills/capabilities requirements. Following two iterations, the team leader checked and revised the coding and the categories, resulting in further discussion until agreement was reached. An example of the coding of a single response is provided in Appendix 1.

The analysis team strove to make the categories discrete and required an unambiguous mention in order to code a statement contained within a response into a specific category. Implied references were not included; for example, ‘quantification of the benefits of soil health / carbon sequestration to add into the metrics / discussion about agriculture’s role in climate change’ could imply a need to consider the natural capital in soils but was not included in the category ‘natural capital’ as this concept was not explicitly mentioned.

A response could be coded in several categories; for example, the following statement was coded in both the ‘requires new primary research’ and ‘combination of existing research’ categories: ‘A lot of the gap could be filled with existing research, but it would need to be pulled together on a global basis – probably would require international collaboration – but primary research with modelling also required’.
Table 1. Categories for coding the responses to the EEF initiative’s call for evidence where respondents were asked to identify: **key knowledge gap/evidence need that would address the selected challenge**

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<th>Category</th>
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| Holistic understanding of coupled socio-ecological systems | Responses indicating an evidence need related to understanding of ecosystem structure and function and links to human benefits. Statements such as the following were coded in this category:  

* ... to assess environmental protection in relation to the human disturbance of the key driving cycles.*  
* ... economic/commercial/regulatory/technological implications of recommended land management practices across sectors for public goods delivery.*  

*The challenge however is to go beyond small-scale process studies to link process understanding across scales with the possible solutions ...*  

*It is critical at the same time to engage with policy-makers who often own only parts of the problem rather than being able to see the full picture.* |
| Natural capital | Statements that specifically mentioned natural capital were coded in this category; responses where these could be implied were not included (as it could be argued that the majority of the responses implicitly referred to natural capital) and statements relating to ecosystem services were not included as they were expressed in such a variety of forms. Statements coded in this category included:  

*Natural capital may be a way to achieve ...*  

*Investing in ecosystem services and natural capital research is a priority ...* |
| Holistic understanding of ecosystems | Responses indicating a need for a broad analysis of environmental quality involving all elements of the ecosystem (i.e. linking air, water, soils, land use etc.). Included statements such as:  

*Tackling declines in biodiversity species and populations requires innovative approaches to asset management and conservation at a range of scales, recognising the importance of ecosystem functions and ecological networks ...*  

*... able to assimilate chemistry, physics and biology information as applied to particular systems – in this case, soils.* |
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| Temporal understanding of change and extreme events and change in socio-ecological systems | High temporal resolution monitoring to identify trends and extreme events of abiotic and biotic variables was identified by statements such as:  

... most valuable data for truly understanding the impacts of extreme events are long-term monitoring data of ecosystems over several decades.  

The evidence need is for the continued collection of long term data.  

Statements concerning the need to monitor long-term economic and social data were also included in this category; for example:  

Long term monitoring of socio-ecological systems ...  

... long term pollution mitigation performance needs to be assessed alongside flood risk management benefits, horticultural opportunities, biodiversity benefits, health and social wellbeing etc. |
| Monitoring and evaluation of policy                                       | Responses indicating a transdisciplinary analysis of policy and the consequences, considering a broad suite of other policies, were required. Examples included:  

... important to develop the scientific understanding of the quantitative interactions between nitrogen issues and to identify the extent of policy synergies and trade-offs.  

Critically, the current policy landscape needs to be examined.  

Note: in total, 66 of the responses included the word ‘policy’ – the response was coded to this category only if it made mention of policy evaluation or some reference to evaluation of regulation of some type. |
| Ecological networks                                                      | Identifying an understanding of the linkages/networks/pathways between species was identified as a need. For example:  

Long term data on population changes over time and drivers of these changes are lacking for many species.  

In addition the interaction among species and their ecosystem functions is not known for many organisms.  

This might include applied research focusing on sources, pathways and routes to dispersal. |
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| Drivers of land-use change           | Responses were coded in this category when an understanding of drivers of change associated with land use was identified as a need. For example:  
  *Changes in land use are the major national and global determinant of changes in the natural environment.*  
  *This means that there are no feedbacks to climate when either land use is changed...*  
|                                      |                                                                                                                                                                                                                                                                                                                                                             |
| Human motivation                     | Responses in this category indicated a need to understand the motivations that result in behavioural change associated with sustainable development of land, water and seas. Examples of statements included:  
  *... how to create behaviour change amongst land owners and managers.*  
  *We need to know what would create behavioural change in both practitioners and patients.*  
  Also motivations related to the use of new technology; for example:  
  *... understand the importance of the use of technology (so understand the user e.g. farmer perspective).*  
  And understanding of the ethical use of new technology; for example:  
  *... geoengineering, nanotechnology and synthetic biology...may raise specific ethical acceptability.*  
|                                      |                                                                                                                                                                                                                                                                                                                                                             |
| Understanding suite of ecosystem services to human health | An understanding of the linkages between ecosystem services, environmental degradation and their impact on human health was specified through statements such as:  
  *... leading to deficits in the ecosystem service and negative impacts to society.*  
  *... potentially health impacts (e.g. more deaths among the elderly).*  
  *... impact on food security and human health.*  
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| Understanding international market forces and material flows | Here, evidence on how market forces and the flow of material may influence UK socio-ecological systems was identified in the response, including the flow of humans related to the environment (ecotourism). Examples of statements included:  
... how external markets in the future will change activities in UK ...  
... require more information on material flows ...  
... need for the transboundary relationships to be addressed in environmental policy making [the focus here was the border between Northern Ireland and Ireland].  
... highlight the importance of uplands in the development of future agri-environmental schemes (especially if WTO rules are applied and the focus of future environmental support schemes becomes income foregone in complying with the support scheme).  
Global population will increase with a shift in economic centre of gravity to the east. Resource shortages will lead to increased inter-state conflict (possible shift in global free trade agreement).  
New trade agreements with countries with low levels of biosecurity may open new pathways for invasions of the UK by pests and diseases.  
The UK Overseas Territories’ economies rely increasingly on ecotourism. |
| Integrated and spatial modelling               | Here, responses called for evidence to link a range of diverse models (not single-focus models like temperature or weather models); for example:  
[We have single] spatial modelling for specific land uses and scenarios...but different sectors and activities have yet to be joined up.  
Some models exist but they need validating in different regions and also extending to be able to predict resilience of ecosystem services, in order to inform appropriate land management advice.  
We need better joined up models to understand how systems function. |
Table 2. Categories for coding the responses to the EEF initiative’s call for evidence where respondents answered the question: could this gap be filled using existing research/knowledge/evidence or does it require new primary research?

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| Requires new primary research | When new research was explicitly called for either by the single word ‘New’ or ‘No’. Examples of such statements included:  
... new research would be needed ...  
... would need primary research ...  
... but this needs supplementary primary research ...  
Or when explicitly stated in sentences such as:  
As well as better prediction and modelling of dispersal and spread there is a need to understand how and when to respond to particular pests and diseases.  
... some fundamental developments in sensor and analytical science would be required.                                                                                                                                                                                                                                                                                                                                                               |
| Synthesis of existing research | Where the knowledge is thought to be available but resources are required to synthesise across datasets. For example:  
A lot of the gap could be filled with existing research, but it would need to be pulled together on a global basis – probably would require international collaboration.  
There has been some work recently (this year and previous)...but different sectors and activities have yet to be joined up.  
Much of the research and knowledge in this area probably exists but needs to be collated from geological groups, tourist boards and others who may not have collected these data for this purpose but the re-purposing of data is often a key first step in identifying major gaps in knowledge.  
The necessary data is already available but, just the research, it has not been integrated together. |
Note: when continued analysis of long-term datasets was indicated, this was not coded as ‘synthesis’ unless linking to other datasets was mentioned. Statements such as the following were therefore not coded in this category:

It could build on existing monitoring currently in place.

| Not requiring synthesis or new research, but rather a need to use existing research | Where sufficient knowledge exists but there is a lack of resources to implement the results. Several respondents called for a greater use of existing knowledge; but if also discussing the need for new or a synthesis of existing knowledge, they were not scored in this category. Examples of respondents’ statements scored in this category included:

No more to very little research is needed. Action is what is needed.

New primary research is not required as the properties and function of the bio-fertilizer has been published in the scientific literature as a series of seventeen papers. |

| Cross-, multi- and inter-disciplinary research | Where the need was identified for scientists to understand and research the linkages between all aspects of the socio-ecological system. For example:

Skills for interdisciplinary work, from problem framing to communication, with involvement of environmental scientists, health scientists, economists, political scientists, software engineers.

... linking ocean-atmosphere physics to health outcome.

Skills to work across social and natural sciences will be very important. |

| Transdisciplinary research | Where a need was highlighted to involve all relevant actors in the co-production of research projects. For example:

Collaboration is not only required between the different research disciplines but also between researchers, regulators, bodies undertaking regulatory testing and industry.

Knowledge and experience of a transdisciplinary approach, including interdisciplinary working and effective stakeholder engagement.

The capacity to fund research which enables all sectors to participate, not only the big business/industry who can afford to send staff to research meetings. |
Table 3. Categories for coding the responses to the EEF initiative’s call for evidence where respondents answered the question: are there any critical skills, data, capabilities that are required in order to address this gap?

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| **Long-term monitoring of a full suite of socio-ecological parameters** | Respondents indicated a need for ecosystem-scale long-term data (preferably geo-referenced) and for monitoring a full suite of socio-ecological parameters, indicated by statements such as:  

*Needs long-term data at high frequency to capture extreme events and responses.*  

*... large-scale catchment-level demonstrator sites, enabling the testing of scaled-up activities that could deliver public goods and associated monitoring approaches.*  

*... near real-time observations are required to know the state of the ocean, which requires sustained observations ...*  

Statements which called for long-term understanding, such as relating to climate change or long-term planning, but did not explicitly call for long-term data were not coded in this category. For example:  

*The long term benefits and services provided by natural environments need to be weighed against any potential developments, regardless of whether they are renewable energy or major roads.* |
| **Linking ecosystem health and human health/wellbeing** | Explicit calls for data linking ecosystems to human health were included in this category, indicated by statements such as:  

*... need much more cross-council inter-disciplinary work linking how environmental quality relates to health and wellbeing.*  

*Evidence that knowledge of the ocean (Atlantic for the UK) may give some predictability of the likelihood of a coming severe winter and therefore potentially health impacts (e.g. more deaths among the elderly).*  

*... assess the impact of loss of ecosystem services and threats to human health.*  

*... primary research linking observations to weather over seasonal time scale (data analysis and modelling, plus link to health data).* |
| **Full system budgets** | Responses indicated that a full ecosystem-wide budget was required considering all inputs and outputs from a system, e.g. carbon, nitrogen, money and human benefits, including life cycle analysis. Included statements such as:  

*... considering all input and loss terms.* |
| **Life cycle analysis.** | Management practices | Highlighting the requirement for data on management practices. For example, statements included:  
*Datasets on management practices are often missing.*  
For example, statements included:  
*Datasets on management practices are often missing.*  
For example, statements included:  
**Economic datasets for a wider array of parameters** |  
A need for economic and socio-ecological economic datasets was identified and was indicated by statements such as:  
*economic data on costs of management for different environmental benefits.*  
*need for sociology and economics and behavioural economics ...*  
Statements which called for the use of economic data rather than its collection were excluded.  
**Earth Observation data** |  
The requirement for satellite and remote sensing data was indicated by statements such as:  
*approaches such as automated sensors and earth observation.*  
*using new European Sentinel satellites.*  
*remote monitoring and satellite technologies.*  
**Linking social and natural sciences together and working with other societal actors** |  
Here, statements indicated a need to improve the skills of individuals involved in research which required natural and social scientists working together. In addition, statements called for scientists to improve their skills when working with non-scientists. For example:  
*enables social science/humanities and engineering (e.g. economics, business studies, law, psychology and civil engineering) to be combined with environmental science.*  
Need to be able to work with business and industry (those that develop the technologies) on these challenges, as well as researchers from different disciplines.  
Scientists need to learn the skill of listening and being willing to work on an equal footing.  
**Specific scientific skills required or skills** |  
This category captured the need for skilled scientists who study specific disciplines. For example:  
*Statisticians; environmental statisticians; high-level statistical skills.* |
| to understand many science disciplines | It also included requirements expressed as an explicit need. For example:

A sound understanding of soils – both soil biology (degradation of organics), soil physics and chemistry (movement of contaminants through soils) would help and there is a skills shortage in this area.

... requires more people with training and practical experience in taxonomy and ecological monitoring.

... effective stakeholder engagement.

Need expertise in re-shaping our monitoring network and its targets.

And/or skills to understand many disciplines. For example:

An understanding of the relevant technologies outside of discipline that develops them. |
5. RESULTS

Overall, 186 responses were provided by at least 64 respondents (30 named individuals and 34 anonymous). These 186 responses (in total for all drivers) were analysed across 10 research themes. 30 named individuals representing organisations, or groups representing organisations, sent replies (see Table 4), accounting for 82% of the responses analysed. A further 34 responses were lodged anonymously.

Table 4. Organisations responding to the call for evidence

<table>
<thead>
<tr>
<th>Organisation</th>
<th>Organisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>BioGeoD/Hills of Hame</td>
<td>Parliamentary Office of Science and Technology (POST)</td>
</tr>
<tr>
<td>Centre for Ecology &amp; Hydrology</td>
<td>South Atlantic Environmental Research Institute (SAERI)</td>
</tr>
<tr>
<td>Committee on Climate Change</td>
<td>Soils Training and Research Studentships (STARS) Centre for</td>
</tr>
<tr>
<td></td>
<td>Doctoral Training</td>
</tr>
<tr>
<td>Dept. of Earth Sciences, University of Cambridge</td>
<td>The Schumacher Institute</td>
</tr>
<tr>
<td>Environmental Change Institute, University of Oxford</td>
<td>UK Overseas Territories Conservation Forum</td>
</tr>
<tr>
<td>Environment Agency</td>
<td>University of East Anglia</td>
</tr>
<tr>
<td>Farm Carbon Cutting Toolkit</td>
<td>University College London</td>
</tr>
<tr>
<td>Forest Research</td>
<td>University of Exeter</td>
</tr>
<tr>
<td>Historic England</td>
<td>University of Manchester</td>
</tr>
<tr>
<td>HR Wallingford</td>
<td>University of Reading</td>
</tr>
<tr>
<td>Integrated Catchment Solutions Programme (iCASP) Office</td>
<td>University of Southampton</td>
</tr>
<tr>
<td>National Farmers’ Union</td>
<td>University of York</td>
</tr>
<tr>
<td>National Oceanography Centre</td>
<td>Wildlife Trusts Wales</td>
</tr>
<tr>
<td>National Trust</td>
<td>Department for Environment, Food &amp; Rural Affairs (Defra)</td>
</tr>
<tr>
<td>Natural England</td>
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</tbody>
</table>

All sectors provided input to the call for evidence (see Figure 4). The ‘Government’ sector was under-represented (5% of all responses) and the response from ‘Civil society organisations’ and ‘Business/Industry’ was low at ~10%. ‘Public sector agencies’ provided the most input (31% of all responses analysed), which is not surprising as this initiative focused on the evidence needs of policy-makers.
Respondents who declined to disclose their name and organisation (see Figure 5) were mainly from the ‘Business/Industry’ (35%) and ‘Government’ (26%) sectors, but individuals preferring to remain anonymous occurred in all other sectors.

While some of the anonymous responses were rather blunt, the evidence needs that they identified appeared valid. Only one respondent provided a reason for not stating their name and organisation, writing: “I have not given my name here because I do not know who is behind this initiative but the Valuing Nature community know me”. The ability to provide anonymous responses appears to have been welcomed by the community and unaffected by trolls.

The 10 research themes derived from the drivers of change and 100-word challenges attracted different levels of support and interest (see Table 5). Discussion of the composition
of the research themes and analysis of the responses are presented in detail in the following subsections of this report.
Table 5. Research themes and associated drivers and challenges, and the number of responses to the EEF initiative’s call for evidence. Challenges for which there was no response are indicated in **BOLD**.

<table>
<thead>
<tr>
<th>Research Theme</th>
<th>Driver Number</th>
<th>Driver Text</th>
<th>Challenge Text</th>
<th>Number of Challenges</th>
<th>Number of Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Land and Marine Use</td>
<td>11</td>
<td>Food security and water security will become significant challenges, perhaps even sources of conflict</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Local economic performance around the UK will be uneven, leading to increased regional disparity</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>21</td>
<td>Lowland/upland land capability and use will face increasing and competing demands</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>24</td>
<td>Patterns of land and marine use will need to change to meet the UK’s food and energy needs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>Planning needs to be future-proofed and more embedded</td>
<td></td>
<td>18</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>The ecosystem approach, landscape-scale approaches, ecosystem services and natural capital frameworks will be significant components of the policy-making process</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>54</td>
<td>Patterns of land use will change as a result of competing demands and regional disparity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Climate Change</td>
<td>4</td>
<td>Climate change is resulting in increased temperatures and increased fluctuation in extreme weather and seasonal events</td>
<td>The UK and its Overseas Territories will not be immune from rising sea levels, flooding, heatwaves and poor air quality</td>
<td>7, 8, 9, 10, 11, 12, 13, 14, 56</td>
<td>9</td>
</tr>
<tr>
<td>3. Economics of Resource Use</td>
<td>1</td>
<td>Agriculture and forestry support payments focused on public goods</td>
<td>1, 2, 3, 4, 43, 44, 59</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>Retailer power will drive farming systems</td>
<td>The value of the UK’s ecotourism markets is likely to increase</td>
<td></td>
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</tr>
<tr>
<td></td>
<td>44</td>
<td>The value of the UK’s ecotourism markets is likely to increase</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>53</td>
<td>High environmental standards will impact on food and forestry</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>4. Soils</td>
<td>50</td>
<td>Loss of agricultural soils</td>
<td></td>
<td>63</td>
<td>1</td>
</tr>
<tr>
<td>5. Biodiversity</td>
<td>26</td>
<td>Pests and diseases will be more widely dispersed</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>32</td>
<td>The continued decline in vertebrate species populations is part of a complex biodiversity picture creating winners and losers</td>
<td></td>
<td>39, 40, 47, 48, 49</td>
<td>5</td>
</tr>
<tr>
<td>6. Environmental Policy</td>
<td>55</td>
<td>Invasive alien species and diseases will be more widely dispersed and will arrive more frequently</td>
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<td>-----------------------------------------------------------------------------------------------</td>
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<tr>
<td>7. Human Health</td>
<td>51</td>
<td>Antibiotic resistance, pollution and provenance</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>52</td>
<td>Human health, and its links to environment, will increase in importance</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>8. Technology</td>
<td>17</td>
<td>Improvements in farming techniques and technology will boost productivity and food security</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>23</td>
<td>New technology will continue to have an impact on the natural environment</td>
<td></td>
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<tr>
<td></td>
<td>30</td>
<td>Technology is likely to play an increasing role in regulation, both in monitoring and compliance</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>37</td>
<td>The Internet of Things will change production processes and practices profoundly</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>9. Circular Economy</td>
<td>2</td>
<td>Circular economy practices will become more widely used and will change what society values</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>3</td>
<td>Citizen engagement is likely to become increasingly important across a range of policy areas</td>
<td></td>
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<tr>
<td></td>
<td>12</td>
<td>Global population is likely to exceed 8.5 billion by 2030</td>
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<tr>
<td></td>
<td>34</td>
<td>Poverty and social injustice is resulting in a disconnection between people and the environment</td>
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<tr>
<td></td>
<td>47</td>
<td>Waste will continue to increase and is likely to cause significant environmental challenges</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>48</td>
<td>Micro-plastics, waste pollutants and emerging contaminants have increasing impacts on marine ecosystems</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. International Focus</td>
<td>10</td>
<td>Demand for greater regional and local autonomy will continue</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>15</td>
<td>Governments will continue to collaborate to address Climate Change and Sustainable Development; not just national governments, but also cities and regions (para-diplomacy)</td>
<td></td>
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</tbody>
</table>

The UK will agree more strategic approaches to environmental delivery through legislative reform as a result of Brexit

Antibiotic resistance, pollution and provenance

Citizen engagement is likely to become increasingly important across a range of policy areas

Global population is likely to exceed 8.5 billion by 2030

Poverty and social injustice is resulting in a disconnection between people and the environment

Waste will continue to increase and is likely to cause significant environmental challenges

Micro-plastics, waste pollutants and emerging contaminants have increasing impacts on marine ecosystems

Governments will continue to collaborate to address Climate Change and Sustainable Development; not just national governments, but also cities and regions (para-diplomacy)
5.1 Land and Marine Use

This research theme is composed of 7 drivers and 18 challenges (see Table 5), and just under a quarter of all responses analysed (i.e. 23%) were relevant to this theme. The drivers and the resulting 100-word challenges focused on the production and use of natural resources from the terrestrial and marine environments.

43% of responses for this research theme related to drivers 21 and 24 (see Table 5), which focused on the holistic need to consider the use of land and marine resources in terms of competing demands, environmental policy and food security. 22% of responses answered challenges relating to driver 36, which explicitly focused on the concepts of natural capital and ecosystem services as a framework to provide knowledge on management options, regional planning and policy formation related to land and marine use.

All sectors responded to this research theme (see Figure 6) – in line with the overall response rate (see Figure 4).

All respondents for this research theme considered that either new research or synthesis work combining knowledge and data from diverse sources was required. (89% were coded as requesting new research and 51% were coded as requesting knowledge synthesis.)

Respondents not explicitly requesting new primary research wrote statements such as:

More work is needed to analyse NC [natural capital] accounts and create either formula or look up tables to provide better estimates for some ecological and social aspects.

… information exists but needs to be brought together in a way that can be relevant to and inform other sectors.
49% of responses for this research theme called for interdisciplinary research, echoing the idea of combining data and synthesising knowledge from diverse sources. A fifth of the responses explicitly called for transdisciplinary research, with statements such as the following submitted from the ‘Business/Industry’ sector:

This challenge echoes what has been known and called on for years – joined up thinking involving all parties is a necessity for sustainable development. It is important that people in authority listen to the people who make a living on the land.

I agree with the aims of this challenge – we need more data on the use of natural capital rather than the simple two extremes which are commonly reported, i.e. business/industry as destroyers and conservationists/environmentalists as saviours.

There was also a request from one anonymous respondent from the ‘Business/Industry’ sector who requested that transdisciplinary research should be inclusive. They wrote:

The capacity to fund research which enables all sectors to participate, not only the big business/industry who can afford to send staff to research meetings.

The majority of responses for this research theme called for a holistic understanding of the full socio-ecological system (see Figure 7). Respondents wrote statements such as:

There are a multitude of impacts of land (including marine areas) use change evident both on land and at sea, and we need to draw these together and try to maximise synergies between policy objectives to avoid the achievements of one set of goals being to the detriment of another. These contradictions and challenges are with the SDGs [Sustainable Development Goals] and in things like water quality and flooding planning and at scales from global to local. We need to understand these potential conflicts and the ways to minimise them…

![Figure 7. Percentage of responses that included statements coded to evidence needs in the Land and Marine Use research theme](image)

Knowledge gaps relating to natural capital, integrated modelling and policy analysis were identified in many of the responses (see Figure 7).
Most responses considered that the natural capital approach was a means to sustain robust human-nature linked systems and called for durable methods to inform policy. For example:

*Effective environmental policy depends on coherent conceptual frameworks and data systems. Such frameworks and systems for OTs [Overseas Territories] need to address links between ecosystems, ecosystem services and economic activity.*

The same respondent went on to suggest a research project focused on a particular method:

*One promising framework is the UN System of Environmental-Economic Accounting Central Framework (SEEA) which applies accounting concepts to environmental entities (natural capital) and ecosystem services (flows of natural capital to economic activity) e.g. agriculture.*

Others explicitly mentioned the need to learn from the past. For example, a representative from a public sector agency wrote:

*It is critical that landscape and cultural heritage are considered within these frameworks as essential elements of the environment, they are currently underrepresented in ecosystem services approaches despite heritage assets (such as field boundaries, farm buildings, water meadows) providing ecosystem services and supporting biodiversity.*

Many statements considered that single-focused process models were not sufficient and that there was a need for (often spatially explicit) integrated models for a more rigorous approach. For example:

*Many models of ecosystem services (flood prevention, pollination, carbon capture, biodiversity-related services) are simplistic and not validated. A more rigorous approach is needed to produce a set of ecosystem service models which are appropriate to inform land management.*

The need to consider the influence of existing policies was highlighted, especially in relation to future land and marine use planning. For example:

*It is important to understand what mechanisms and legislation is needed to effectively safeguard designated landscapes and seas. Currently, in spite of protections, these areas can be impacted. Planning decisions need to consider not just the direct effects within the area of work but also the wider impacts on adjacent areas of land. We need evidence to show how wide ranging the impacts of new developments can be and then information on effective mechanisms to halt these for protected land- and seascapes.*

Another respondent wrote:

*The long term benefits and services provided by natural environments need to be weighed against any potential developments, regardless of whether they are renewable energy or major roads. Costs and benefits of planning applications need to look at the long term and landscape scale of impact to fully appreciate whether the development is necessary.*

The majority of respondents for this research theme (76% – see Figure 8) considered that evidence needs were required either at UK-wide scale or at UK-wide including the Overseas Territories scale.
A single response indicated an evidence need related only to the UK’s Overseas Territories. However, it is probable that this respondent considered this a high priority for the Overseas Territories but perhaps not exclusively for them. We make this assumption because the response focused on research needs related to a robust implementation of the natural capital and ecosystem service frameworks which has global applicability.

In conclusion, respondents recommended research to further the use of the natural capital and ecosystem service frameworks and integrate these studies with analysis of existing and future policies. The use of integrated spatially explicit models was recommended by respondents as a means to assimilate knowledge across diverse disciplines in order to consider the full socio-ecological-coupled system when creating policy.

5.2 CLIMATE CHANGE

This research theme is a composite of drivers 4 and 40 (see Table 5). Driver 4 focused on global climate change while driver 40 focused on climate change in the UK’s Overseas Territories. The nine 100-word challenges articulated by the workshop participants considered many aspects, from extreme events such as flooding and invasions by alien species and pests to adaption and mitigation measures and the need for better forecasting.

‘Public sector agencies’ and research organisations (i.e. ‘Other public sector’) were the primary respondents for this research theme (accounting for 84% of the responses in total). It is notable that no academic provided a relevant response and that few individuals from the ‘Business/Industry’, ‘Government’ or ‘Civil society organisation’ sectors did so (see Figure 9).
Figure 9. Sectoral responses to the Climate Change research theme

Evidence needs relating to the quantity and quality of data on temporal change were the most articulated need for this research theme (accounting for 60% of respondents). Between 40% and 50% of responses called for evidence related to developing a holistic understanding of ecosystems and socio-ecological systems utilising integrated modelling. Fewer responses (less than 10%) mentioned other evidence needs required to answer the challenges related to climate change. See Figure 10.

Figure 10. Percentage of responses that included statements coded to evidence needs in the Climate Change research theme

40% of respondents understandably emphasised the need for long-term data covering a range of abiotic and biotic aspects. For example, a representative of a public sector agency wrote:

*Testing effectiveness of adaptation requires long-term monitoring of climate change impacts in areas with different management strategies including but not restricted to those which have been carried out as adaptation measures. Greenhouse gas emissions need better*
monitoring on the ground. The role of intertidal and marine habitats is particularly uncertain. Existing monitoring of soils and ecosystem processes, e.g. Environmental Change Network, need to be protected and strengthened.

Others focused on the need for long-term monitoring of the marine environment, with statements such as:

*Predicting weather events needs good knowledge of the ocean and sustained observations of the oceans (UK weather influenced by the state of the Atlantic Ocean).*

The problems associated with funding long-term data were recognised by several respondents, particularly from the public sector. For example:

*The evidence need is for the continued collection of long term data. The more variable and difficult to predict events are, the more there is a need for detailed and long term data. This is required not only to feed into models that can help with predictions and scenarios, but also to ascertain what is actually happening to ecosystems on the ground, through long term monitoring. The importance of long term data and how to provision it effectively needs to be recognised. It is not something that fits easily into short term funding cycles, and it is critical to the integrity of the data that there are not gaps left by lack of funding. High frequency and high resolution is key.*

The need to consider all elements of the ecosystem was stressed as a key research gap by almost half of the responses for this research theme (47%). Statements such as the following highlighted the need for donors to fund programmes of sufficient depth to consider both the effect of ecosystem processes on the climate and the effect of climate change on ecosystems and their ability to enhance human wellbeing:

*A capability to conduct ecosystem-scale long term research, so that we can quantify the multiple direct and indirect pathways by which extremes impact emergent ecosystem properties, such as water quality and fishery production.*

*… we need to understand the impact of land use and climate change on the soil structure and how this impacts biogeochemical and hydrological cycling…*

*The more variable and difficult to predict events are, the more there is a need for detailed and long term data. This is required not only to feed into models that can help with predictions and scenarios, but also to ascertain what is actually happening to ecosystems on the ground.*

Many respondents also recognised as a key research gap a holistic understanding of the role of humans in climate change. Respondents articulated the need for research in terms of both actions and policies which encourage or discourage activities related to climate change. The need for research relating to adaption to and mitigation of climate change, particularly associated with extreme events, was also identified. The need for developing integrated models was blended into responses such as those above and the following:

*From a socio-ecological perspective, extreme events are not purely climatological. As well as direct impacts of extreme weather on people and property, extreme biological/ecological responses (e.g. toxic algal blooms, fish kills) are also highly relevant to society. However, the relationship between extreme climatological drivers and ecological responses is not necessarily simple, e.g. non-extreme climatological drivers could cause extreme ecological*
change, if a threshold is reached. We need to understand the relationship between climatological and ecological extremes, if we are to construct models that are capable of projecting the likelihood of future impacts. Since extremes are (by definition) rare, we need a long-term approach to ecological monitoring so that we can quantify the impacts of multiple events, rather than single events, and then understand and model their effects. This long-term research must be complemented with high temporal resolution monitoring, so that we can understand the timescales of impact at the ecosystem and societal level.

In order to correctly estimate the impact of climate change on UKOTs [UK Overseas Territories], climate change and its effects should not be seen in isolation, but should be evaluated against the rapidly changing levels of direct human impact on the OT environment, specifically in the marine environment.

Primary research is needed at the right scale to determine local areas that are going to be hardest hit in terms of extreme weather patterns and sea level rise.

The UK has world class monitoring for a number of freshwater systems and the datasets generated from this work are already giving us an understanding of the potential impacts of climate change. Long term monitoring is critical in tracking changes in our current systems and in providing the data and process understanding to allow us to better model future events.

Two thirds of responses for this research theme considered that the research should be UK-wide and almost a third of the responses did not state a geographic focus of the studies (see Figure 11). Interestingly, a single response indicated that the climate change evidence need was only relevant to Wales, England and the UK’s Overseas Territories. This response focused on sea level rise and the respondent either considered that this was not an issue in Scotland or perhaps made a mistake on data entry.

![Pie chart showing the geographic focus of the responses relevant to the Climate Change research theme](image)

**Figure 11. Geographic focus of the responses relevant to the Climate Change research theme**

In conclusion, the respondents to this theme stressed the need for long-term data not only to identify temporal trends in environmental change but also to capture extreme events and allow mechanistic understanding and thus improve models for forecasting and policy scenario studies. Respondents also called for research with sufficient depth and longevity to allow a holistic understanding of ecosystem processes and human drivers.
5.3 Economics of Resource Use

This research theme was composed of 4 drivers and 7 challenges (see Table 5), and focused on the influence of economic driving forces on environmental issues. The individual 100-word challenges concentrated on the influence of market forces (supply chain and public subsidiaries) on products from the terrestrial and marine environments, or on the economic influence of recreation and tourism on the environment with a particular focus on the UK’s Overseas Territories. (35% of responses supplied evidence needs for challenge 44, which focused explicitly on the economies of UK Overseas Territories.)

A third of the responses for this research theme were provided by the ‘Business/Industry’ sector, with the farming and forestry industries notable contributors. But all sectors highlighted key gaps in knowledge relating to the creation of sound environmental policy.

![Figure 12. Sectoral responses to the Economics of Resource Use research theme](image)

As might be expected, the majority of respondents (90%) considered it necessary to consider evidence for the full socio-ecological system. The role of markets and the flow of goods and materials (including people) was highlighted by 65% of respondents and the natural capital approach to valuing the environment was emphasised by 45%. 30% of respondents reported that they considered that new research should focus on creating integrated and spatially explicit models, and 25% reported that it should focus on the monitoring and evaluation of existing policy in order to learn from the past. A quarter of respondents thought that there was a need for evidence on all aspects of the ecosystem when considering policy instruments and measures designed to influence the economic use of resources. A fifth of respondents highlighted the need to understand human behaviours related to the use of natural resources. See Figure 13.
The complex influence of market forces on land holding, production systems and the global economy was emphasised, as evidenced by the following response:

Consolidation of land (and so land management by fewer) might be an outcome of Brexit (or might not) due to yet greater retailer power and their focus on lower prices (often through intermediaries such as food processors or fresh produce supply chain managers) – but what evidence is there to support the implicit assumption that "larger farm holdings" will reduce environmental goods and services (or the other implicit component that more smaller farm holdings will improve the environment) in the UK? At the national level, I recognise the respective changes in each variable over time during the post-war period, but that is just a correlation of course. There is a related gap not articulated: if an outcome of Brexit is a yet greater dependency on food inputs (and from beyond the 27 remaining EU states) then would UK policy be exporting environmental problems such that the global environmental effect is negative overall (with the worst consequences faced by those in developing countries least able to fund mitigation activities)?

In terms of natural capital, several respondents considered that tools and integrated modelling approaches may help provide the evidence needed to enhance policy creation. For example:

Some work is already being undertaken on this but we need to continue to develop the methodology. Some data already exist that would feed into the further development of the methodology but more current data on the status of our natural capital assets and the flows of services are needed to ensure that any valuation work is current and up to date.

A representative from a public sector agency stressed (in relation to Common Agricultural Policy funding post-Brexit) the need for the long view by writing:

... are beginning to investigate this but there is still a research gap around the contribution of heritage assets to the environment and ecosystem services.
One respondent specifically called for research on natural capital accounting in the UK’s Overseas Territories and a greater understanding of the ecosystem services that flowed from them by writing:

*I think that there is a great opportunity to invest in new primary research bringing UKOTs into line with investment in mainland UK. Investing in ecosystem services and natural capital research is a priority, coupled with joined up thinking with social sciences (and respective funding councils).*

A key research gap around understanding the motivation and behaviours of sectoral actors was articulated by such statements as:

*Will 'educating the public about the true cost of food' actually change the power of retailers? People will still buy best value, and that will be dominated by the monetary cost. I fear that only if environmental costs are monetised and passed directly to the buyer will behaviour be changed substantially.*

*This challenge ignores 'consumers' and appears to consider the 'retailers' as the price setter. Consumers have since the start of subsidised food production bought food at lower than the cost of production. The role of the large supermarkets has been poorly presented in the evidence supplied to policy makers and the general public. There is a need for a comprehensive economic analysis across a wide range of food sectors to determine the true economic position. Finding 'average' farms and 'average' retailers is problematic but unless the 'consumer' who is also 'tax payer' and the 'voter' fully understood what they are paying for and what their taxes are used for there is little chance of real sustainable development.*

In terms of tourism, several contributors, focusing their response on the UK’s Overseas Territories, indicated that increased tourism was not necessarily desirable; rather, a more diverse range of economic activities for these territories was needed. For example:

*We already know how to maximize tourism. Ecotourism, nature tourism, mass tourism, boutique tourism… The challenge is convincing politicians (the key segments of the public to which the politicians answer) that maximising ecotourism isn't actually the answer… We need to convince politicians to stop maximising and pursue real sustainability.*

"*The UKOTs' economies rely increasingly on ecotourism." So the solution isn't more ecotourism, it’s diversification. Finding other 'industries' that each OT can get into that doesn’t involve as much development (habitat loss & pollution) as ecotourism.*

The holistic nature of the research required to tackle policy related to the economic use of natural resources was articulated by a respondent from the 'Business/Industry' sector when they wrote:

*This challenge requires a range of data covering different disciplines, e.g. economic, cultural, social and environmental, and a commitment to long-term data collection and potentially brings new actors into knowledge management, e.g. citizen scientists. Engagement is required with several other areas of policy, e.g. trade, technology, innovation and consumer protection.*

A third of the responses for this research theme reported that the geographic focus should be on the UK’s Overseas Territories (see Figure 14); in part this is because challenge 44 was specifically focused on UKOTs’ economies. Other challenges relating to the agricultural
supply chain and public subsidiaries were relevant to both the UK and its Overseas Territories. Despite agriculture being a devolved policy issue, none of the respondents considered that research should be focused on a single region of the UK.

![Economics of Resource Use](image)

*Figure 14. Geographic focus of the responses to the Economics of Resource Use research theme*

In conclusion, the need to understand the multifaceted influence of natural resource use on the environment in the UK, its Overseas Territories and globally was considered a high-priority area for future research. The natural capital accounting approach was viewed by many as a practical and useful one but respondents noted that it required more research to ensure robust evidence that can inform policy.

### 5.4 Soils

This research theme focused on a single driver and challenge (see Table 5) which addressed several key unknowns relating to soils, including soil diversity, quality and health. A third of the responses for this research theme were supplied by academics and a third by public sector agency staff, with the final third supplied by representatives from the other sectors (see Figure 15).
The majority of respondents considered that new primary research (84%) and/or synthesis of existing knowledge or datasets (42%) were required. One respondent, addressing specifically the challenge to soil health in terms of the addition of bio-fertilisers, stated that no new research was required and provided a reference to his research. They wrote:

*New primary research is not required as the properties and function of the bio-fertilizer has been published in the scientific literature as a series of seventeen papers. This work has been the subject of a new book entitled "The Properties and Function of the Organo-Zeolitic Bio-fertilizer" recently published by LAP Lambert Academic Publishing, Saarbrucken, Germany.*

The most important evidence need identified by respondents for this research theme was a holistic understanding of ecosystems (a need identified by 53% of these respondents – see Figure 16). Soils were recognised as critical to many aspects of the ecosystem, including soil health, the impact of soils to human wellbeing, the role of soil contributing to climate change, the unknown influence of climate change on soil health and the subsequent consequences for food production.
A comprehensive response to this research theme was provided by staff and students in a university department, echoing many of the other individual responses. They compartmentalised the evidence needs into seven bundles:

a) Data or methods for retarding soil erosion are well versed in the literature. However, there are other issues around soil deterioration and nutrient load that need further study.  
b) More guidance should be given to farmers on the importance of replacing the resources that they remove, rather than waiting until they have mined it out and deficiency symptoms have set in.  
c) The physical properties of peatlands in particular are yet to be fully understood, e.g. the true direction of movement from growth and decay. If these properties were better understood we could create a more accurate estimate of peatland carbon stocks and carbon storage potential. 
d) More research is required into soil biology and linking this to farming practice, particularly using biological methods to keep nutrients in the field and in available forms, and managing pest populations. 
e) The Soil Association produced a report in 2016 summarising current research into the effect of glyphosate on soil health, but found that the evidence for its effects on soil biology is not yet conclusive. Further primary research is required to fill this gap. 
f) New primary research, and consolidation of and modelling using existing research, is required. Deeper understanding of how different soil types respond to changes in land cover and use is needed. Especially pertinent are questions around how long do undesired structural changes (i.e. compaction) to the soil take to be remediated by changing or reverting land use to its former type? How will these structural changes be affected by climate change, and in turn, how might the energy transfer between the atmosphere and soil surface be altered by these changes? How can we adjust our models to address this? Questions of immediate public/policy interest such as ‘can we plant trees to alleviate downstream flooding?’ and, by implication ‘can we plant enough trees now, in the right places, to alleviate the type of stormflow that we might expect with a warmer climate in 30, 50 or 100 years’ time?’ may be answered with greater surety once these knowledge gaps are addressed. 
g) There is a pressing need for methods that allow qualitative and quantitative analysis of nanomaterials in soil environments to be developed.

Other respondents focused on specific aspects such as soil function, soil erosion, urban soils and climate change:
need to develop cost-effective approaches to determine soil health both at the national scale and farm scale. The focus … what soils functions are we losing and the costs of these. This knowledge will then help determine the policy actions to help reduce the losses and restore the critical functions.

We need a better understanding and monitoring of soil movement from the landscape into water courses. We need to know the economic costs of silting of rivers and the associated dredging and do a better job of keeping soil on the fields.

Shrink-swell soils are one of the major economic natural hazards we face every year. Estimates are that this is already more than £400 million a year. Are there ways to better manage the environment to reduce the impact on infrastructure? How do we future proof soils for droughts? Would adding more carbon help retain more water and reduce some shrinkage? … Shrinking and swelling of the ground (often reported as subsidence) is one of the most damaging geohazards in the UK today costing the economy an estimated £3 billion over the past 10 years (ABI, 2006). The Association of British Insurers has estimated that the average cost of shrink-swell related subsidence to the insurance industry stands at over £400 million per year.

Current land atmosphere models lack a dynamic soils component with regard to the soil structure. This means that there are no feedbacks to climate when either land use is changed or the climate changes, especially with regard to the hydrological cycle.

There was no regional focus to the evidence needs reported (see Figure 17).

Figure 17. Geographic focus of the responses to the Soils research theme

In conclusion, respondents recognised the role of soil in the environment as fundamentally important because it affected many aspects related to environmental policy. They recommended a diverse range of research topics that collectively would enhance policy-makers’ knowledge. There was consensus that research should consider soils more explicitly within research programmes (for example, in programmes focused on climate change or land use) so that the influence of policy on soil form and function is explicitly considered.
5.5 BIODIVERSITY

The Biodiversity research theme is a combination of 3 drivers and 5 challenges (see Table 5). The drivers and challenges focused on invasive alien species, pests and diseases and the decline of species.

All sectors provided input to this research theme. ‘Public sector agencies’, ‘Academics’ and representatives of ‘Civil society organisations’ were the most prominent, representing 39%, 22% and 22% of responses respectively. See Figure 18.

![Biodiversity Pie Chart](image)

*Figure 18. Sectoral responses to the Biodiversity research theme*

The majority of respondents (83%) called explicitly for new research, while 44% called for synthesis of existing knowledge. For example:

*These gaps can be addressed through existing research but would clearly benefit from further investment as the fragmented research in this area stretches only so far.*

One anonymous respondent, however, explicitly stated in relation to challenge 40 (focused on invasive species in the UK’s Overseas Territories) that no new primary research was needed. They wrote:

*No. We know enough or it can be learned very quickly when something new invades. What is needed, in every case, is effective control measures. And those, in every case, just need lots of money. We can fund all the fancy research we want but without effective control programmes that knowledge has proven to be meaningless.*

The need to consider holistically the linked human-nature system and all the interactions within the ecosystem was highlighted (see Figure 19).
Figure 19. Percentage of responses that included statements coded to evidence needs in the Biodiversity research theme

Statements such as the following highlighted the need to provide evidence considering aspects such as biosecurity, environmental degradation and trade-off between species:

Biosecurity – the exclusion, eradication and effective management of pests and invasive species – requires multifactorial management of the environment, tourism and trade, especially of plants and animals. New trade agreements with countries with low levels of biosecurity may open new pathways for invasions of the UK by pests and diseases.

There is clear evidence for non-linear relationships between environmental degradation and biodiversity/ecosystem services. In the face of these non-linear relationships, standard DPSIR [Drivers, Pressure, State, Impact, Response] management approaches may not be appropriate. By the time a pressure has caused an impact on an ecosystem service, the stimulated response may be too late (e.g. habitat restoration takes years to put into effect), thus leading to deficits in the ecosystem service and negative impacts to society. Instead, we need a more proactive framework where environmental risk is assessed and responded to. For example, engineers do not wait for a bridge to collapse before mending it – they monitor damage and respond proactively. At the moment, our ability to quantify environmental risk is very limited, as is the communication and management of that risk. This endangers our ability to manage scarce resources, maintain the ecosystem services underpinning societal wellbeing and maintain rich and healthy biodiversity in the face of other land use pressures. This is particularly salient in terms of leaving the EU where precautionary principles are integrated into the environmental acquis (sets of laws and regulations).

... we need new primary research on many more species, the interactions amongst them and their function in the environment. Interactions amongst species must be tested by well designed experiments carried out to determine parameters for ecosystem resilience under potential climate and future environmental scenarios. Need to understand function of species in the ecosystem to help look for functional trade-offs amongst species.

44% of respondents recognised a lack of knowledge relating to ecological networks as a key research gap. They wrote, for example:
In order to develop a coherent ecological network ensuring resilience of our biodiversity and ecosystem services, we need to understand how species move through landscapes. Current indicators of connectivity are based on structural connectivity and do not reflect landscape structure from a ‘species eye view’ (i.e. reflecting the true barriers or features that facilitate dispersal).

Our understanding of the importance of connectivity (both physical and functional) for maintaining species populations is limited and in particular how this will change with climate change. We also need to better understand the circumstances in which increasing connectivity might not be wise or necessary, for example due to the potential spread of pests and diseases.

Strong support for this proposal with a particular focus on the resilience of ecological networks and how this can be measured, maintained and improved in the context of long term climate/environmental changes. How effective are different measures?

A better understanding of how sites act as part of an ecological network, in particular resolving uncertainty around the best way of facilitating species dispersal in different groups and the relative merits of ‘bigger, better, more and joined’ (elements of Lawton Review recommendations).

Over half of respondents (61%) considered it important to integrate the knowledge from a range of disciplines. For example:

Empirical evidence is needed. The combined use of genetic and ecological approaches will help fill this gap.

There is also a need for interdisciplinary research, i.e. understanding human perception of environmental risk, and communicating environmental risk.

Research therefore needs to be underpinned by collaboration at the landscape scale, and more resources to enable wide stakeholder engagement, including more encouragement of cross-disciplinary research and cross-council working.

![Figure 20. Geographic focus of the responses to the Biodiversity research theme](image_url)
In conclusion, the key research gaps relating to the spread of pests and alien species were focused on understanding ecological networks and the role of humans in dispersal processes. Similarly, a key research gap was identified relating to the role of humans in degrading ecosystems and the subsequent effects on biodiversity survival. Respondents reported that the knowledge obtained from research projects which utilised tools and models in the field of ecological networks would provide policy-makers with more robust evidence with which to create policy both to protect humans from pests and diseases and to enable biodiversity to survive in an increasingly human-dominated landscape.

5.6 Environmental Policy

This research theme derives from a single driver and 2 challenges (see Table 5) focused on the knowledge required so that UK administrations can deliver new environmental regulations post-Brexit.

The response for this research theme was relatively even across sectors, in line with the total number of responses to the call for evidence (see Figure 21).

![Figure 21. Sectoral responses to the Environmental Policy research theme](image)

All respondents to this research theme called for new primary research and 33% considered that by synthesising existing knowledge new evidence relevant to producing better environmental policy could be achieved.

In particular, respondents highlighted the need to consider the full socio-ecological system (see Figure 22) and consequently involve a wide range of stakeholders when evaluating new policy options.
Figure 22. Percentage of responses that included statements coded to evidence needs in the Environmental Policy research theme

Statements included, for example:

*I agree we need more evidence of the real impact of a new policy – currently such analysis is clearly not effective given the reduction in natural capital we witness. We need policy makers to understand their limitations and fund research to consult on the likely outcome of a policy change ... to make effective policy which has no unforeseen consequences, e.g. farming and forestry policy currently in UK means integrating trees on farmland is discouraged.*

*The farming and forestry industries are forced by policy to compete, i.e. the grant and subsidy systems focus only on one sector – we need the evidence to highlight why this is bad for the ecosystem and humans’ enjoyment of the environment. The ideas of agri-forestry have been around for years but policy actively discourages integration of farming and forestry. New research analysing the policy landscape and reporting the views of farmers and foresters is needed so that policy makers can understand what they are doing.*

The long view associated with all legislative reform was also highlighted, with statements such as:

*To achieve this long-term perspective, we do need long-term monitoring to understand the baseline before changes are made and the long-term effects of making change.*

*The challenge is optimistic for Brexit which is great to see – but long term policy change requires long term understanding. The people funding research need quick results for their personal careers – this means they do not like to fund long term research. Too much research is short term single focused and is funded to benefit individual careers not society.*

The importance of environmental policy to all regions of the UK and its Overseas Territories was recognised by respondents (see Figure 23).
In conclusion, the key research gaps suggested by respondents focused on a need for greater analysis of the effects of current policy and for scenario planning. In particular, inter-sectoral effects were highlighted as a neglected area. Respondents called for more consultation with a wider range of stakeholders to consider the likely impact of policy change.

5.7 HUMAN HEALTH

The Human Health research theme centred on 2 drivers, each with a single challenge (see Table 5). One focused on the use of antibiotics and the risk of chemical contamination of the environment and the other on the opportunities the natural environment presents for human health.

The ‘Government’ sector did not respond to either of the 100-word challenges, but all other sectors offered opinions on the evidence needs for this research theme (see Figure 24).
The evidence needs for this research theme centred on the need to understand the linkages between human health and the environment (cited by 100% of respondents) and specifically to understand the coupled socio-ecological system (60%) and the interlinkages between components of the ecosystem (40%). (See Figure 25.) A fifth of respondents also considered that there was a lack of knowledge relating to the understanding of human motivation and behaviour.

![Figure 25. Percentage of responses that included statements coded to evidence needs in the Human Health research theme](image)

The need for research to integrate all the multifaceted aspects of the environment was also expressed directly. For example:

*As this challenge indicates there needs to be better integration of knowledge.*

Another respondent expressed the same sentiment but was more specific:

*The challenge is how to design an environmentally effective and integrated approach to ecosystem health and human wellbeing that includes the biophysical alongside the socio-economic. Ecosystem services (ES) and nature-based solutions (NBS) go some way towards this, but so far they struggle in practice to truly engage all relevant actors.*

This respondent went on to suggest that new primary interdisciplinary research was needed:

*…start by funding people from different fields to work with practical people who would use the knowledge produced – they know the problem and can often suggest solutions which we need the science to prove if really practically useful.*

Over half of respondents (53%) called for studies that were more interdisciplinary in order to identify key evidence needs for this research challenge.

The ecosystem service concept was mentioned by many respondents. For example:

*We need to understand how ecosystem structure and functions relate to the delivery of ecosystem services. This is particularly true for regulatory services where the environment*
is key. Also important for cultural services, where environmental quality is less directly linked.

The need to identify indicators of ecosystem services was stressed. For example:

*Most studies use proxy indicators of ecosystem service (e.g. environmental quality) and this does not reflect services at all.*

The key issue of trade-offs between ecosystem services was emphasised by respondents to this research theme. For example:

*The evidence is building on the capacity of ES and NBS to deliver multiple benefits, but the synergies and trade-offs between desired outcomes and actions to achieve them are less well understood and the evidence is less. More research in this area could be beneficial, especially on how to move from theory to practice.*

Environmental monitoring, especially of the aquatic and marine environments, was stressed in relation to the environmental risk of chemical contamination from human medicines. For example:

*To understand sources, pathways, persistence and impact of emerging chemical pollutants in the natural environment requires data at higher spatial and temporal resolution than currently available using traditional sampling and laboratory analysis. This data is currently missing because of economic drivers preventing more intensive manual sampling and because technology is currently incapable of making these measurements.*

Organisms, especially aquatic organisms, are being exposed to low levels of different pharmaceutical compounds in the environment. Some studies have suggested behavioural changes of such exposure, such as increased predation of fish because of a diminished fear response. However, the extent of impacts and hence risks is far from clear.

*In addition to understanding and quantifying the impact on food security and human health, there is a need to understand how chemicals in the environment affect aquatic ecosystems (e.g. transfers through the food chain, and impacts on ecosystem structure and function). There is also a need to better quantify pollutant transport from the land to the marine system.*

**Analytical methods for modern compounds and their breakdown products. Understanding of behaviour of chemicals in the environment.**

There was also an indication of a lack of evidence around the concept of nature-based solutions both for mitigating the effects of chemical pollution and to directly improve human health (especially in urban environments). For example:

*The role of nature-based solutions in addressing contaminants in the natural environment needs to be better understood. This needs to consider not only those services already provided by ecosystems, but what they could provide were they restored or improved. Reintroductions of previously native species, such as beavers, could contribute to this.*

*Our urban public parks and green spaces are of immense heritage and cultural significance. They have, and have had, an important role in ameliorating urban pollution and sustaining urban lifestyles and they are usually the largest assets in the Green Infrastructure. They are a wonderful inheritance. We need to ensure these parks and green spaces are well*
maintained and contribute fully to the Green Infrastructure and we lack evidence to make the case.

Historic environment has a role to play here – connecting people to places, benefits for health and wellbeing. Also in many urban and peri-urban contexts green spaces are themselves heritage assets, understanding this and working with this is essential for maximising the benefits of those spaces and in caring for them.

Research on understanding human motivation was also called for:

We need to know what would create behavioural change in both practitioners and patients. Currently, there is a feeling that only medication is the solution to illness. We need to understand what it is that stops people accepting that going for a walk or sitting in the park is a valid treatment. The message we are getting is that GPs and the general public KNOW this is true, but they do not act on this knowledge.

This respondent went on to suggest a holistic research programme:

It is important to look at the long term and multiple benefits of a treatment. Although a modern medical treatment may treat one aspect of ill health or a single symptom, the benefits of green prescriptions are that they solve underlying issues and multiple issues. This needs to be considered fully in any research.

The majority of respondents considered that there was no specific regional focus, with the majority reporting that the evidence was needed at a UK-wide scale or UK-wide including UK Overseas Territories scale (see Figure 26).

Figure 26. Geographic focus of the responses to the Human Health research theme

In conclusion, the evidence needs reported by respondents for this research theme focused on considering a holistic view of human health and the environment through interdisciplinary studies. But surprisingly few respondents (7%) considered that it was important to combine social and natural scientists in a single project, despite a call to consider human motivations (see Figure A2.5). This may have been because they considered this inherent when they called for interdisciplinary studies.
The concept of ecosystem services was highlighted as a means to provide evidence to encourage integration of knowledge and to inform policy-makers. More research on nature-based solutions was called for as respondents considered that more knowledge of this approach could inform policy-makers on measures and instruments to mitigate the effects of chemical pollution (especially in the aquatic environment) and could directly benefit human health in the urban environment.

5.8 Technology

This research theme combined 4 drivers and 4 challenges. These 100-word challenges considered new technology to monitor the environment, boost production and digitally gather information and link it together (i.e. the Internet of Things).

No representative from the ‘Government’ or ‘Civil society organisations’ sectors responded to the challenges in this research theme (see Figure 27). The ‘Other public sector’ category dominated the responses.

Figure 27. Sectoral responses to the Technology research theme
Respondents considered that technological innovations could provide key evidence to policy-makers, if research into the development of those innovations was funded. The following response from a public sector agency sums up many of the individual responses linking the need to research technology, data and its uses:

… some key elements which stand out:

• Technology needs: There is a need for a more creative use of technology to make better, more integrated decisions. A critical evidence need is around the role of new technologies in reducing pressure on resources, resolving conflicts, increasing resilience at various different scales.

• System based needs: A systems based approach will be essential to deliver real changes for the UK economy. In many areas of the natural environment, it will be necessary to act on multiple systems in tandem to get environmental improvements and get the maximum benefit from actions. This will require better understanding of the contributors to environmental damage and recovery, the interplay between them and how changes in one system will affect another.

• Data needs: Understanding of how long term datasets are maintained while at the same time reforming monitoring to provide data that more appropriately captures the levels and improvements in for example air pollution and its impacts in real time. There is a need to explore how we integrate these different elements together to help build resilience against shocks and determine what measures could be deployed to protect or enhance ecosystem services. A fusion of technology, systems based approaches and data will also be needed to better understand risk, uncertainties and complexities in decision-making.

Research into sensor technology to enhance long-term monitoring was highlighted in many fields: e.g. predicting extreme events, driving innovations in regulation and methods of compliance assessment, informing land design and planning, and natural resource management (e.g. air and water quality). Examples of statements included:

Needs long-term data at high frequency to capture extreme events and responses – can use innovative new approaches such as automated sensors and Earth observation to capture impacts/responses at high frequency e.g. EO [Earth observation] of phytoplankton (chlorophyll) every 1-2 days using new European Sentinel satellites.

… research needs to address how to extract RNA/DNA from environmental samples with in situ / autonomous devices (e.g. for pathogen detection) and to develop assays to quantify organic pollutants (e.g. pharmaceuticals by using recombinant antibodies, aptamers or affimers).

Present national scale surveys of ecosystem state and change (such as the Countryside Survey and the National Forest Inventory) are labour intensive and expensive, and slow to perform, and do not capture the short-timescale changes and impacts that would help understand sensitivities and predict effects. Many surveys have been cut back. In addition, detailed monitoring activities at exemplar sites have also been scaled back over years, or are under threat, even though these can produce the temporal detail required, even if only for a limited set of sites. The IoT [Internet of Things] could help fill some gaps in monitoring, for example real time monitoring of drought impacts on tree growth and C [carbon] sequestration, and ground-truthing wide area satellite-derived info.
This respondent went on to consider funding mechanisms and wrote:

However, making this sort of technology-driven approach pay for itself through PES [payment for ecosystem services] or other mechanisms, so that it could provide a large scale assessment, rather than answering scientific questions about environmental impact at a few sites, is a substantial challenge.

Several respondents also included the need for research to improve data management. For example:

This requires innovation, ways to digitally collect, store and share data.

…requires new research on how to link the data sources, and how to finance such developments (i.e. make a market for the information to justify the costs).

…to link data resources in the most effective ways and continue to develop modelling capability…

Some respondents also raised the ethical use of technologies. For example:

Innovative technologies – such as geoengineering, nanotechnology and synthetic biology – have the potential to offer environmental benefits, but need to have legislation to enable their responsible use, financial feasibility and development. These innovations can minimise and reverse environmental impacts while contributing to economic growth. However, some of these technologies may have substantial transboundary effects, such as geoengineering, or may raise specific ethical acceptability, such as the use of synthetic biology – the process of developing or redesigning new biological entities and systems – to resurrect extinct species or create new lifeforms.

The same respondent went on to stress the need for interdisciplinary studies:

An understanding of the relevant technologies outside of the discipline that develops them, in other words interdisciplinary teams working on the implications of emerging technologies.

![Figure 29. Geographic focus of the responses to the Technology research theme](image-url)
In conclusion, respondents urged donors to fund research into technological developments, particularly sensors and the linking of sensors (i.e. the Internet of Things), to provide long-term monitoring of the environment in order to enhance policy-makers’ and public sector agencies’ ability to build cheap and effective compliance monitoring, as well as to provide an evidence base for new policy.

The technical challenges were summarised by one respondent as follows:

…challenges currently being faced include image resolution, data accuracy, ease of processing, the quality and objectiveness of many models, uncertainties around issues such as what aspects of natural capital underpin ecosystem services in a particular area and appropriate regulatory frameworks.

5.9 Circular Economy

This research theme linked 5 drivers and 7 challenges (see Table 5) which collectively consider citizen engagement in science and care for the environment (e.g. via waste disposal and recycling).

‘Public sector agencies’ were the predominant sector to respond to the challenges in this research theme (see Figure 30). No representatives from the ‘Government’ or ‘Other public sector’ categories submitted key research gaps for this research theme.

![Figure 30. Sectoral responses to the Circular Economy research theme](image)

64% of respondents for this theme suggested that the research gaps should be addressed by considering the full socio-ecological system, while 36% suggested that it should be done by full evaluation and monitoring of current policy. 27% suggested that the links between the circular economy and human health was a key research gap, and the same number suggested involving the concept of natural capital as such a gap (see Figure 31).
In particular, respondents wrote in relation to understanding the full socio-ecological system. For instance:

*There is an opportunity to continue the UK tradition of recognising the environment in its entirety, that 'natural' environment is the result of human activity and the separation between the natural and the historic is often far from clear cut. Looking at what an integrated approach might look like would be hugely beneficial.*

Policy-related evidence needs included analysis considering a wide view of policy. For example, one respondent wrote:

*Key knowledge needs include analysis of:*
- how policy can support the development of secondary markets for recycled materials through the supply of good quality recycled material and demand for reprocessed products.
- the opportunities for businesses to improve resource efficiency through use of eco-design and the role for government to support this.
- how policy can maximise the opportunities of the transition to a more resource efficient economy.

Over a quarter of respondents to this research theme (27%) stated that there was a need for transdisciplinary research particularly in relation to understanding the circular economy. One reply to the question relating to the skills and capabilities required to address the evidence need answered simply:

*Practical people!*

Another suggested that there was a need for evidence to determine if the transdisciplinary approach was effective in practice. They wrote:

*There are a few examples of transdisciplinary research in the UK and examining these could significantly highlight the advantages of this approach. New primary research should collect*
data from all actors of few case study transdisciplinary research projects and focus on projects which claim to have followed a transdisciplinary research approach.

Over half of the responses did not suggest any geographic focus for the research associated with this research theme (see Figure 32).

![Figure 32. Geographic focus of the responses to the Circular Economy research theme](image)

In part this is because several public sector agencies submitted their evidence needs directly to NERC and did not state a geographic focus for any of the 100-word challenges. Those stating a geographic focus indicated that evidence for citizen engagement in waste disposal was a particularly important research gap in the UK’s Overseas Territories. One wrote:

**The UK’s commitments to meeting its biodiversity targets require a greater focus on assisting its Overseas Territories in their transition towards more environmentally sustainable practices and green economic development. Further research and innovation in supply chain analysis, industrial production, disposal systems and eco-toxicology is needed to examine and implement forward-looking solutions. These steps will both reduce consumption and support moves towards a more circular economy.**

In conclusion, the majority of respondents to this research theme highlighted a need for evidence centred on the production, utilisation and recycling of waste which would involve all sectors of society.

### 5.10 International Focus

This research theme has 2 drivers and 2 challenges. These articulated issues relating to the need to consider international collaboration, transboundary relationships and the role of UK scientists in solving global environmental problems.

The fewest responses were assigned to this research theme (see Table 5) and consequently it is unsurprising that not all sectors were represented (see Figure 33). Three ‘Other public sector’ organisations responded, perhaps indicating their role in representing the UK Government and its agencies in international activities.
All respondents highlighted the necessity to consider the full socio-ecological system when conducting research to fill evidence gaps. Integrated and spatial modelling was considered an important tool by 71% of respondents and the need to understand markets and the flow of material was highlighted by 57%. 43% of the responses mentioned a need to understand human motivation and the temporal rate of change. See Figure 34.

Integrated modelling was suggested by the following statement:

*Modelling needs to go beyond single media modelling (air, water, soil, ghg etc) and address the joined up picture.*

Climate change and food security were common themes in the responses to this research theme. For example:

*Climate change food insecurity is likely to be concentrated in conflict-affected regions and developing countries, but food security may rise for developed nations and corporations that*
are able to buy up agricultural land globally. Global agricultural production is vulnerable to climate change impacts such as severe weather events like floods and droughts, including the yield of the five crops (rice, wheat, maize, millet and sorghum) that account for 60% of energy intake for the world’s population. Studies suggest that many of the most commonly raised crops and livestock animals may not be able to adapt to changes in climate. Drought and lack of water or irrigation will be a major challenge, but even in areas that become warmer and wetter, ranges and distribution of weeds, fungal pathogens and pests are likely to increase.

Understanding how global contextual forces (arising from macro-economic, technological and geopolitical changes) will impact on domestic food security.

We need to understand – forecast and monitor – the demands for food and water in the UK in an international context.

One respondent provided a very full response taking nitrogen as an example and explaining the interlinkages particularly relevant to the international context:

Research is needed…to assess environmental protection in relation to the human disturbance of the key [global] driving cycles. The case study of nitrogen in the environment provides a good example. Humans have doubled the supply of nitrogen compounds, where nitrogen fertilizers have been the fuel of the Green Revolution. Humanity has been fed, but at a huge cost as nitrogen losses contribute to air pollution, water pollution, greenhouse gas emissions, biodiversity loss, loss of soil quality and stratospheric ozone loss. These flows combine emissions of nitrogen oxides from combustion sources, leading to multiple interacting impacts on the environment. The systemic nature of the problem calls for an integrated approach to taking action. In this context it becomes important to develop the scientific understanding of the quantitative interactions between nitrogen issues and to identify the extent of policy synergies and trade-offs. Models are needed that can express to what extent policy and practice options would contribute to environmental improvements and in increased wellbeing for citizens. Critically, the current policy landscape needs to be examined. It needs to be explored to what extent the current fragmentation of nitrogen related policies is exacerbating the current barriers to UK policy implementation and to our achievement of international commitments under a whole range of UN and other multilateral agreements. Nitrogen is perhaps unique in crossing so many boundaries with so many impacts. But this does not mean we should forget the interactions with other element cycles. The point is that current efforts have over-emphasised carbon at the expense of others issues, while current efforts on nutrients (considering N, P, C, Si and others) have tended to see this as only a water-based problem. The same applies with air pollution, interactions with S, N, O3 and particulate matter are well known, but have not succeeded in developing the policy connection with other threats. This points to the opportunity to use nitrogen as a means to connect each of these issues, and assess to what extent development of a stronger shared gravity can help overcome the barriers to change.

Another equally full response focused on the concept of planetary boundaries and the evidence needs required for the implementation of the framework. It suggested that research should focus on:

…developing understandings of the three dimensions for bridging across scales – the biophysical, socio-economic and ethical…

It went on to suggest a need to develop:
understandings of the connections between (a) local vulnerabilities, critical loads and potential ecological ‘hotspots’, and (b) the regional level PBs [planetary boundaries] that relate to the way sub-global dynamics affect the functioning of the Earth system as a whole, so that an integrated approach to identifying UK limits and targets can be developed.

The recognition of UK scientists in the international community was highlighted by several respondents who urged NERC to remain outward-looking. For example:

The UK is acknowledged as leading in engaging industry in ocean-observing innovation (e.g. through ocean carbon capture and storage integrity monitoring systems, shellfish safety assurance). The UK could build on this strength to address the gap of policy, technology and environmental management methods for the marine environment.

It is also important to promote effective networking with international partners, so that we can generate globally-relevant models and insights into these effects, and put NERC and the UK at the forefront of this field.

The geographic focus for this research theme is shown in Figure 35.

![Figure 35. Geographic focus of the responses to the International Focus research theme](image)

In conclusion, respondents to this research theme focused on the need to consider transboundary issues (particularly food security and air pollution) in a global context, supporting the view that global consensus is the most effective route to environmental protection.

5.11 COMMON REQUIREMENT ACROSS ALL RESEARCH THEMES

Across all responses, there was a common desire to look beyond the narrow disciplinary approaches and conduct interdisciplinary projects to address the most pressing evidence gaps identified in the 100-word challenges. There is evidence that the donor community is recognising this need with the creation of UK Research and Innovation (UKRI). However, one respondent was concerned about the need for new mechanisms:

...would require a multidisciplinary / cross council / pan UKRI effort with technologists, environmental scientists and analytical chemists / life scientists working together. Currently
the mechanisms for assembling, coordinating and funding such multidisciplinary teams are limited.

The fundamental mechanism of competition within our society was recognised as a hindrance to interdisciplinary studies. An anonymous respondent from the ‘Business/Industry’ sector, writing in response to whether new primary research was required for understanding the effect of policy on the natural capital of the UK, wrote:

Yes if people worked together – but competition is embedded in our society – scientists compete for research funds, research councils compete with each other, businesses compete and knowledge is a critical weapon and all individuals have to look out for themselves!

Despite these misgivings, approximately half of the respondents to this call for evidence recommended interdisciplinary studies – specifically requesting funding to create new knowledge by encouraging integration of existing datasets from different disciplines to address a wide range of environmental issues.

Approximately a fifth of respondents to the call for evidence went one step further and requested that NERC fund transdisciplinary research (i.e. actively involving all sectors of society in the co-design and implementation of science). One respondent from the public sector wrote in response to the challenge associated with emerging technologies and environmental regulation:

Collaboration is not only required between the different research disciplines but also between researchers, regulators, bodies undertaking regulatory testing and industry. A particular opportunity is improved coordination of regulation and technology development including pull-through into funding opportunities.

Several respondents requested that research donors consider the users of the research they fund more explicitly by insisting on transdisciplinary studies involving both policy and practice. A representative of a civil society organisation wrote:

Researchers, farmers and other organisations need more funding to work together to tackle these issues at the landscape scale.

The natural capital concept was also mentioned in all research themes. This concept was seen as a framework to encourage integration of datasets and knowledge streams. Although the natural capital concept is often equated with the discipline of economics, the need to involve other disciplines to provide a wide definition of natural capital was recommended by respondents. For example:

…economic and non-monetary valuation studies of the natural environment; ecosystem services (eco-tourism; water supply, quality and waste; and pollination).

Being able to quantify these services, and potentially put an economic valuation on them may help open up financial mechanisms for investment (e.g. local carbon offsetting schemes), or enable further research investment. At the same time, the socio-economic value of island ecosystems is also needed – i.e. a social baseline. These environments can be valued for many non-monetary reasons, and opening up UKOTs [UK Overseas Territories] to ecotourism (as is the ambition on St Helena) could lead to tensions between visitors and islanders. Combined interdisciplinary studies and those drawing on island studies literature research could be very helpful here.
The need for long-term data was mentioned in all 10 research themes. The fact that NERC is currently going through a period of considerable change (i.e. negotiating self-governance for its research centres and adjusting to the opportunities presented by the creation of UKRI) was noted by respondents. Many were afraid that the UK would terminate its current suite of long-term data, reducing the evidence provided to policy-makers across all research themes.

6 CONCLUSIONS

A wide range of respondents from the full suite of sectors responded across all 100-word challenges (30 named individuals or organisations and 34 anonymous responses). The ability of the respondent to answer anonymously appeared valuable and encouraged forthright and direct responses. It is noticeable that a higher proportion of individuals in the ‘Government’ and ‘Business/Industry’ sectors preferred to respond anonymously.

The responses, grouped into 10 research themes, highlighted a wide variety of evidence needs required in order to enable the creation of robust and effective UK environmental policy in the future.

The conclusions for each theme were:

Land and Marine Use
Respondents recommended that NERC fund research to further the use of the natural capital and ecosystem service frameworks and integrate these studies with analysis of existing and future policies. The use of integrated spatially explicit models was recommended by respondents as a means to assimilate knowledge across diverse disciplines in order to consider the full socio-ecological-coupled system when creating policy.

Climate Change
Respondents stressed the need for long-term data not only to identify temporal trends in environmental change but also to capture extreme events and allow mechanistic understanding to be developed, and thus improve models for forecasting and for policy scenario studies. Respondents also called for research with sufficient depth and longevity to allow a holistic understanding of ecosystem processes and human drivers.

Economics of Resource Use
The need to understand the multifaceted influence of natural resource use on the environment in the UK, its Overseas Territories and globally was considered a high-priority area for future research. The natural capital accounting approach was viewed by many as a practical and useful approach, but respondents noted that it required more research to ensure robust evidence that can inform policy.

Soils
Respondents recognised the role of soil in the environment as fundamentally important because it affected many elements related to environmental policy. They recommended a diverse range of research topics that collectively would enhance policy-makers’ knowledge. There was consensus in the replies that NERC should consider soils more explicitly within research programmes, such as in programmes focused on climate change or land use, so that the influence of policy on soil form and function is explicitly considered.
**Biodiversity**
The key research gaps related to the spread of pests and alien species were focused on understanding ecological networks and the role of humans in dispersal processes. Similarly, a key research gap was identified relating to the role of humans in degrading ecosystems and the subsequent effects on biodiversity survival. Respondents reported that the knowledge obtained from research projects which utilised tools and models in the field of ecological networks would provide policy-makers with more robust evidence with which to create policy to protect humans from pests and diseases and to enable biodiversity to survive in an increasingly human-dominated landscape.

**Environmental Policy**
The key research gaps suggested by respondents focused on a need for greater analysis of the effects of current policy and for scenario planning. In particular, inter-sectoral effects were highlighted as a neglected area. Respondents called for more consultation with a wider range of stakeholders when considering the likely impact of policy change.

**Human Health**
The evidence needs reported by respondents focused on considering a holistic view of human health and the environment through interdisciplinary studies. The concept of ecosystem services was highlighted as a means to provide evidence to encourage integration of knowledge and inform policy-makers. More research on nature-based solutions was called for as respondents suggested that more knowledge of this approach could inform policy-makers on measures and instruments to mitigate the effects of chemical pollution (especially in the aquatic environment) and could directly benefit human health in the urban environment.

**Technology**
Respondents urged NERC to fund research into technological developments, particularly sensors and the linking of sensors (i.e. the Internet of Things), to provide long-term monitoring of the environment in order to enhance policy-makers’ and public sector agencies’ ability to build cheap, effective compliance monitoring as well as to provide an evidence base for new policy.

**Circular Economy**
The majority of respondents highlighted a need for evidence centred on the production, utilisation and recycling of waste and urged the inclusion of all sectors of society.

**International Focus**
Respondents focused on the need to consider transboundary issues, particularly food security and air pollution, in a global context, supporting the view that global consensus is the most effective route to environmental protection.

Overall there was a strong call across all research themes for interdisciplinary research, with respondents often explicitly calling on donors to fund transdisciplinary researchers and to involve non-science actors in project design. Funding streams to ensure that not only ‘large and powerful’ non-science actors contributed their expertise to the co-design and co-production of environmental research were recommended.
APPENDIX 1 EXAMPLE OF CODING A RESPONSE TO CATEGORIES

~Response Number 60.
Sector: Other public sector
Environmental need code 3 (focused on enhanced environmental policy)
Driver 41
Challenge number 57

Challenge 57 Text
There is an opportunity enshrined within the EU exit for the UK to become a world leader in terrestrial and marine environmental management and technology and to derive significant economic, social and environmental public benefits. In order to achieve this in the short term, policy must remain effective and robust. To support long-term growth, we must retain exemplar policies and build upon them, through clear targeting of outcomes. This also requires an effective system to measure ecosystem benefits and to communicate and embed both of these clearly across all policy areas. All of the above requires long-term strategic planning and resourcing in order to reap the full benefits which can clearly deliver net economic, environmental and social gains.

Response to Q1. Respondents were asked to identify ‘key knowledge gap/evidence need that would address the selected challenge’

The amount of data available on different aspects of the environment is expected to grow rapidly with innovation in remote monitoring and satellite technologies while costs are expected to drop as technology and usage advance. This data could be used to inform land design and planning, natural resource management, air and water quality mechanisms and other environment-related activities. For example, traces of organisms’ DNA in the environment, known as environmental DNA (eDNA), can be monitored to paint a picture of biodiversity. Though in its infancy, this advancing research can be used to assess biodiversity in a landscape – for instance, in river systems – using less effort and at a lower cost than traditional sampling methods. In theory, the increase in data provides opportunities for managing the same area of land for multiple benefits and risks, such as floating housing in areas used for flood storage, and the technologies to facilitate this, such as environmental decision support software tools. However, challenges currently being faced include image resolution, data accuracy, ease of processing, the quality and objectiveness of many models, uncertainties around issues such as what aspects of natural capital underpin ecosystem services in a particular area and appropriate regulatory frameworks.

Response to Q2. Respondent answered the question Could this gap be filled using existing research/knowledge/evidence or does it require new primary research?

New primary research would be required to identify what data is needed for any such system to work effectively, particularly case studies in different areas to understand the extent of challenges involved, but could be informed by previous initiatives such as Natural England’s Ecosystem Service Pilots. While the limitations of current ecosystem service models are well known, developing ones that work for planners at the appropriate scale will require new research that is co-produced with not only planners but also communities affected by the decision.

Response to Q3. Respondent answered the question Are there any critical skills, data, capabilities that are required in order to address this gap?
Ecosystem modelling, better understanding of the ecology of ecosystem services, social ecological systems.

This response was coded positively for the following categories

Question 1
- Holistic understanding of coupled socio-ecological systems
- Natural capital
- Holistic understanding of ecosystems
- Monitoring and evaluation of policy
- Integrated and spatial modelling

Question 2
- Requires new primary research
- Transdisciplinary research

Question 3
- Long-term monitoring of a full suite of socio-ecological parameters
- Earth Observation data