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Developing and piloting a UK Natural Capital Stress Test

Final Report

Prepared for WWF-UK

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Quality information

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Glossary

Term	Project definition
Acute	A subset of impacts in the model which deal with short-term (often severe) changes in service provision e.g. flood events
Adaptation/behavioural response	The existing, planned, or anticipated response to ecosystem service change that is intended to mitigate impacts of that change
Case study	An example to demonstrate how the stress test approach may be applied to address a particular question of policy interest
Chronic	A subset of impacts in the model which deal with longer-term incremental changes in ecosystem service provision e.g. changes in soil productivity
Drivers	Themes that will generate changes in natural capital
Impact	The effect on ecosystem service provision from a change in natural capital or the resulting economic effects from a change in ecosystem services
International impact	The effect that similar changes in natural capital might have worldwide, realised as economy-level changes (e.g. price changes, import availability)
Model	The process for quantifying the acute and chronic impacts of changes in ecosystem service provision on the UK economy
Project methodology	The steps taken to design and pilot the natural capital stress test in this project
Scenario	A broad narrative describing the possible future stresses on natural capital relating to five direct drivers of change
Sensitivity	The extent to which changes in variables generate different outcomes
Stress test approach	The initial approach put forward for use and development by Government and other users
Shocks	Irregular events leading to acute changes in natural capital and ecosystem service provision
Stresses	Ongoing pressures leading to chronic changes in natural capital and ecosystem service provision
Variables	The quantified changes in ecosystem service provision associated with natural capital impacts; these are used to estimate the total change in service provision which feed into the model

Acronyms

Term	Project definition
BEIS	Department for Business, Energy & Industrial Strategy
BMV	Best and Most Versatile agricultural land
CCRA	UK Climate Change Risk Assessment
CICES	Common International Classification of Ecosystem Services
Defra	Department for Environment, Food & Rural Affairs
GDP	Gross Domestic Product
GVA	Gross Value Added
NCC	Natural Capital Committee
NCST	Natural Capital Stress Test
ONS	Office for National Statistics
UKNEA	UK National Ecosystem Assessment
UKNEA-FO	UK National Ecosystem Assessment Follow-On

Executive Summary

Overview

This report sets out the results of a study that developed and piloted a new Natural Capital Stress Test (NCST) for the UK, to help the Government to track emerging environmental risk 'hot spots' in the economy, pinpointing which business sectors are most at risk, in order to help identify the need for and to prioritise policy responses.

The study findings show that the loss or degradation of natural capital could lead to significant impacts on the national economy by 2050 if actions are not undertaken to curb or adapt to the potential changes. These impacts could be particularly significant for the most at-risk sectors, such as the food and beverages sector.

Degradation of the natural environment, both in the UK and overseas, is already posing mounting risks to our economy and businesses (e.g. due to flooding, soil erosion, and air pollution). These findings underline the importance of developing a better understanding of, and carefully managing, these risks in order to safeguard the UK's future economic resilience and prosperity.

Context and rationale for the study

Natural capital is the stock of renewable and non-renewable natural assets (minerals, soil, air, water, and all living things) that provide benefits to people. These assets contribute to the economy and human wellbeing directly and indirectly in many different ways.

The Natural Capital Committee (NCC) has warned that the condition of many of these assets is at high or very high risk.[1] Changes in natural capital assets are already imposing significant costs on the UK economy and businesses,[2] and the growing risks to natural capital could have potentially significant impacts on the future growth of the UK economy.[3,4]

The NCC also identified a gap in our understanding around the impact of changes in natural capital on UK macroeconomic performance; recommending further work to promote a better understanding of *"the impact of changes in natural capital upon the economy, jobs, and growth"* in its advice to Government on priorities for research.[5] The importance of understanding these issues for policymakers was emphasised at a workshop held as part of this project where one of the participants observed, "*ultimately, the issues that keep decision makers awake at night are GDP, unemployment, and inflation."*

In light of these recommendations, WWF-UK is interested in drawing on the stress test approach used in the financial sector to develop and pilot a 'natural capital stress test' (NCST) for the UK. Using the financial stress testing analogy, an NCST is a scenario analysis exercise in which various impacts associated with one or

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[1] Natural Capital Committee (2014), 'The State of Natural Capital: Restoring our Natural Assets'. Report to Economic Affairs Committee.
[2] Natural Capital Committee (2015) The State of Natural Capital Protecting and Improving Natural Capital for Prosperity and Wellbeing.
[3] Atkinson G. (2015) Natural Capital and Economic Growth. Natural Capital Committee Discussion Paper [online] available at http://nebula.wsimg.com/402030805e7bc7a4a9849e7bb3ec3dff?AccessKeyId=68F83A8E994328D64D3D&disposition=0&alloworigin=1 (last accessed 10 February 2017)
[4] Natural Capital Committee (2014), 'The State of Natural Capital: Restoring our Natural Assets'. Report to Economic Affairs Committee.
[5] Natural Capital Committee (2015), 'Advice to Government on research priorities'.

more plausible but adverse future scenarios are identified. Here, the analysis tests a plausible but relatively extreme adverse scenario of ecosystem service decline, to gauge the resilience of the economy.

An NCST could therefore be part of a toolkit to provide the UK Government, businesses, and other stakeholders with a means to systematically track emerging environmental risks affecting the economy, and pinpoint which sectors of the economy are most at risk in order to help identify appropriate policy responses.

Aims and approach

The overall aim of this project was to develop and pilot an NCST methodology that could be applied by the UK Government, businesses, and other stakeholders to identify the impacts of environmental degradation in economic terms in order to help prioritise and inform efforts to mitigate the most significant risks.

The approach taken to developing and piloting an NCST for the purposes of this project was as follows:

- Reviewing the literature on existing stress testing and related approaches to identify any lessons learned for applying the concept to natural capital.
- Undertaking a series of semi-structured interviews with stakeholders from Government, academia, and the private sector in order to identify the key decision making processes which an NCST should aim to support.
- Developing an outline approach to conducting an NCST based on four key steps: (1) determining the scope of the stress test; (2) formulating a plausible adverse scenario, based on existing evidence, to be tested; (3) identifying and quantifying the impacts on ecosystem services that would arise in that scenario; and (4) identifying and valuing the economic impacts of those changes in ecosystem services.
- Piloting the approach by looking at plausible adverse changes in the provision of three ecosystem services by 2050: crops and livestock, water supply, and flood regulation.
- Reviewing and revising the approach and pilot results through two workshops with key stakeholders and a peer review process from relevant technical experts.

Findings

The UK economy benefits from a wide range of ecosystem services, provided by domestic and international natural capital stocks. Different sectors of economic activity depend to different degrees on different services. For the purposes of developing and piloting the approach developed as part of this project, three ecosystem services were selected that, *prima facie*, are likely to be of greater economic significance than other services. These were selected by means of a qualitative assessment of the dependence of each economic sector on each ecosystem service to first identify which services are of most importance to the economy as a whole.

This qualitative assessment applied a set of criteria to successively filter the ecosystem services identified in the European Environment Agency's Common International Classification of Ecosystem Services down to the services to be taken forward for more detailed investigation as part of the project. Models were then developed for each of the ecosystem services selected in order to quantify, in broad terms, the potential impact on economic activity in 2050 of changes in the provision of each ecosystem service under a plausible scenario of change (see Table 1 below).

Table 1. Overview of pilot scenario

Pilot scenario
The scenario was developed around the five key drivers of ecosystem change identified in the UK National Ecosystem Assessment. **Climate change** - The international community fails to meet the required reductions in greenhouse gas emissions to limit warming to two degrees and instead follows a four degrees of warming path. The subsequent impacts cause significant reductions in the amount of water in the environment that can be sustainably withdrawn, while also increasing the demand for water during the driest months. The frequency and magnitude of floods in the UK also rise significantly and cause growing costs to a range of economic sectors. Globally, changes in the climate system disrupt food production in the rest of the world. International food prices increase as a response to the supply shock, with an assumed doubling of prices, similar to the price hikes of 2007-08. **Invasive species** - Increasing demand for global imports and a more diverse supply chain, together with changes in the climate and land use, lead to a significant increase in the frequency and severity of pest and disease outbreaks in the UK and growing costs for the agriculture industry. **Habitat change** - A reduction in public subsidies for UK agriculture results in abandonment of land with low agricultural productivity. Growing demand for housing results in urban expansion into Green Belt and peri-urban farmland areas and onto riverine and coastal floodplains. **Nutrient enrichment and pollution** – Relaxation of environmental regulations results in increases in livestock stocking densities and more widespread and intense use of pesticides and fertilisers causing long-term decreases in the quality of soils and water and further decline in pollinator populations. This in turn results in increased costs for agriculture, water treatment and reduced capacity of ecosystems to regulate flooding. **Overexploitation of resources** – Growth in demand for water exacerbates pressures on increasingly scarce water resources in some parts of the country. Water shortages become commonplace.

As such, the NCST piloted in this project aimed to answer three key questions related to the three ecosystem services identified:

- **Crops and livestock:** What is the potential scale of the impact of a reduction in the output of agricultural crops and livestock in 2050 due to a combination of acute tail-end shock events such as floods and disease outbreaks, and chronic declines such as falling soil productivity and a loss of natural pollinators?
- **Water supply:** What is the potential scale of the impact of a reduction in water availability due to an acute drought event in 2050 that is made more severe by chronic growth in demand that exceeds the natural replenishment of water resources?
- **Flood regulation:** What is the potential scale of the impact of a one-off repeat of the winter floods of 2013/14 given the greater numbers of people and properties at risk of flooding due to ongoing changes in the climate system and population by 2050?

The answers to these three key questions are summarised in Table 2 and explained in more detail in the following sections.

Table 2. Headline results from the pilot NCST exercise

Ecosystem service	Scenario	Estimated impacts in 2050
Crops and livestock	**Output shock in 2050** from disease outbreaks, flood events, wildfires, poor weather events, and heatwaves	0.9% reduction in GDP 347,000 jobs lost
	Productivity losses over time to 2050 from changes in growing conditions and land use, declines in pollinators, and falling soil productivity	0.2% reduction in GDP 66,000 jobs lost

Ecosystem service	Scenario	Estimated impacts in 2050
Water supply	**Three-month UK wide drought in 2050, if there had been continued depletion** of water reserves from now until 2050	1.0% reduction in GDP 354,000 jobs lost
	Three-month UK wide drought in 2050, if water reserves had been protected and maintained at current levels	0.5% reduction in GDP 156,000 jobs lost
Flood regulation	**Repeat in 2050 of the 2013/14 winter floods** with continued population growth and limited action on climate change	70% increase in damages to £2.2bn (2013/14 prices)

The ability of the stress test to generate such measures of macroeconomic performance goes some way to addressing the research gap identified by the NCC. Of course, GDP is narrow as an indicator and, in the context of the current exercise, may not adequately reflect the longer-term damage to productive capacity (e.g. to the UK capital stock); just the consequences for economic activity. Indeed, were the data available to include them in this analysis, mitigation, adaptation and recovery measures could all *increase* GDP. One direction for future work would be to consider what other evidence could complement the indicators above.

Crops and livestock

For the modelling, assumptions needed to be made about the extent to which adaptations could be made in response to these changes, and on whom the biggest impacts would fall. For example, for crops and livestock, the impact, in terms of the loss of economic activity, depends critically on how easily the sectors that use agricultural products can adapt to reduced availability without curbing their own production.

One relatively low cost way of adapting is to source the same products from abroad. For a short-term crisis, this means a temporary switch to imports. For chronic declines, it means a persistent increase in dependence on imported food. However, the pilot exercise assumed that similar trends in natural capital degradation are at work elsewhere (evidence in the 2005 Millennium Ecosystem Assessment[6] bears out this assumption).

A particular crisis event (such as flooding) may not occur in several countries at once, and so it may be feasible to rely on imports to buttress food security. But if, for example, flooding affects much of continental Europe at the same time as the UK, there will be a substantial loss of supply in this global region and ensuing competition for the available exports from the rest of the world. For chronic declines in agricultural output, reliance on imports is a still less plausible solution if other countries are experiencing similar declines.

In a short-term crisis, the scope for adaptation may be limited. Shortage of agricultural inputs may limit production in food and beverage manufacturing and possibly in wholesaling, retailing, and catering services. Food shortages will be communicated by higher prices, with more severe impacts on poorer households, who spend a larger proportion of their budget on food. The uncertainties in this kind of exercise are large but, in scenarios modelled in the pilot exercise, the reduction in UK GDP in 2050 could be as large as 0.9%. While small in aggregate, the reductions in output are concentrated in the agriculture and food-production industries. In some cases, the impacts could exceed 20% of the sector's gross value added. There would also be smaller, knock-on effects on catering and hospitality services.

In the case of a chronic decline in agricultural output, the question becomes: how does food production adapt over time? Are there mitigating actions (which probably impose higher production costs) that could be taken,

[6] Millennium Ecosystem Assessment (2005). Ecosystems and human well-being : synthesis (PDF). Washington, DC: Island Press. ISBN 1-59726-040-1.

and what sort of shift in the composition of food production could be expected? The scenario includes reduced livestock production and clearly the downstream processors, wholesalers, and retailers of meat products and dairy producers would face higher costs, while higher prices would curb household meat and dairy consumption. What is less clear is the capacity to increase production of the alternatives (say, less land-intensive meats and vegetarian proteins) in the face of other pressures on ecosystem services. In scenarios modelled as part of the pilot exercise, the annual losses in economic activity from a chronic decline in livestock production, meat processing, and dairy products could grow to as much as 0.5% of UK GDP by 2050 (though the main results, in Table 2, suggest an impact closer to 0.2%). In the meat processing and dairy industries, gross value added could be 15-20% lower in 2050 than in a 'no degradation' case.

Water supply

In the case of an acute water shortage, the cost implications for businesses again depend on how easily the sectors that use water can adapt to reduced availability. However, unlike the crops and livestock case, water rationing is presently achieved through regulation rather than a price mechanism. At present, a combination of measures to enhance efficiency, restrict certain types of water use, and run down water reserves is typically sufficient to see out a drought. In the future, with long-term growth in demand exceeding supply, the headroom provided by reserves would be smaller and, hence, more severe drought management measures may be required.

It is difficult to anticipate how this scenario would play out. Water is typically a small input for most sectors, but small is not the same as non-essential or easily substitutable. If an economy had to rely on a scaling down of production to reduce water demand, the impact on GDP could be large (it can take a large reduction in output to achieve quite a small reduction in water use). In the event of a nationwide, three-month drought in 2050, for example, the modelling undertaken in this study estimated an impact that amounted to around 1% of GDP. Using the same method, but with action taken to maintain the headroom provided by reserves at their current levels, the impact could be closer to 0.5% of GDP. In this analysis, with the economy simply scaling down production, the most affected sectors in terms of the percentage reduction in gross value added are agriculture, mining and quarrying, and utilities (particularly energy). Were water reserves allowed to deteriorate, these sectors could see reductions in gross value added of 4-5% in the event of a drought in 2050. These reductions could be halved were action taken to maintain and protect water reserves at their current levels.

In practice, any reduction in headroom over time would, no doubt, signal the need for action to pre-empt such a crisis. The point of an NCST would be, amongst other things, to identify areas where early action might be necessary to avoid future risks.

This example illustrates how a long-term (chronic) decline in natural capital (water reserves) can change the severity of an acute shock (a drought) by reducing the capacity of the system to absorb that shock. For some ecosystem services, natural capital decline can make the economy more vulnerable (less resilient) to shocks. A stress test provides a framework with which to understand, and account for, such effects.

Flood regulation

The costs of degraded flood regulation services depend on the extent of physical damage caused by a flooding event as well as losses of production. The scenario examined in this study draws upon the Climate Change Risk Assessment (CCRA) findings that a flood event of given likelihood (1 in 75 years' probability), is expected to have a larger impact in the future because climate change is projected to increase the magnitude of the event and because land use changes impair flood regulation and put more properties in 'at risk' areas.

The results of the pilot exercise suggest that the costs of physical damage to property from such an event might be some 70% higher in 2050 than those associated with the 2013/14 experience (£2.2bn rather than £1.3bn, in 2013/14 prices). The analysis suggests that more of the future damage costs would fall on housing and businesses. Together, these two sectors could account for more than half of the total damage costs of a flood in 2050 (up from 46% in 2013/14). Under the trends assumed in the scenario, the implication is that these sectors would become more exposed over time. However, due to a lack of data, neither the 2013/14 estimate nor the projection for 2050 includes the costs of lost production due to disruption to business activity (either because premises are flooded or because infrastructure is damaged).

Conclusions

The development and piloting of an NCST approach in this study demonstrates that the loss or degradation of natural capital could lead to significant impacts on the national economy by 2050 if actions are not undertaken to curb the damage or adapt to the potential impacts. These impacts could be particularly significant for the most at-risk sectors, such as the food and beverages sector. In this way, a stress test can help fill the gap in understanding highlighted by the NCC with respect to *"the impact of changes in natural capital upon the economy, jobs, and growth"*.[7] However, given the significant methodological challenges and data gaps identified, it is also clear that we still have relatively limited understanding of environmental risks and their economic impacts, and that more research and analysis is required to address this.

The pilot NCST undertaken in this project demonstrated that there are significant uncertainties involved in estimating and quantifying the extent of natural capital risks and the impacts they could have on the economy. It should be emphasised that only a small selection of ecosystem services were examined in the pilot exercise and it was not possible to aggregate the various impacts across the three ecosystem services explored (due to the different assumptions and approaches used). As such, each estimate only represents a portion of the aggregate impact on the UK economy of changes in natural capital and the estimates should not be interpreted as comprehensive or even a lower bound for the full range of potential consequences of natural capital loss or degradation.

One of the lessons from this exercise has been that particular pathways of impact of ecosystem services change on the economy call for bespoke modelling that is tailored to the particular circumstances envisaged in each case. With the current state of knowledge, no single model appears capable of capturing the key features of the narrative for different ecosystem service changes. The analysis also encountered uncertainties over:

- The scale of loss of ecosystem services that should plausibly be considered.
- The possible breach of tipping-points or thresholds beyond which there would be a sharp deterioration in service provision.
- The ease with which firms can adapt to temporary or longer-term changes in resource availability or productivity.

As a result, the quantitative estimates produced by the modelling are inevitably subject to a degree of uncertainty. Drawing an analogy with financial stress testing, which assesses the resilience of financial institutions to tail-risk economic shocks, the aim of the exercise was to identify the potential exposure of the economy to a decline in ecosystem services that, as far as present knowledge permits, represents an eventuality that society should plan for. Unlike a financial stress test, this analysis cannot rely significantly on historical events to determine the parameters for the test because this is likely to be entering uncharted territory. Also, the set of potential impacts and interactions with regard to natural capital is far more complex.

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[7] Natural Capital Committee (2015), 'Advice to Government on research priorities'.

Further work could be undertaken to begin to address some of these uncertainties and resolve some of the issues identified through the piloting. This might include, for example:

- Improving the evidence base to better describe the risks to the UK's natural capital and ecosystem services. This could involve undertaking primary research or aligning with existing research projects (such as the Climate Change Risk Assessment) to fill in key gaps in understanding.
- Creating a framework for the development of stress test scenarios. Such a framework may not only provide useful guidance for those involved in deploying an NCST, but may also facilitate consistent assessments that could be repeated periodically in the same way as financial stress tests are applied to banks.
- Expanding the scope of the NCST by piloting additional ecosystem services and exploring the extent to which adaptation and behavioural responses on the part of businesses could be incorporated to provide a more realistic assessment of the economic impacts of changes in ecosystem service provision.

Critically, the approach developed and piloted in this project could support decision making for a wide range of Government and private sector stakeholders (see Table 3).

Table 3. Potential users of an NCST

Potential user group	Decision-making in which an NCST could be of use
HM Treasury	Supporting annual budgetary decision-making e.g. informing budgetary allocations and measures as well as Spending Reviews and Comprehensive Spending Reviews
Department for Health	Supporting decision-making and budget allocations around preparation for natural capital related public health challenges and estimating the potential costs of such impacts
Department for Business, Energy & Industrial Strategy	Informing the UK national infrastructure plan and industrial strategy e.g. identifying the contribution of natural capital to productivity/growth and mitigating risks
Local Enterprise Partnerships	Identifying risks to the growth of local economies and local employment and developing local growth strategies which take into account resilience of natural capital stocks
Cabinet Office	Updating the UK National Risk Register to account for environmental change and informing mitigation planning decisions
Defra	Informing the 25 Year Environment Plan for restoring natural capital, and identifying areas where market failures might require intervention and identifying priority metrics for monitoring natural capital (including with respect to economic impacts)
Environment Agency	Supporting decision-making relating to crisis preparation and undertaking national level risk assessments which incorporate the economic impacts of flood events
Foreign & Commonwealth Office	Informing the formulation of international economic, trade, security, and environmental policies
National Infrastructure Commission	Understanding the level of resilience of national infrastructure schemes to future natural capital risks
UK and international business	Identifying key vulnerabilities in cross-sectoral supply chains and developing more resilient supply chains

In order to improve the applicability of the NCST developed and piloted in this project, a number of practical steps could be taken to communicate and refine the approach:

- Workshops could be organised with the relevant Government departments to identify the most significant potential applications of the NCST, who might use the approach and when, and any modifications that might improve its usability for specific applications.

- Businesses and sector associations could be invited to comment on the development of scenarios relevant to particular sectors, explore how the approach could align with the Natural Capital Protocol,[8] and collaborate in adapting the process for business use.

- A discussion (or study) could be initiated to assess the extent to which the Government and business will be able to adapt and respond to the potential natural capital changes and economic impacts identified through the NCST, in order to identify appropriate policy responses, particularly in the context of the Government's 25 Year Plan for the Environment.

It is clear that more work is required to develop the natural capital stress testing approach further, to improve the robustness of results and increase its applicability. However given that the economic risks highlighted in this first pilot testing exercise are quite significant, some additional investment in this approach would be arguably warranted.

[8] Natural Capital Coalition (2016) Natural Capital Protocol [online] http://naturalcapitalcoalition.org/protocol/

1. Introduction

1.1 Context and rationale

Nature is fundamental to human life: it underpins human wellbeing and provides the food, energy, and materials that are vital to economic prosperity and development. Natural capital is the stock of renewable and non-renewable natural resources (geology, soil, air, water, and all living things) that combine to yield a flow of ecosystem services which generate benefits to people.

These ecosystem services contribute to the economy and human wellbeing directly and indirectly in many different ways. They provide products that are sold directly, such as fish or agricultural crops; supply inputs to the production of goods, such as water; support landscapes and wildlife that promote tourism and recreation; and deliver the wider conditions that underpin a well-functioning economy, such as a healthy environment that supports a productive workforce and natural infrastructure that reduces exposure to climate-related impacts such as floods, landslides, or fires.

Despite the importance of the benefits provided by the UK's natural capital assets, the Natural Capital Committee (NCC) has warned that many of these are at high or very high risk.[9] With the UK population projected to grow by over nine million people over the next 25 years[10], and a significant pipeline of UK infrastructure investment identified by the Government, pressure on natural assets is likely to increase. This is likely to be further exacerbated by the effects of a changing climate. The most recent Climate Change Risk Assessment for the UK, for example, identifies specific risks to crop and fisheries productivity, the ecological health of rivers and lakes, and the viability of coastal defences.[11]

Changes in natural capital assets and the services that flow from them are already imposing significant costs on the UK economy and businesses[12] – costs which have largely gone unnoticed as the services provided are typically unpriced and either excluded from, or invisible within, conventional measures of economic growth or business performance.

However, as the extent of the changes grows, the costs are becoming increasingly apparent in increasingly tangible ways: from water shortages to flooding and coastal erosion, declining soil quality and pollinator abundance which affect arable agriculture, and increasing healthcare costs associated with declining air quality. Ongoing trends and the future state of natural capital assets could therefore have potentially significant impacts on the growth of the UK economy.[13,14] The UK also depends (and impacts) on stocks of natural capital elsewhere in the world through international trade and supply chains, exposing the economy to further risks from natural capital depletion beyond the UK.

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[9] Natural Capital Committee (2014), 'The State of Natural Capital: Restoring our Natural Assets'. Report to Economic Affairs Committee.
[10] ONS (2016) 2014-based national population projections reference volume [online] available at https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationprojections/compendium/nationalpopulationprojections/2014basedreferencevolumeseriespp2/anexecutivesummary2014basednationalpopulationprojectionsreferencevolume (last accessed 10 February 2017).
[11] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[12] Natural Capital Committee (2015) The State of Natural Capital Protecting and Improving Natural Capital for Prosperity and Wellbeing.
[13] Atkinson G. (2015) Natural Capital and Economic Growth. Natural Capital Committee Discussion Paper [online] available at http://nebula.wsimg.com/402030805e7bc7a4a9849e7bb3ec3dff?AccessKeyId=68F83A8E994328D64D3D&disposition=0&alloworigin=1 (last accessed 10 February 2017)
[14] Natural Capital Committee (2014), 'The State of Natural Capital: Restoring our Natural Assets'. Report to Economic Affairs Committee.

This is reflected in the World Economic Forum 'Global Risks Landscape' which shows that a cluster of interconnected environment-related risks – including extreme weather events, climate change, and water crises – have consistently featured among the top-ranked global risks for the past seven editions of 'The Global Risks Report'. Environment-related risks again stand out in this year's global risk landscape[15] and are also shown to be closely interconnected with other risk categories. Indeed, stark warnings have been made about the risks posed by a series of interacting global pressures related to climate change and demands for energy, water, and food that could coincide to create an unprecedented set of circumstances.[16]

Recognising the value of natural capital in decision-making has the potential to change the way in which it is managed and used. In particular, it could contribute to a better understanding of the potential impacts of natural capital depletion, and the potential benefits of efforts to protect and enhance natural capital. In this way, valuing natural capital could help to facilitate prioritisation of issues to address, and comparison of the costs and benefits of different policy options. Moreover, placing a value on natural capital could also help to ensure that nature is not just seen as a 'nice to have' that is unconnected to the economy or wellbeing, but is instead recognised as a foundation underpinning the UK economy and society.

Through the work of the NCC, TEEB (The Economics of Ecosystems and Biodiversity), the Natural Capital Coalition, and others, the level of understanding of natural capital has grown considerably over recent years. This understanding has also come to include the potential economic and social impacts of natural capital depletion, and the potential benefits of protecting/improving specific assets. This is reflected in, amongst other things, the growing number of users of the Natural Capital Protocol, signatories to the Natural Capital Finance Alliance, and efforts by the UK Government – the Department for Environment, Food and Rural Affairs (Defra) and the Office for National Statistics (ONS) in particular – to monitor the state of natural capital and incorporate it into the System of National Accounts where possible.

The NCC and UK National Ecosystem Assessment Follow-On (UKNEA-FO) have, however, both identified a gap in the understanding of the impact of changes in natural capital on UK macroeconomic performance. More specifically, the UKNEA-FO identified a need to improve the Government's *"analytical capability around macroeconomy–environment interactions"*[17] while the NCC, in its advice to Government on priorities for research, recommended further work to promote a better understanding of *"the impact of changes in natural capital upon the economy, jobs and growth".*[18]

In particular, the NCC identified the need for empirical and theoretical work to resolve the most relevant questions for policy-making, which were identified as follows:

- *"How do changes in our natural capital affect measures such as national income, growth and jobs both directly and indirectly?*
- *What sort of frameworks do we need to examine, measure and model these links effectively?*
- *How do these changes vary across the short- and long-term?"*[19]

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[15] World Economic Forum (2017) The Global Risks Report 2017 12th Edition [online] available at http://www3.weforum.org/docs/GRR17_Report_web.pdf (last accessed 10 February 2017).
[16] Beddington (2009) and the World Economic Forum's (2011) Global Risks Report. This is often referred to as the 'perfect storm'.
[17] Anger et al. (2014), 'UK National Ecosystem Assessment Follow-on. Work Package Report 2: Macroeconomic implications of ecosystem service change and management: A scoping study', UNEP-WCMC, LWEC, UK.
[18] Natural Capital Committee (2015), 'Advice to Government on research priorities'.
[19] Natural Capital Committee (2015), 'Advice to Government on research priorities'.

The importance of understanding these issues for policy makers was emphasised at a workshop held as part of the project where one of the participants stated that, "*ultimately, the issues that keep decision makers awake at night are GDP, unemployment, and inflation."*

In light of these recommendations, WWF-UK is interested in the possibility of developing and piloting a 'natural capital stress testing' methodology which aims to contribute to this understanding. A stress testing approach is fundamentally a scenario analysis exercise in which various impacts associated with one or more plausible future scenarios are assessed. The analysis involves testing a plausible but relatively extreme adverse scenario, with the intention of testing the resilience of the system.

The Government already requires the financial sector to conduct stress testing in relation to financial shocks. Stress testing is now also being conducted in relation to future climate change impacts[20] and the United Nations Environment Programme has encouraged the more widespread uptake of 'sustainability stress tests' – assessments of the impacts on financial assets and institutions of a range of environmental factors such as air pollution, carbon emissions, natural hazards, and water stress.[21]

WWF-UK has therefore proposed that the UK Government adapts and adopts the concept of stress testing used in other sectors, and applies it to help assess and inform policy related to natural capital management. In 2015, WWF-UK commissioned a piece of work by eftec to examine how natural capital stress testing could be conducted.[22] The work identified a need to adapt the concept of a financial stress test to a significant extent, and specifically to focus on national or sectoral economic performance metrics (e.g. related to economic productivity, jobs, and growth), rather than asset values and ratios as measures of potential impact.

1.2 Aims and objectives

The overall aim of this project was to develop and pilot a methodology for natural capital stress testing that could be applied by the UK Government and the private sector in order to help identify and assess the risks (in economic terms) of ongoing or worsening environmental degradation and/or depletion, and to help the Government to prioritise and inform efforts to mitigate the most significant risks.

The specific project objectives were to:

- Develop a methodology (and appropriate indicators/metrics) for assessing potential risks to different sectors of the UK economy and/or on the overall economy from natural capital degradation and/or depletion.
- Apply this methodology to assess the potential risks under a plausible future scenario based on, among other aspects, extrapolation of existing trends.

The methodology and pilot results presented in this report are intended to demonstrate proof of concept, recognising that there are still gaps in our knowledge of the resilience of many forms of natural capital, and specifically the thresholds beyond which they become less productive or cease to function, as well as the ability to model the complex interactions between various drivers of change and changes in natural capital and ecosystem services.

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[20] See, for example, Boston Common Asset Management (2015) Are Banks Prepared for Climate Change [online] available at https://bostoncommonasset.com/Membership/Apps/ICCMSViewReport_Input_App.ashx?IX_OB=None&IX_mId=18&IX_RD=Y&ObjectId=731308 (last accessed 10 February 2017); and http://www.bankofengland.co.uk/research/Pages/conferences/1116.aspx
[21] UNEP (2015) Financing the Transition. *Our Planet: Global Climate Action Innovations and Best Practice*. December 2015. [online] available at http://web.unep.org/ourplanet/december-2015/unep-work/financing-transition (last accessed 10 February 2017).
[22] eftec (2016), 'Developing a UK national economy natural capital stress-test', For WWF-UK.

1.3 Report structure

The remainder of the report is structured as follows:

- **Section 2** describes the concept of an NCST, some of the key issues that were considered in developing the approach, as well as some of the potential applications (i.e. how it might be used to inform policy making and the kinds of specific policy questions it could potentially be used to help answer).
- **Section 3** sets out an approach to conducting an NCST and identifies some of the tools and resources that may be helpful in formulating scenarios, assessing impacts, and quantifying these in economic terms.
- **Section 4** sets out the principles by which changes in ecosystem services lead to economic impacts. This provides guidance on the kinds of effect that might need to be captured in a quantitative assessment.
- **Section 5** presents the results of an exercise to pilot the approach described in Section 3. It illustrates how an NCST may be used to derive headline indicators of macroeconomic impact, as well as to address specific issues of policy interest at different scales.
- **Section 6** seta out the conclusions of the pilot exercise, identifies some of the limitations of the approach, and provides recommendations for further work to address these issues.

The main report is accompanied by a series of **appendices**, including the methodology employed to develop the approach outlined in Section 3 and an overview of the process for determining the scope of the pilot NCST. The economic model used for estimating the economic impacts of changes in natural capital and ecosystem services is available separately.

2. Concept and application

2.1 Concept of a natural capital stress test

Following the 2008 financial crisis, the Bank of England recommended that regular stress testing of the UK banking system should be undertaken to assess the system's ability to withstand shocks. In this context, the potential impacts of possible future economic events (including financial crises etc.) on the solvency of individual financial institutions are assessed as a way to highlight the potential scale of future shocks and identify key problem areas, as well as to inform remedial actions to help build resilience of the sector. The Bank of England defines its stress testing approach as follows:

"A stress test examines the potential impact of a hypothetical adverse scenario on the health of the banking system and individual institutions within it. It allows policymakers to assess banks' resilience to a range of adverse shocks and ensure they are adequately capitalised, not just to withstand those shocks, but also to support the real economy if a stress does materialise."[23]

The concept of a stress testing approach is therefore essentially a scenario analysis exercise in which various impacts associated with one or more future scenarios are assessed. The analysis involves testing a plausible but relatively extreme adverse scenario, with the intention of testing the resilience of a system. The scenarios in stress testing can cover ongoing stresses to particular assets (e.g. increases in the spread of pests and diseases in the case of natural capital stress testing) as well as particular shock events (e.g. droughts and water shortages).

The aim of this project was to apply this concept to provide the UK Government with a new approach to help inform policy making. It is proposed that an NCST could form part of the Government's policy 'toolkit'; being used to systematically track emerging environmental risk 'hot spots' in the economy and pinpoint which business sectors are most at risk and why. This approach could help to identify the need for policy responses and to prioritise areas of need although could not be used to inform the design of specific policy interventions. In addition to use by the UK Government, the NCST approach could also be useful for businesses as they are among the main stakeholders who are at risk from natural capital change.

2.2 Potential applications

Given the potentially broad scope of an NCST, there is an equally broad range of potential policy applications and decisions which could be supported through its use. This section provides an overview of some of the key policy questions which could be addressed through the use of an NCST approach:

- What risks do particular natural capital shocks and stresses (either domestic or international) pose to the UK economy as measured by key macroeconomic indicators (e.g. GDP, productivity, jobs, and inflation)?
- Which economic sectors are likely to be most at risk from these natural capital shocks and stresses?

[23] Bank of England (2015). The Bank of England's approach to stress testing the UK banking system

- To what extent might different regions of the UK be at risk from natural capital shocks and stresses?
- How do natural capital shocks and stresses from domestic sources compare to international sources in terms of the risks they pose to the UK economy?
- Which of the potential natural capital shocks and stresses pose the greatest risks to the UK economy, and might therefore require intervention?
- Which of the potential natural capital shocks and stresses pose the greatest risks to particular UK economic sectors (e.g. manufacturing, food/beverages, or agriculture)?
- What is the specific level of risk exposure to natural capital shocks and stresses for particular UK economic sectors?
- What is the potential for longer term changes in the resilience of the UK economy due to natural capital shocks and stresses?
- How do the risks associated with different natural capital shocks and stresses change over time e.g. which are most pressing over the short term and which may be more significant over the longer term?

Ultimately, an NCST should be able to address each of these policy questions. While the approach developed in this project goes some way to being able to provide answers to the first four questions, there is further work to be done before it can be applied more widely and comprehensively. This includes, for example, extending the economic model to cover a wider range of natural capital and ecosystem service impacts and addressing some of the limitations that became apparent through the process of piloting the approach (see Section 6).

Further, for the purposes of this project risk was defined in terms of the magnitude of an impact multiplied by the likelihood of it occurring. Drawing on the financial stress test approach, this project did not explicitly consider the likelihood of particular events or impacts occurring, but rather looked at the magnitude of the impacts should they occur. As such, the term 'risk' is not applicable to the NCST approach developed in this project. Risks could be evaluated using this approach in future, although further work would be needed to quantify the likelihood of potential impacts occurring.

In assessing the potential uses for an NCST, it is also important to consider the potential users of the approach. A preliminary list of potential users was collated at the start of the project in order to better identify their anticipated needs and steer the development process accordingly. The list of potential users was informed by interviews, workshops, and a review of UK Government decision-making processes. The results are summarised in Table 4. The approach was not designed with one single user group in mind; rather, it tried to address a range of anticipated uses and requirements in order to demonstrate proof of concept. Future iterations of an NCST approach could incorporate the specific requirements of different users.

Table 4. Potential users of an NCST

Potential user group	Information generated by an NCST that could be of interest to user group	Decision-making in which this information could be of use
Public sector		
HM Treasury	Potential macroeconomic impacts of ecosystem service changes, in particular the impacts on GDP, productivity, inflation, and employment (at the economy-wide and sectoral-level), and the impacts on the UK as an investment prospect	Supporting annual budgetary decision-making e.g. informing budgetary allocations and measures as well as Spending Reviews and Comprehensive Spending Reviews
Department for Health	Impact on healthcare costs across all of society	Supporting decision-making and budget allocations around preparation for natural

Potential user group	Information generated by an NCST that could be of interest to user group	Decision-making in which this information could be of use
		capital related public health challenges and estimating the potential costs of such impacts
Department for Business, Energy & Industrial Strategy	Impacts on productivity, growth, and infrastructure across all sectors and the strategic consequences of anticipated impacts	Informing the UK national infrastructure plan and industrial strategy e.g. identifying the contribution of natural capital to productivity / growth and mitigating risks
Local Enterprise Partnerships	Local spatially disaggregated impacts across all sectors and areas	Identifying risks to the growth of local economies and local employment and developing local growth strategies which take into account resilience of natural capital stocks
Cabinet Office	Food and resource supply security, and resilience to international changes in natural capital	Updating the UK National Risk Register to account for environmental change and informing mitigation planning decisions
Defra	Impacts of changes in ecosystem service provision on different sectors (particularly farming, the environment, and rural economies) and areas where market failures may require policy intervention	Identifying areas where market failures might require intervention and identifying priority metrics for monitoring natural capital (including with respect to economic impacts)
Environment Agency	Flood impacts at a national and regional scale	Supporting decision-making relating to crisis preparation and undertaking national level risk assessments which incorporate the economic impacts of flood events
Foreign & Commonwealth Office	International natural capital impacts and dependencies, their trade implications, and international relations/conflict risk identification	Informing the formulation of international economic, trade, security, and environmental policies
National Infrastructure Commission	Impacts on national infrastructure and resilience of UK infrastructure to environmental change	Understanding the level of resilience of national infrastructure schemes to future natural capital risks
Private sector		
UK and international business	Sector or supply chain- specific impacts	Identifying key vulnerabilities in cross-sectoral supply chains and developing more resilient supply chains

2.3 Key issues considered during development

Given this overview of the concept and applications of an NCST, there were a number of issues that were considered in developing and piloting the approach. An overview of some of the key issues, and how they were tackled, is set out below:

- **Type of natural capital considered** – natural capital provides both ecosystem services (e.g. timber, food, clean air) and abiotic services (e.g. minerals and fossil fuels). Given that the relationship between the extraction and use of minerals and fossil fuels and the UK economy is already well understood and reflected in the national Environmental Accounts, the focus of this project was on ecosystem services. Three ecosystem services in particular – crops and livestock, water supply, and flood regulation – were selected for the purposes of piloting the NCST approach. The rationale for focusing on these three services is set out in Section 5 and in Appendix A.

- **Impacts and dependencies** – assessments undertaken at a company or organisational level typically distinguish between the impacts the body has on natural capital and the extent to which it depends on natural capital for its continued operation (see the Natural Capital Protocol[24]). For this project, the results of the NCST focused on highlighting the dependence of the UK economy on natural capital, with impacts on natural capital from a range of sources captured as part of the scenario to be tested.

- **International vs. domestic dimension** – the UK economy is exposed to a range of impacts resulting from domestic changes in natural capital (e.g. a national drought event leading to changes in UK manufacturing output) and international changes (e.g. a global pest outbreak leading to a reduction in agricultural outputs and corresponding changes in international food prices). Both international and domestic impacts are included within the NCST approach developed for this project. However, for two of the services piloted (water supply and flood regulation) there were no international impacts identified that were considered likely to lead to changes in UK service provision. As a result, the focus of the NCST for these two services was on the impacts of a domestic change in natural capital on the domestic economy (environment-to-economy effects). By contrast, for the crops and livestock service, the international dimension was captured under the assumption that the kinds of effects that might affect this service would simultaneously occur abroad. This was captured through an economy-to-economy effect i.e. a change in natural capital in the rest of the world has economic effects in the rest of the world, and those economic effects are transmitted to the UK by trade linkages for the products produced elsewhere that are most affected by the impact.

- **Chronic vs. acute impacts** – the aim of this project was to capture the impacts of both natural capital shocks and stresses. In light of this, the NCST approach included separate calculations for both acute events (i.e. short-term, often severe changes in services such as flood events) and chronic events (i.e. long-term incremental changes in service provision such as declines in soil productivity).

- **Resilience** – in addition to direct impacts (such as a reduction in crop output due to an ongoing decline in soil productivity), chronic changes in natural capital could have indirect effects in terms of making the UK economy less resilient to acute events in future. For example, an ongoing reduction in water availability over time could make certain economic sectors more vulnerable to acute drought events. This issue of resilience was explored to some extent in the pilot NCST (through the water supply service) although could be investigated further in future studies.

- **Development of the stress test scenario** – in order to pilot the NCST approach developed in this project, a scenario describing a possible natural capital future in 2050 was formulated. The narrative for the scenario was structured around the direct drivers of natural capital change identified in the UKNEA. The projected changes in natural capital and ecosystem services were then expressed through a series of quantified variables. The scenario was based on a review of the literature and aimed to represent a plausible but extreme adverse future. As noted above, the scenario focused on changes in UK natural capital with international impacts transmitted through economy-to-economy linkages (e.g. import prices).

- **Qualitative vs. quantitative assessments** – the focus of this project was on developing an approach which could provide quantitative estimates of the impact of changes in natural capital on the UK economy. In future, a qualitative approach could be developed alongside this approach which draws on the outputs of the quantitative model to provide indicators of the scale of potential impacts on particular economic sectors. This approach could, for example, employ a red, amber, green scoring system to communicate the potential impacts on the UK economy from natural capital change. This could in turn be used to identify where further assessment may best be focused.

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[24] Natural Capital Coalition (2016) Natural Capital Protocol [online] http://naturalcapitalcoalition.org/protocol/

- **Impact metrics** – ideally, the scale of the impacts should be expressed using metrics that are already familiar to the intended users or target audience, and that are comparable to or compatible with the metrics used by other forms of environmental or economic assessments. In light of this, the project has focused on presenting the results in terms of standard macroeconomic metrics such as gross domestic product (GDP), gross value added (GVA), employment, and prices.

- **Time horizons** – as set out above, the scenario used to pilot the NCST approach used a time horizon of 2050. Future projects could look at alternative time horizons to identify and compare the extent of short, medium, and long term impacts.

- **Discounting** – the scenario used to pilot the NCST approach looked at the impacts of natural capital shocks and stresses in a particular year (2050). As a result, the economic model did not look at the flow of values over time and there was no discounting of impacts.

- **Spatial distribution of impacts** – the pilot NCST focused on quantifying the impact of natural capital shocks and stresses on the UK economy as a whole so impacts were not spatially disaggregated on a regional basis. However, a supplementary analysis was included which looked at the potential regional impacts in order to illustrate how this approach could be undertaken in future projects.

- **Sectoral impacts** – the pilot NCST analysed the impacts associated with changes in the provision of three ecosystem services. Two of these (crops and livestock, and water supply) are examples of provisioning services, which generate flows of resources that can be used productively in the economy. Other products are derived from those resources and feed through supply chains to produce final goods and services. Scenarios that consider provisioning services are therefore inherently scenarios of sectoral dependency and impact. By contrast, the third service (flood regulation) is a regulating service which has a different impact pathway through the economy. The pilot NCST applied a model developed specifically for this project to show one way (but only one way) that the sectoral impacts might be analysed for this regulating service.

- **Aggregation of impacts** – the NCST approach developed for this project was designed to address the cumulative impacts or combined effects on the UK economy arising from multiple natural capital shocks and stresses occurring over the same time period. In light of this, the estimates of change in service provision were based on aggregates of a range of natural capital changes impacting on each of the three services (e.g. estimating the combined change in crop output based on changes in precipitation, land use, and crop diseases etc.), although data limitations meant that aggregation of all potential impacts was not possible. It was intended that the impacts on each ecosystem service would then be aggregated to estimate the combined effects on the UK economy; however, due to the different types of modelling approaches required for each service, the uncertainties involved were considered too large to reasonably allow for an aggregate estimate of the total impact to be presented.

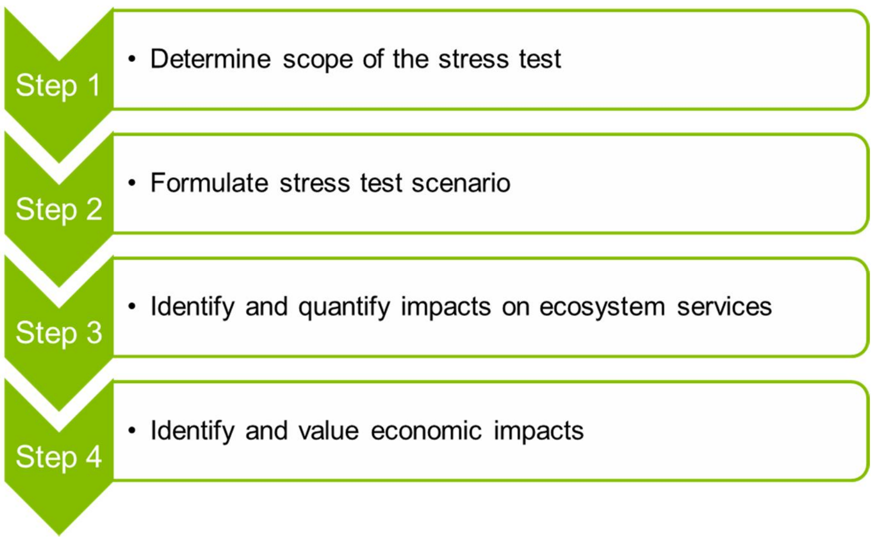
- **Selection and application of appropriate approaches and models** – while, for the purposes of the pilot NCST, an economic model was developed specifically for the analysis of the ecosystem services considered, this is by no means the only quantitative assessment approach available. The model developed for this project embodied specific assumptions that have a bearing on the final results. There are a range of techniques that could be applied to a stress test and each has its own strengths and weaknesses. Moreover, different scenarios and ecosystem services pose different challenges and questions in a stress test. Later sections of this report emphasise the importance of selecting tools that are fit for particular purposes, rather than trying to apply a single approach in all cases. In the future, a full NCST would benefit from an inventory of approaches and models to aid selection of the best approach.

3. Approach to conducting a stress test

3.1 Overview

In order to provide an overview of how an NCST could be used by Government or other users, a preliminary approach to conducting an NCST was developed as summarised in Figure 1. Further details on each of the steps involved are set out in the sections that follow. It is important to note that this is a *preliminary approach* which will require further development and refinement over time in order to make sure the approach is useful and practical for decision makers.

Figure 1. Outline approach to conducting an NCST



3.2 Methodology

Step 1. Determine the scope of the stress test

Aim

It is proposed that the first step of an NCST should be to define the scope of the stress test and the specific questions to be addressed. Given that an NCST can be a complex and resource intensive undertaking, a scoping process can help to prioritise work on those sectors and services deemed to be of most interest, at greatest risk, or where the impacts are likely to be most significant. Ultimately, the purpose of the scoping step is to focus the user's effort and available resources on the natural capital impacts that are most material to the UK economy.

Approach

A preliminary approach to determining the scope of an NCST is set out as follows:

- **Economic sector review** – qualitatively assess the dependency of each economic sector on a range of ecosystem services in order to identify the services which are of most importance to the economy. This could be done using the Economic Sector Review matrix developed for this project which provides a list of economic sectors (UK Standard Industrial Classification of Economic Activities 2007[25]) that are scored against a list of ecosystem services (CICES Version 4.3[26]) using a three-point scale (High, Medium, Low). In this matrix the strength of the sector-service interaction is assessed according to the extent to which a change in the supply of one or more ecosystem services might cause significant impacts (positive or negative) on one or more economic sectors. The matrix populated as part of the pilot exercise in this project could provide a basis for future scoping exercises although it should be updated periodically to capture changes in natural capital or the UK economy over time.

- **Ecosystem service prioritisation** – build on the economic sector review above to assess the list of ecosystem services against a wider range of criteria in order to identify a priority list of services to be included within the NCST. This could be done using the Ecosystem Service Prioritisation matrix developed for this project which sets out a range of criteria for prioritising services for inclusion. As above, the values within the matrix populated as part of this project could be reviewed and revised to allow the scoping process to reflect the needs of the user.

Useful resources

- Common International Classification of Ecosystem Services (CICES) (2016), 'CICES Version 4.3'.
- Companies House (2007), 'Standard industrial classification of economic activities (SIC) 2007'.
- Economic Sector Review matrix (see Appendix B and Excel workbook which is available separately).
- Ecosystem Service Prioritisation matrix (see Appendix B and Excel workbook which is available separately).
- Natural Capital Committee (ongoing), 'State of natural capital' reports.
- UKNEA-FO (2014) 'Work Package Report 2: Macroeconomic implications of ecosystem service change and management: A scoping study'.

Step 2. Formulate stress test scenario

Aim

Once the scope of the stress test has been determined, it is proposed that the next step should be to formulate the scenario to be tested. The Bank of England defines the scenarios used for financial stress testing as follows:

"The stress scenarios incorporated in the Bank's concurrent stress tests are not forecasts. Rather, they are coherent 'tail-risk' scenarios designed to be severe and broad enough to assess the resilience of UK banks to adverse shocks, which can occur even when risks are not elevated."[27]

As such, the scenario should aim to describe a possible future in which a range of natural capital shocks and stresses occur. The scenarios used in stress testing are not, therefore, probabilistic predictions of what is likely to happen, but are, instead, descriptions of a series of adverse shocks and stresses which could occur.

[25] Available to download at: https://www.gov.uk/Government/publications/standard-industrial-classification-of-economic-activities-sic
[26] Available to download at: http://cices.eu/
[27] Bank of England (2016), 'Stress testing the UK banking system: key elements of the 2016 stress test'.

Approach

A preliminary approach to formulating a scenario is set out as follows:

- **Select the time horizon for the assessment** – when selecting an appropriate time horizon, it is important to bear in mind the purpose for which the stress test is being applied as there are potential trade-offs between the use of shorter and longer term horizons. A five year time horizon may, for example, feed into investment planning cycles although it may fail to identify natural capital stresses which build up over longer time periods, such as changes in the global climate system.

- **Identify the key drivers of change around which the scenario is to be built** – the UKNEA identified five direct drivers of ecosystem change which provide a useful framework for constructing scenarios for natural capital stress testing: invasive species; climate change; habitat change; nutrient enrichment and pollution; and overexploitation of resources.

- **Prepare a narrative (storyline) to describe the projections for drivers of change within the selected timescale** – the scenario narrative can be developed based on a review of the literature or through a group workshop discussion where users can identify the issues of most interest and the 'what if' questions that they would like the stress test to answer. Involvement of users can also help to establish credibility and legitimacy, as well as the saliency of the storylines that are developed.[28] The scenario should be conceivable or plausible (i.e. have a reasonable probability of actually occurring) in order that it is seen as credible, yet sufficiently extreme (in the 'tail' of the probability distribution) such that it tests the resilience of the system. When developing the scenario narrative it is also important to be clear about the extent to which behavioural responses (adaptation) are built in (particularly over longer time horizons) and how influences outside the UK may drive changes in the condition and extent of the UK's natural capital stocks.

Useful resources

- Beddington (2012), 'Food, energy, water and the climate: A perfect storm of global events?'.
- Cabinet Office (2015), 'National Risk Register for civil emergencies - 2015 edition'.
- Committee on Climate Change (2017), 'Climate change risk assessment 2017'.
- Environment Agency (2006), 'Environment Agency scenarios 2030'.
- Environment Agency and Natural Resources Wales (2013), 'Current and future water availability – addendum. A refresh of the Case for Change analysis'.
- Foresight Land Use Futures Project (2010), 'Final project report'.
- Lloyds (2015), 'Food system shock: The insurance impacts of acute disruption to global food supply'.
- McKenzie & Rosenthal (2012), 'Developing scenarios to assess ecosystem service tradeoffs: Guidance and case studies for InVEST users'.
- UKNEA (2011), 'Chapter 25 scenarios: Development of storylines and analysis of outcomes'.

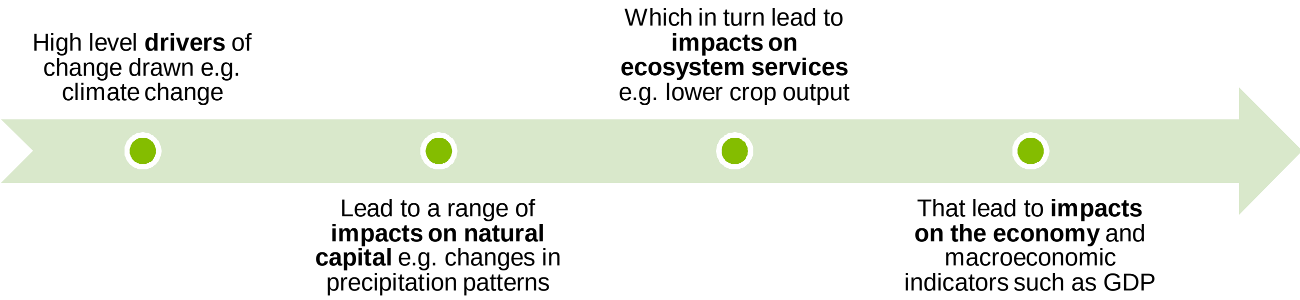
[28] Rounsevell, M. & Metzger, M. (2010) Developing qualitative scenario storylines for environmental change assessment. Wiley Interdisciplinary Reviews: Climate Change, 1(4), 606–619.

Step 3. Identify and quantify impacts on ecosystem services

Aim

Once the scenario narrative is set out, it is proposed that the next step should be to map out the pathways though which these drivers could impact on ecosystem services and to quantify the extent of change in a format which can be input into the economic model. An outline of the process of linking a qualitative scenario narrative with an economic model is set out in Figure 2. This process can also help to identify any gaps in the evidence base which may inform the specific aspects which may need further research.

Figure 2. Overview of the link between a qualitative scenario narrative and an economic model



Approach

A preliminary approach to identifying and quantifying impacts on service provision is set out as follows:

- **Establish impact pathways** – map out the pathways though which the high level drivers of change could impact on natural capital, ecosystem service provision, and macroeconomic indicators in order to identify all of the potential linkages that could be quantified in the stress test.
- **Quantify changes in natural capital** – populate the impact pathway by quantifying, where possible, the extent of changes in natural capital resulting from changes in the high level drivers. This is likely to require a detailed literature review together with the use of spreadsheets to estimate the extent of any changes. It is likely that the quantitative assessment will need to draw on a wide range of sources, each of which may apply different sets of assumptions (e.g. around population growth, rates of climatic change, and time horizons) in deriving estimates of the changes in natural capital. It is therefore important to be clear on how the estimates reported in the various sources have been derived and under what assumptions, as well as to consider whether any adjustments could or should be made, and the implications for analysis and interpretation of the stress test results. Given the complexity of bringing together multiple different sources, which draw on their own underlying assumptions and calculations, expert review may be useful at this point.
- **Quantify changes in ecosystem service provision** – quantify the cumulative change in ecosystem service provision arising from the changes in natural capital. Capturing the cumulative impacts is important because of the many interactions between ecosystem services, which mean that focusing on one particular service or one particular change in natural capital may underestimate the total extent of any change. For example, a scenario focused solely on modelling the impacts of a reduction in water availability on crop output would fail to capture important natural capital interactions such as the impact of crop pests and diseases or changes in flood events on crop output. This approach would also fail to capture important cumulative effects across different services, such as the combined impact on the economy from a loss of crop output and a reduction in water availability for other uses such as residential and industrial. Where possible the impacts on service provision can be drawn from the literature; however, in most cases additional calculations will be required to combine different data sets to generate an understanding of cumulative impacts.

Useful resources

There is a sizeable evidence base that can be used to estimate changes in natural capital and ecosystem service provision under different scenarios. For example, the CCRA 2017 evidence base includes several comprehensive modelling exercises which estimate changes in water supply and flood events over a range of time horizons (2030, 2050, and 2080). The models draw on a similar set of underlying assumptions (with respect to rates of population growth, climate change trajectories, and levels of adaptation) which allows direct comparison and aggregation of changes in service provision.

However, one limitation with this resource is that the focus is limited to two specific services and similar resources are not available for other services such as crops and livestock. This therefore requires drawing on additional studies which use different sets of assumptions which, as noted above, can introduce uncertainty into any estimate of aggregate impacts.

Step 4. Identify and value economic impacts

Aim

Having developed the scenario of changes in ecosystem service provision in the earlier steps, it is proposed that the final part of the stress test should seek to understand the implications for the economy. This will usually involve quantitative analysis to gauge the impacts and, if relevant and possible, their distribution across different sectors and regions etc.

The availability and quality of the data and evidence will vary greatly by scenario and ecosystem service. This should be borne in mind when applying particular techniques or models. Improper application may lead to false confidence in the precision of any results (in the face of uncertainty) or misinterpretation of the results (which may hinge on particular assumptions). The selection of techniques and models matters and there is no single approach or model that can be universally applied: different approaches fit different situations. For the stress test, quantitative analysis is therefore a pragmatic exercise to explore the potential economic implications of a scenario and gauge the level of exposure to trends/changes in natural capital and ecosystem services. Careful synthesis and interpretation are crucial, and complexity is not always a virtue.

As a formal approach to impact analysis, this step may help to highlight areas of uncertainty as well as gaps in both the evidence base and the existing inventory of techniques/models. In this way, the results from a stress test can also highlight priorities for future research.

Approach

A preliminary approach to identifying and valuing economic impacts is set out as follows:

- **Identification and quantification of the direct economic impacts** – having quantified the impacts on ecosystem services, it is necessary to translate those impacts into their economic equivalents. This involves an identification of the entry points for ecosystem services into the economy and an exercise to map those impacts to the economic data. The categorisation of ecosystem services (into provisioning, regulating, and cultural services) can guide this process (see Section 4). For example, a change in a provisioning ecosystem service such as crops represents a reduction in crop output. This reduces the (potential) level of production in the agriculture industry. However, because the definition of the agriculture industry in the economic data is wider than just crops, the value of the direct economic impact may need to account for crops' share of the industry's total output (if the original ecosystem service assumption was specified as a percentage, for example). Other steps here might include conversions to or from real terms etc.

- **Identification of transmission mechanisms through the economy** – it is the transmission mechanisms that give rise to indirect ('knock-on') effects. The analyst should specify the linkages (if any) that might lead to impacts elsewhere in the economy. This is largely a question of interdependency. Using the crops example from before, this step would involve an identification of which industries depend on agricultural output; here, mostly food manufacturing.

- **Identification of likely behavioural responses** – agents often alter their behaviour as responses to change. Households might switch to other sources of goods and services or reduce their consumption. Firms might also substitute, or raise prices, or find other ways to economise on inputs. An assessment of the possible behavioural responses provides a list of actions that could mitigate or amplify certain effects.

- **Selection and application of quantitative techniques** – the previous steps define the economic logic of the scenario. It is here that the analyst operationalises the economic framework by applying one or more techniques or models. The availability and suitability of data and tools will vary by scenario and ecosystem service. Because of this, there is unlikely to be one single approach that is applicable to all cases. Moreover, the analysis of the economic impacts of ecosystem-service change is still a relatively unexplored area of research. Particular tools might only capture limited aspects of a particular problem. There may be cases where a combination of approaches is required. It is at this stage that the analyst must make an informed judgment as to which approaches would be most appropriate and whether there are any substantial sources of uncertainty in the results.

- **Assessment of sensitivity to key assumptions (if applicable/possible)** – sensitivity analysis (varying key input assumptions and examining the change in the results) helps to identify which inputs most affect the final outcome. In cases where uncertainty is high, it can also help to bound the results in a way that helps to establish the order of magnitude, even if no numerical result can be considered individually robust.

- **Synthesis and interpretation of the final results** – having completed the analysis for one or more ecosystem services, the final part of the stress test is to draw conclusions (including limitations) from the individual assessments and, if appropriate, aggregate those results.

Useful resources

It is difficult to recommend any specific approaches or models because much depends on the scenario and ecosystem service under investigation. The quantitative assessment requires judgment as to which tools are most appropriate. Instead, Section 4 provides some guidance as to the kind of economic logic that might need to be considered and reflected in a credible approach.

In addition to ensuring a plausible set of direct impacts (which follows from the scenario design), channels for indirect impacts, and behavioural responses, Section 4 also emphasises the importance of a level of detail that is appropriate (detailed enough) for the ecosystem service. This is applicable to both economic data (e.g. by industry and/or region) and environmental/physical data (e.g. to identify the spatial distribution of water resources or assets exposed to flooding events).

In terms of economic data, the most important UK source is the ONS which publishes disaggregated industrial data (such as input-output tables). Any credible analysis would need to use or be consistent with such data.

There are a wide range of models available that could be applied to an assessment. These have differing strengths and weaknesses and are therefore fit for different purposes. A suitable level of detail is critical (as above) but so are the assumptions that underpin these models. In the absence of a suitable existing approach/model, options range from a synthesis of existing research (possibly to establish simple rules of thumb to apply to the assessment) to the development of new approaches and models. Where modelling might be costly to do, or where much analysis has already been done (such as in climate change research), synthesis of existing evidence may well represent the best use of resources.

4. Analysing the economic impacts of ecosystem service change

4.1 Overview

Ecosystem services are diverse in the range of goods and benefits they provide, including their economic goods and benefits. Because of this diversity, changes in different ecosystem services can have very different impacts. Consequently, an assessment approach that is appropriate for one service may not be appropriate for another. The problem of variation in effects is compounded by differences in the availability and quality of the evidence across services. For some ecosystem services, the evidence base and data may be too limited to support sophisticated analysis. Consequently, there is unlikely to be one approach or model that can be applied to assess the economic impact of a change in *any* ecosystem service.

Different approaches will be suited to different applications and combinations of approaches may be required. It would be inadvisable to depend on (or advocate) a single approach or model as being applicable in every case. In this light, quantitative assessments in the stress test should be understood as pragmatic exercises to gauge the level of sectoral exposure to changes in natural capital and, in turn, ecosystem services. This is entirely compatible with the idea and motivation of a stress test but the user should appreciate the uncertainty that comes with quantitative analyses of this type.

These concerns aside, a quantitative approach has the advantage of requiring a formal framework within which to assess the impacts of ecosystem service change. This process forces the analyst to be explicit in the relationships captured by their approach and in the assumptions that underpin the analysis. Such frameworks can be scrutinised and tested.

Given the diversity of ecosystem services, the analytical approaches in a stress test must fit, as far as possible, the circumstances of the individual ecosystem services. These circumstances include:

- The narrative of the scenario itself, and the evidence to support it.
- The availability of data/evidence to inform and specify the changes in ecosystem services. This includes any uncertainty about these changes.
- The translation of changes in ecosystem services into their corresponding concepts in economic statistics.
- Assumptions about the scope for, and likely, behavioural responses. These could either mitigate or amplify the impacts.
- The level of uncertainty that arises and compounds from the above, affecting the level of confidence with which the final results can be interpreted.

Given the uncertainty at various points in the evidence collection and analysis, and the diversity of ecosystem services, it is particularly difficult to be prescriptive about the economic assessment approach.

Section 4.2 sets out various considerations when designing an economic impact analysis. It first justifies the focus of the stress test on observable macroeconomic indicators, rather than other work that seeks to attach values to the benefits of ecosystem services. The section then goes on to explain the broad logic by which changes in ecosystem services lead to economic impacts. This covers the sources of impact and the transmission and feedback mechanisms that might operate to determine the overall impacts. In this way, the section provides a way of thinking about the sources of exposure to natural capital degradation.

Section 4.3 then elaborates on the economic impacts that might be most relevant for each of the three categories of ecosystem service. The section ends by emphasising the importance of using data at a sufficient level of detail to conduct a credible assessment.

Finally, Section 4.4 focuses on including industrial disaggregation in the assessment if supply chains might matter and argues that some ecosystem services can only be adequately assessed in spatial terms. In this way, the section provides some high-level guidance on what might make for a credible and sufficiently comprehensive piece of economic analysis.

4.2 Focus of the stress test

The stress test developed in this project emphasises the impact on observable macroeconomic indicators. This sets it apart from other work that has tried to understand the economic implications of changes in natural capital *as if* those costs (externalities) were priced in. An approach that uses observable indicators seems more relevant to a stress test because it explores what could happen in the event of a change in ecosystem services. Such an approach can highlight how large the changes in economic activity and jobs might be, and the distribution of those impacts across the economy. The stress test plays out a scenario and makes an assessment in terms of potential (observable) economic damage.

In contrast, an externality-pricing approach asks 'by how much are ecosystem services undervalued in monetary terms?'. Such an approach has something to say about the value of ecosystem services. However, what it highlights is the extent of the benefits that people enjoy without necessarily having to pay for them (financially). It sheds light on the value of natural capital but does not so clearly highlight the economic *consequences* of natural capital degradation. It is those consequences that are of relevance in a stress test and which provide the justification for the approach set out here.

Of course, by narrowing the stress test to observable economic indicators, the approach adopts a similarly narrow view of the value of ecosystem services, albeit a view that is still relatively unexplored in existing research. A stress test that focuses on these indicators will necessarily only capture part of the full contribution of ecosystem services to human wellbeing. The aim of an economic assessment along the lines set out in Section 3 is to recognise the dependence of the *economy* on largely unpriced ecosystem services, and not to attempt to address wider impacts on wellbeing. This deliberately limited scope should not be interpreted as a judgement about which impacts are most important: rather, this analysis simply represents one part of the picture.

4.3 Understanding the economic impacts of changes in ecosystem services

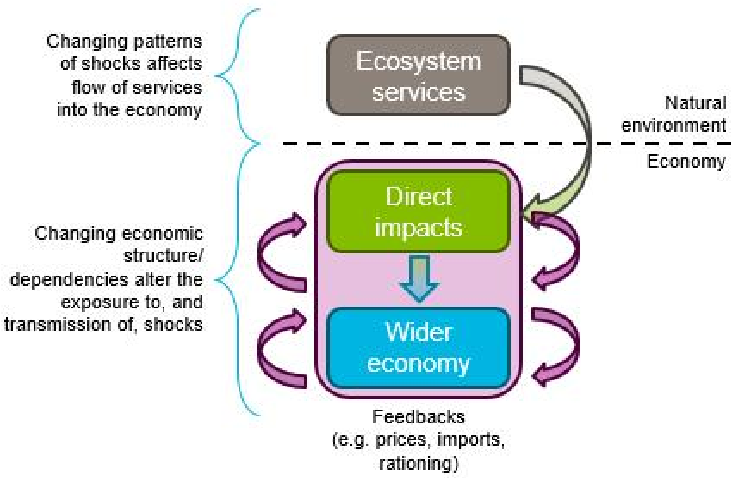
Figure 3 sets out the broad effects that any economic assessment of changes in ecosystem services must capture. The diagram shows how:

- Changes in ecosystem services alter the flow of benefits into the economic system, identifying the cross-over from the natural environment domain (the source of ecosystem services) to the economy domain.

- Changes in the flows of benefits directly affect specific parts of the economy through their impacts on one or more sources of economic value. Broadly, these sources can be categorised as: inputs to production; regulation/maintenance of productive assets; and sources of intrinsic/intangible value.[29] Sectors that benefit directly in any of these ways are the entry points for ecosystem services into the economic system. As discussed earlier, a focus on observable macroeconomic indicators leaves the last of these broad ecosystem service categories (relating to intrinsic/intangible value) largely outside the scope of the stress test developed here.

Economic impacts are not necessarily confined to particular industries or sectors at the interface between the natural environment and the economy. Because of supply-chain dependencies and income/expenditure effects, impacts in one sector may be transmitted through the wider economy. It is by this mechanism, for example, that a reduction in water supply (which reduces output of the water industry) can constrain output in manufacturing industries that produce food and drink. In turn, the hospitality industry might see a consequent reduction in (domestic) supply. Lower output in all these sectors will tend to lower employment and incomes. Because of these interactions, a narrow assessment of only the direct impacts will fail to capture the wider economic effects and system vulnerabilities of a change in ecosystem services.

Figure 3. How changes in ecosystem services lead to economic impacts



The labels on the left-hand side of Figure 3 distinguish between the two sources of economic impact from a change in ecosystem services:

- The pattern of shocks in ecosystem services.
- The socio-economic structure of the economy.

The first of these concerns the way in which natural capital degradation might lead to more or larger shocks to ecosystem services; that is, a change in the pattern of the shocks that originate in the natural environment. Examples of this include an increase in the severity of a drought or a change in the frequency (likelihood) of a flood. These represent changes in the flow of benefits from the ecosystem services. Analyses of these kinds of shocks focus on the economic impacts of changes in natural capital; a failure to maintain or preserve natural capital generates larger environmental impacts that are transmitted to the economy. The economy is therefore more exposed to external (environmental) shocks and trends.

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[29] These correspond to the three categories of ecosystem services.

The second is about the structure of the economy itself and how this increases or reduces vulnerability to economic impacts that arise from a given change in an ecosystem service. Factors here include population growth in water-stressed areas and urbanisation. In both cases, these trends increase the population that would be affected by a water shortage or a reduction in air quality. Similarly, a less resource-efficient (or more resource-dependent) economy would be more affected by a disruption to its natural capital. An economy that is more reliant on imports is more vulnerable to impacts in the rest of the world, while an economy that is more reliant on domestic resources would be more vulnerable to events that affect a substantial part of national production.

This point about import dependency touches on the wider issue of international sources of economic impacts. One way to think about the international dimension is to imagine a system as depicted in Figure 3, but for each country. The question is then how impacts in one country might cross over into another. In most cases, the transmission mechanism is likely to take the form of an economy-to-economy interaction. By this channel, a change in natural capital abroad leads to an economic impact abroad. It is that economic impact that feeds into the UK economy, via trade. In many cases, it is therefore probably sufficient to analyse international effects as the economic consequences for the UK of economic effects abroad. This does not mean that there should be no work to understand the effects of foreign natural capital (this is necessary to develop a credible scenario) but that the quantitative problem during the economic assessment part of the stress test could be reduced to an economy-to-economy modelling issue.

4.4 Different types of ecosystem service

There are many ways in which natural capital can provide benefits (ecosystem services) to people. The latest version of the European Environment Agency's Common International Classification of Ecosystem Services (CICES) groups these services into three broad categories ('Sections').[30] These categories yield quite different forms of economic value. For each of these categories, Table 5 lists example ecosystem services, along with a description of the type of value the service brings to the economy, and how the depletion or degradation of the underlying natural capital assets affects that economic value.

Table 5. Sources of economic value from ecosystem services

Category	Examples	Source of economic value	Direct implications of depletion / degradation
Provisioning	- Crops and livestock - Fisheries - Water supply - Timber	- Inputs to production/direct consumption	- Lower/costlier production
Regulation and maintenance	- Air quality regulation - Flood regulation - Global climate regulation	- Maintenance/protection of human and physical assets	- Impaired productive capacity - Costs of defence/repair - Costs of alternatives
Cultural	- Recreation	- Intrinsic (amenity) value	- Lost welfare/wellbeing - Costs of maintenance/repair

[30] European Environment Agency (2013), 'Common International Classification of Ecosystem Services', Version 4.3 (January 2013).

Provisioning ecosystem services are the most straightforward to understand because the benefits enter the economy as physical flows e.g. agricultural products and water. These services also represent resources for use in the production process. It is comparatively straightforward to establish the direct value of these services because agents (farmers, water companies etc.) incur costs to extract/harvest the resources and sell them on to other producers or consumers. These services therefore have a market value, although this does not necessarily represent the 'full' value of the services. For example, extraction activities often generate externalities (such as pollution) but such costs are not always borne by the extractors unless there has been a specific intervention that internalises these costs (such as carbon pricing or environmental regulation).

As a flow of services that crosses the boundary between the natural environment and the economy, changes in flows of these ecosystem services (or the requirements of their services) are straightforward to understand as impacts that either:

- Constrain output e.g. through reductions in farmland that limit domestic agricultural production.
- Raise extraction costs, such as the need to transport water from further afield.

In contrast to provisioning services, the benefits of regulating ecosystem services do not themselves enter the economy. Instead, natural capital assets that provide these benefits serve to maintain and protect *other* assets, whether these are natural (pest/disease control, pollination etc.), human (health), or physical ('fixed' capital, such as buildings, machinery and infrastructure). Degradation of the underlying natural capital has economic impacts because it generates higher costs, usually by requiring an economic response. An example of this is flood regulation. In the absence of (existing) natural flood protection, the alternatives are:

- Invest actively in flood prevention such as planting trees and vegetation to slow water flows.
- Construct defences to protect against future flooding.
- Accept the damage to assets (which may well impair future economic activities) and, possibly, incur further costs of repair, replacement, or remediation.

In other cases, degradation may generate a requirement for an (artificial) alternative like pesticides or fertilisers, also at a cost.

One issue to be aware of with this category of ecosystem service is that any response to degradation comes at a cost to fund that response. This matters because, except for complete inaction, a response alters the growth path of the economy. If the economy is operating at full capacity (i.e. there are no further resources that can be mobilised), then resources will be diverted from other activities. This will not necessarily change GDP in the short run, but could alter the distribution of income. If resources are diverted from investment in new productive capacity, the long-run growth rate may be reduced. If the economy is operating far from full capacity, the alternatives above would generate more economic activity and raise GDP.[31] Flood defences require more construction activity and therefore support more jobs and higher income. What is missing from a GDP-only assessment is the damage to the underlying assets (in effect, the impact on the balance sheet of the economy) and the consequent reduction in productive capacity. For the purposes of a stress test, any change in economic activity arising from mitigation or adaptation activities should be interpreted as a 'cost' in the sense that it is compensating for the consequences of natural capital degradation.

What is also missing from a GDO-only assessment is any comparison with a counterfactual case in which, say, early action (at some cost): avoids the cost of accumulated damage, or, alternatively, finances to address

[31] The result has simply been to 'marketise' a service previously provided by the natural environment.

the consequences of degradation are diverted from other activities. In the extreme, this may also result in substantial pressure on other aspect of the economic system (such as insurance, to cover the cost of losses and finance to pay for new investment). By putting such pressure on these systems, natural capital stress may in turn stress other systems (such as financial buffers). In this respect, it is important to bear in mind that the impacts of changes in regulating ecosystem services often represent a problem of hidden or opportunity cost. As with the GDP impacts of repair and reconstruction, it may be sufficient to understand the impacts as being (marketised) costs, rather than attempt to construct a full counterfactual. That said, an analysis of the costs of (in)action would be a worthwhile future goal, in the same way as has been carried out previously for climate change. Different approaches may be able to handle this in different ways. It remains an open question as to whether this should be captured in an NCST or if it is best dealt with in existing financial stress tests. The two are not mutually exclusive, however.

The final CICES category concerns cultural ecosystem services. These services typically include significant 'non-use' values. This poses some difficulties for valuation because there are typically no market transactions involved and, moreover, some of the benefits may come from the continued presence of the asset, even if some people do not use them.[32] Methods to establish the value of such services may focus on estimating people's 'willingness to pay' for a benefit or, conversely, their 'willingness to accept' (how much they would need to be compensated for the loss of a good or service).

This third category does have some bearing on production and conventional macroeconomic aggregates, for example, through benefits to human health and in supporting the tourism industry, and these effects could be analysed using the approach developed in this report. However, since much of the value is embedded in the amenity, the service itself is not a directly observable macroeconomic benefit and is difficult to value. This pilot project did not attempt an analysis of any cultural ecosystem services. Further research would be needed to develop an appropriate quantitative approach.

4.5 Data requirements and the appropriate level of detail

As mentioned in the previous section, it is difficult to be prescriptive about the precise approach or model that should be used because of the diversity of ecosystem services.

That said, the clearest requirement of any economic analysis of ecosystem services is a sufficient level of detail to represent the most salient effects. That level of detail may well be high because the benefits of ecosystem services tend to be specific and there are usually few, if any, substitutes. For example, certainly for the first two categories of ecosystem service (provisioning; and regulating), interdependencies between industries are critical to understanding the transmission of economic impacts. This requires industrially-disaggregated data and methods that can account for the interdependencies.

Disruptions to provisioning services interrupt the flow of resources into the economy. This affects not only the industry that acts as the conduit for resources to flow from the natural environment into the economy but also the industries that rely on products derived from those resources. Disruptions from changes in regulating services (such as hazard regulation) also interrupt resource flows but in a different way. In this case, it is because of damage to economic assets, which serve as delivery channels. Disruptions to these channels can hinder the production, transport, and consumption/conversion of natural and economic resources. They may

[32] In addition to the value from use, UK Government guidance on appraisal and evaluation also identifies the 'option' and 'existence' value of a good. Option value is the benefit that arises from the availability of a good i.e. the ability to use the good at a future date. Existence (or 'bequest') value, on the other hand, refers to the value that comes from the continued existence of something to the benefit of present and/or future generations. For more information see HM Treasury (2003), 'The Green Book: Appraisal and evaluation in central Government'

also raise the costs of operation.

For these reasons, it is unlikely that an approach that fails to capture industrial detail could reasonably quantify the economic impacts. Approaches without this level of detail are unlikely to be suitable in isolation, although they could complement other techniques as part of a more holistic assessment.

Approaches that do capture economic structure typically incorporate an input-output table. These tables are depictions of the transactions between industries and are central to the construction of consistent national accounts. Moreover, there are well-established methods for carrying out analysis using these tables, although techniques to analyse changes in demand are more developed than those to analyse changes in supply.[33]

More sophisticated applications of input-output models are also available.[34] Such models have more detailed behavioural responses and some even have explicit treatments of resource use in physical terms. They may also be able to assess impacts over time. However, these models are data-intensive and often designed to be applicable to a wide range of economic issues. It will not necessarily be the case that the detail in these models will be sufficient to capture the specificities of certain ecosystem services. Finally, these models will embody assumptions about how the economy functions that are inherent to the models' design and underlying economic philosophy. These assumptions must be considered carefully before the models are applied. The consequent trade-off is between sophistication and applicability. There may also be resource concerns because of the level of expertise required to apply such models.

The other main data consideration in an economic assessment of ecosystem services is the level of geographical detail. Certain ecosystem services provide localised benefits. Some services cannot be carried very far, requiring economic activities to locate nearby. An example of this is water supply, for which reductions in one area cannot easily be compensated for by a transfer from somewhere else.

Other ecosystem services, like hazard regulation, might only be relevant to a specific location. Any reasonable assessment of the impacts requires an understanding of local conditions such as the:

- Characteristics (for example the footprint) of, say, a flooding event.
- Economic structure of the area such as the number and type of the assets on a floodplain. Flooding of farmland has very different economic consequences to flooding in an area populated by offices. Similarly, the loss of connectivity from a flooded road will have very different implications if the connection is between rural rather than urban areas.

The location-specific features of some ecosystem services make it hard to generalise some impacts to a UK level. A more comprehensive assessment would require spatially-disaggregated:

- Environmental data on water resources, floodplains etc.
- Economic data, to understand the kinds of economic activity that take place in different areas.
- Data on infrastructure and buildings, to identify assets like road networks and housing.

Analysis at such levels of detail does, however, come at higher cost (assuming data availability), involving combined economic and GIS analysis. The level of effort that goes into such exercises should be proportionate to the aims of the assessment.

[33] The consequences of natural capital degradation tend to be supply restrictions.
[34] These include Computable General Equilibrium and macroeconometric input-output models.

5. Piloting the approach

This section of the report shows how the NCST approach described in Section 3 was applied in practice in the pilot exercise. A results section then provides indicative estimates of the nature and significance of economic impacts associated with changes in three ecosystem services: crops and livestock, water supply, and flood regulation. A series of brief case studies are also presented to illustrate how the outputs of the NCST might be analysed and interpreted to answer specific questions of interest.

5.1 Approach to piloting

Step 1. Determine the scope of the stress test

The first step of the project was to determine the scope of the NCST to be piloted. To begin, a mapping exercise was undertaken to identify the level of ecosystem service dependence by economic sector. Once a high level overview of the dependence of each sector on ecosystem services had been established, the next step was to draw on this information to identify which services should be prioritised for developing and piloting the NCST approach. This was done using the matrices provided in Appendix B. Further details on the methodology used are set out in Appendix A.

On the basis of this scoping exercise, eight services were identified as making potentially significant contributions to the UK economy. These were then subjected to further deliberative assessment, including consideration of practical aspects such as the availability of methods and data to support quantification of both physical and economic impacts. Through this process, 'crops and livestock', 'water supply' and 'flood regulation' were identified as the three services to be investigated further in the pilot NCST (see Table 6).

Table 6. Identifying the ecosystem services to be included in the pilot stress test

Ecosystem service	Rationale	Selected for modelling?
Crops and livestock	High policy relevance, significant impacts on future provision, good approaches for quantification, and demonstrated impact on macroeconomy (2007/08 food price spikes)	ü
Fisheries	Similar type of service to 'crops and livestock' although more challenging to detect an impact on the wider economy and more difficult to quantify impacts on future provision	û
Timber	Challenging to identify a scenario leading to a change in timber provision that is detectable at an economy wide level	û
Water supply	Significant impacts on future provision of service and potential for diffuse impacts whereby the whole economy becomes more vulnerable as a result of water scarcity	ü
Air quality regulation	Growing policy interest in this service although challenging to link to macroeconomic indicators	û
Flood regulation	Key issue for a range of economic sectors, significant future impacts on this service from a changing climate, and likely to be possible, although challenging, to quantify	ü
Global climate regulation	While an important service, a stress test would be unlikely to add value given previous and ongoing efforts in this area	û
Tourism and recreation	Significant economic sector although challenging to identify natural capital scenarios which impact the 'quantity' rather than the 'quality' of the service	û

Step 2. Formulate stress test scenario

A literature review was then undertaken to put together a high-level narrative description of the potential change in each of the five UKNEA drivers that would describe the scenario to be used as the basis of the model in the pilot NCST. The resulting narrative is set out below – the evidence base supporting each aspect of the narrative is set out in Appendix A.

Climate change

Globally, the international community fails to meet the required reductions in greenhouse gas emissions to limit warming to two degrees. The resulting climate scenario in the UK follows the projections set out in the UKCP09 ‘High Emissions’ scenario on the four degrees of warming path. The subsequent impacts cause significant reductions in the amount of water in the environment that can be sustainably withdrawn, while also increasing the demand for water during the driest months. The frequency and magnitude of floods in the UK also rises significantly and cause growing costs to a range of economic sectors. Globally, changes in the climate system lead to a doubling of international food prices.

Invasive species

Increasing demand for global imports and a more diverse supply chain, together with changes in the climate and land use, lead to a significant increase in the frequency and severity of pest and disease outbreaks in the UK and growing costs for the agriculture industry.

Habitat change

Greater emphasis on competing in the international market and securing trade deals leads to cuts in public subsidies for UK agriculture and there is a marked shift from subsidising food production towards allowing the market to determine the level of agricultural output. This shift leads to a widespread abandonment of agricultural land in upland areas with limited agricultural productivity. At the same time, the UK population continues to grow which leads to growing demand for housing resulting in the relaxation of Green Belt restrictions and widespread urban expansion into farmland areas surrounding cities, increased development of housing infrastructure on floodplains and coastal margins, and the creation of new towns on areas previously used for agriculture.

Nutrient enrichment and pollution

Environmental regulations are also relaxed in order to support intensification of the remaining farms to allow them to compete with less constrained international producers. This leads to increases in livestock stocking densities and a spike in the use of pesticides and fertilisers which causes short term productivity boosts and longer term increases in soil degradation, water pollution, and loss of natural pollinators. Combined, this creates rising costs for agricultural productivity and water treatment, and reduced capacity of ecosystems to regulate surface water flows during flood events.

Overexploitation of resources

Demand for residential water use grows in line with the increase in population and creates additional pressures on already-stretched water resources in some parts of the country. In the drier areas of the country water shortages become commonplace leading to frequent restrictions. These pressures are further exacerbated by increasing demand for irrigation water due to the changing climate and the growing demand for water to meet the energy needs of a growing population.

Step 3. Identify and quantify impacts on ecosystem services

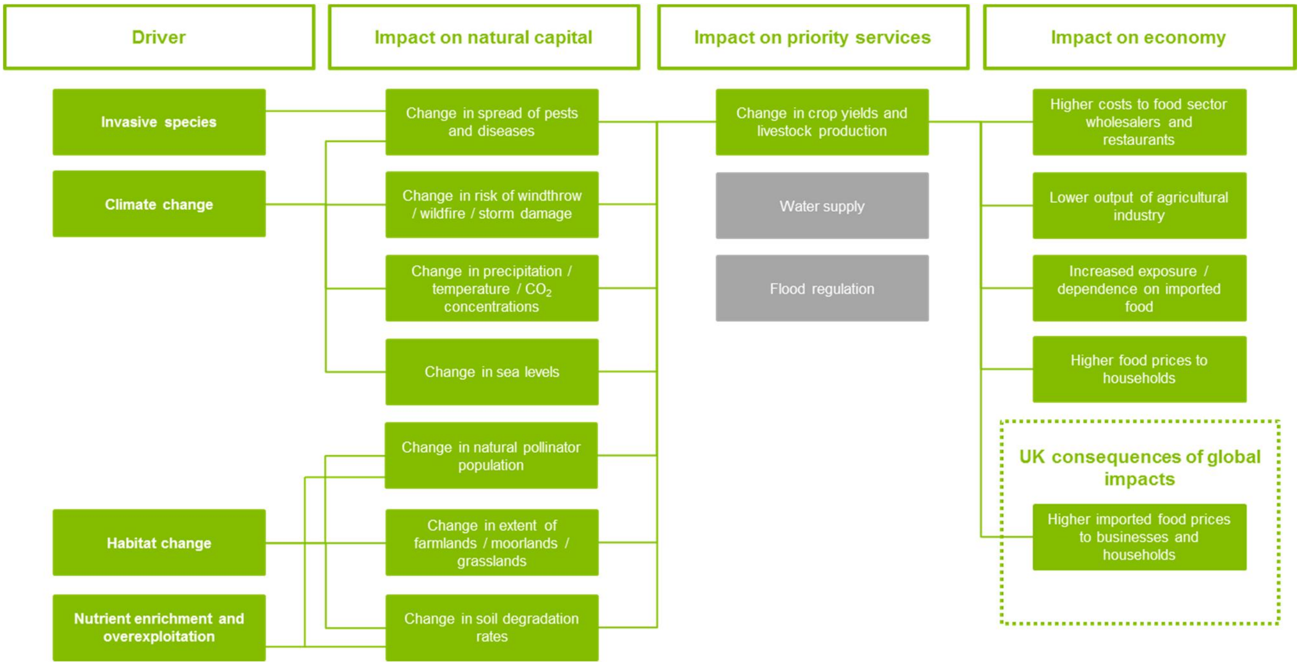
A more detailed literature review was then undertaken in order to map out the pathways though which the drivers could impact on ecosystem services, and to use these pathways to move from a descriptive narrative to a quantitative estimate of the extent of change in natural capital and ecosystem service provision.

This process also highlighted gaps in the evidence base and helped to re-frame the aspects of the scenario that could be quantified and modelled in the pilot exercise based on the available data. An outline of the process for each of the three services is set out below.

Crops and livestock

The impact pathway for the crops and livestock service is set out in Figure 4.

Figure 4. Impact pathway for 'crops and livestock' service



A series of assumptions and calculations were then used to estimate the change in the provision of crops and livestock resulting from each of the natural capital impacts identified in the impact pathway. An overview of the process is set out in Table 7 with more details on the assumptions involved provided in Appendix A.

Table 7. Overview of impacts on natural capital from high level drivers and resulting impacts on crops and livestock

Key impacts	Impact on natural capital by 2050s	Impact on crops and livestock	Quantified
Change in spread of pests and disease	Increased impacts on winter wheat and barley from diseases such as Barley Yellow Dwarf virus due to climatic changes and activity of aphid vectors[38]	Acute reduction in crop yields of 10.3% of total value by 2050 per disease outbreak[35,36,37]	ü
	Increased impacts on livestock due to diseases such as bluetongue and liver fluke[38]	Acute reduction in livestock production of 1.0% of total value by 2050 per disease outbreak[39,40,41]	ü
Change in drought and flood risk	Increase in the area of Best and Most Versatile (BMV) land at high risk of flooding to 790,000 ha[42]	Acute reduction in crop yields of 18.3% of total value by 2050 per flood[43]	ü
	Increase in water supply deficits during low flow events and restrictions on agricultural water use	Impacts on agricultural output due to drought events are captured in the 'water supply' service	û
Change in risk of windthrow / wildfire / storm damage	Increase in wildfire risk[44] and loss of crops to fire damage	Acute reduction in crop yields of 0.2% of total value by 2050 per fire[45]	ü
Change in precipitation / temperature / CO_2 concentrations	More frequently waterlogged soils in winter and reduced soil moisture in summer leading to increase in weather patterns seen in 2012 where poor weather (wet winter/spring, dry summer) led to reduced wheat and potato yields[46]	Acute reduction in crop yields of 5.9% of total value by 2050 per year with poor weather event[47]	ü
	Increase in wheat and sugar beet yields due to better growing conditions together with decrease in potato yields[48]	Chronic increase in crop yields of 1.1% of total value by 2050[49]	ü
	Increase in heatwave events which lead to loss of milk yield from livestock[50]	Acute reduction in livestock production of 0.2% by 2050[51]	ü

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35 Crop Bayer Science http://www.bayercropscience.co.uk/our-products/seed-treatment/redigo-deter/bydv/
36 Farmers Weekly http://www.fwi.co.uk/arable/spring-wheat-now-makes-up-5-of-uk-wheat-area.htm
37 Defra (2015) 'Provisional 2015 cereal and oilseed rape production estimates'.
38 Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
39 Veterinary Record http://veterinaryrecord.bmj.com/content/161/16/571.6
40 Pfizer Animal Health http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2013/06/Liver-fluke-in-cattle-costs-and-control.pdf
41 AHDB Dairy https://dairy.ahdb.org.uk/market-information/farming-data/milk-yield/average-milk-yield/#.WH5PiNWLS71
42 Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
43 Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
44 Gazzard et al. (2016), 'Wildfire policy and management in England: an evolving response from Fire and Rescue Services, forestry and cross-sector groups'
45 Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
46 Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
47 Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
48 CCRA (2012), 'Climate Change Risk Assessment for the Agriculture Sector'.
49 Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
50 Dunn et al. (2014), 'Analysis of heat stress in UK dairy cattle and impact on milk yields'.

Key impacts	Impact on natural capital by 2050s	Impact on crops and livestock	Quantified
Change in sea levels	Average increase in sea levels of 0.34 metres[52] leading to loss of 0.1% of BMV land through costal erosion[53]	Chronic reduction in crop yields of 0.04% of total value by 2050[54]	ü
Change in natural pollinator population	Decline in natural pollinator populations and distributions to the extent that pollinator visits to crops fall[55]	Chronic reduction in crop yields of 4.9% of total value by 2050[56,57]	ü
Change in extent of farmlands / moorlands / grasslands	Subsidy reductions take all Less Favoured Area (LFA) land in England out of production	Chronic reduction in livestock production of 19.6% of total value by 2050[58,59]	ü
	Increase in development of agricultural land to meet growth in housing demand	Chronic reduction in crop yields and livestock production not quantified due to limitations of evidence base	û
Change in soil degradation rates	Widespread deterioration in soil quality due to erosion, loss of soil organic content, and compaction[60,61,62]	Chronic reduction in crop yields of 3.8% of total value by 2050	ü

The impacts on natural capital were then aggregated to provide an estimate of the cumulative change in ecosystem service provision (see Section 5.5). As set out in Table 7, it was not possible to quantify each of the impacts of natural capital change on the provision and crops and livestock and the resulting scenario modelled in the pilot NCST was as follows:

- What is the potential scale of the impact of a reduction in the output of agricultural crops and livestock in 2050 due to a combination of **acute** tail-end shock events including disease outbreaks, flood events, wildfires, poor weather events, and heatwaves?
- What is the potential scale of the impact of a reduction in the output of agricultural crops and livestock in 2050 due to a **chronic** change in productivity resulting from improved growing conditions for certain crops, loss of agricultural land through coastal erosion, declines in natural pollinator populations, reduction in farming in upland areas, and falling soil productivity?

Water supply

The impact pathway for the water supply service is set out in Figure 5 and the estimates of change in natural capital and ecosystem service provision are set out in Table 8.

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[51] Dunn et al. (2014), 'Analysis of heat stress in UK dairy cattle and impact on milk yields'.
[52] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[53] Ramsbottom et al. (2012), 'UK 2012 Climate Change Risk Assessment for the Floods and Coastal Erosion Sector'.
[54] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[55] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[56] Biesmiejer et al. (2006), 'Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands'.
[57] UK NEA (2011), 'Chapter 14: Regulating Services'.
[58] RBR (2016), 'Farm Business Survey 2014/2015 Hill Farming in England'.
[59] Defra Soil Research Programme 'Review of the weight that should be given to the protection of best and most versatile (BMV) land Technical Report SP1501/TR Final Report'.
[60] UK National Ecosystem Assessment Follow-On (2014), 'Work Package Report 1: Annex 4 – Case studies'.
[61] Cranfield University (2013) for the Adaptation Sub-Committee. Work for the 'Managing the land in a changing climate' report
[62] Graves et al. (2015), ' The total costs of soil degradation in England and Wales'.

Figure 5. Impact pathway for 'water supply' service

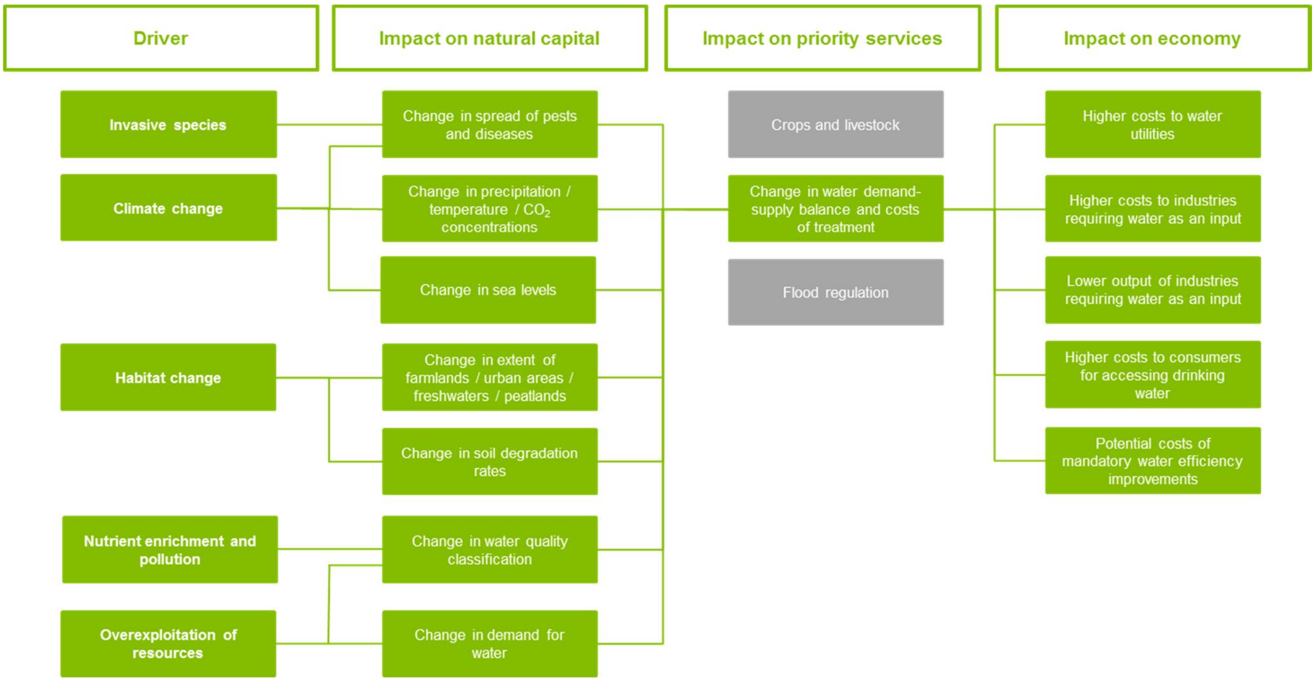


Table 8. Overview of impacts on natural capital from high level drivers and resulting impacts on water supply

Key impacts	Impact on natural capital by 2050s	Impact on water supply	Quantified
Change in spread of pests and disease	Increased incidence of invasive species (especially aquatic plants and invertebrates)[63]	Chronic increase in water treatment costs not quantified due to limitations of evidence base	û
Change in precipitation / temperature / CO_2 concentrations	Change in precipitation patterns contributes to lower flows in summer months[64]	Chronic reductions in supply of water which increase the impacts of acute drought events based on the evidence base set out in the CCRA	ü
		Assuming acute drought event occurs for a 3 month period	ü
Change in sea levels	Average increase in sea levels of 0.34 metres[65]	Chronic increase in groundwater saline intrusion into aquifers not quantified due to limitations of evidence base	û
Change in extent of urban areas/ freshwaters / peatlands	Increase in population leading to increase in intensification of remaining agricultural land and urbanisation of river catchment which reduces capacity of ecosystems to regulate water quality	Chronic increase in water treatment costs not quantified due to limitations of evidence base	û

[63] Dawson et al. (2016), 'Climate Change Risk Assessment 2017: Infrastructure'
[64] Dawson et al. (2016), 'Climate Change Risk Assessment 2017: Infrastructure'
[65] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.

Key impacts	Impact on natural capital by 2050s	Impact on water supply	Quantified
Change in soil degradation rates	Continued erosion of sediments contributing to sedimentation of water	Chronic increase in water treatment costs not quantified due to limitations of evidence base	û
Changes in water quality classification	Intensified agriculture and wetter autumns and winters increases the severity of diffuse agricultural pollution and low summer river flows less effectively dilute pollutants	Chronic increase in water treatment costs not quantified due to limitations of evidence base	û
Change in demand for food / water / raw materials	Increase in population of 10% to 83 million people leading to the demand for water across the UK to increase by 9%[66]	Chronic increase in demand for water which can emphasise the impacts of acute shocks during drought events based on the evidence base set out in the CCRA 2017	ü

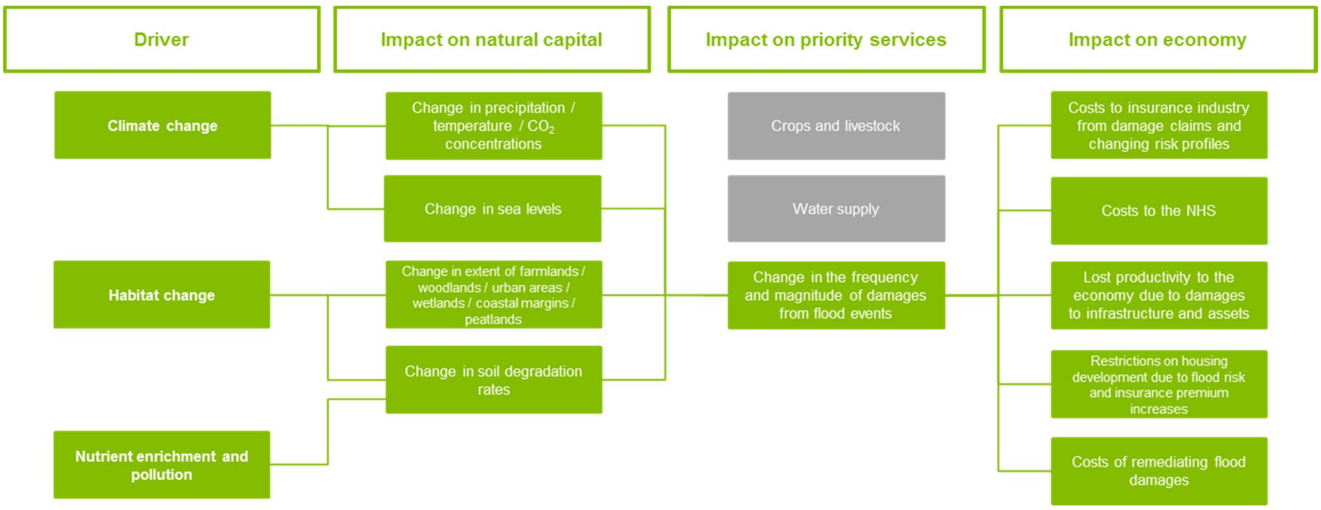
Given the limitations of the evidence base, the impacts on water supply for the purposes of the pilot NCST were focused on quantifying the chronic changes in the demand and supply of water, and how these ongoing chronic changes could lead to greater exposure to acute drought events in future. More specifically, the pilot aimed to answer the question, how much greater could the magnitude of impacts from a drought event in 2050 be due to chronic declines in water availability based on a comparison between:

- The impacts of a three-month drought event in 2050 (assumed here to be a period when water levels are at low flows for three months) if water availability declines to the extent projected by CCRA 2017.
- The impacts of a similar drought event in 2050 if water availability was maintained at its current levels.

Flood regulation

The impact pathway for the flood regulation service is set out in Figure 6 and the estimates of change in natural capital and ecosystem service provision are set out in Table 9.

Figure 6. Impact pathway for 'hazard regulation' service



[66] HY Wallingford (2015), CCRA2: Updated projections for water availability for the UK Final Report'.

Table 9. Overview of impacts on natural capital from high level drivers and resulting impacts on flood regulation

Key impacts	Impact on natural capital by 2050s	Impact on hazard regulation	Quantified
Change in precipitation / temperature / CO_2 concentrations	Average increase in peak river flows of 23%[67] and events of intense rainfall between 1 to 6 hours duration of 20%[68]	Increase in risk of acute fluvial flood events based on the evidence base set out in CCRA 2017	ü
		Increase in risk of surface water flood events based on the evidence base set out in CCRA 2017	ü
		Assuming increase in risk of acute flood events based on the evidence base set out in CCRA 2017	ü
Change in sea levels	Average increase in sea levels of 0.34 metres[69]	Increase in risk of acute coastal flood events based on the evidence base set out in CCRA 2017	ü
Change in extent of woodland / urban areas / wetlands	Increase in population of 10% to 83 million people[70] leading to an increase in urbanisation mainly at the expense of agricultural land although some additional development on floodplains	Chronic increase in number of properties at risk from flooding during acute events	ü
		Chronic decrease in capacity of ecosystems to regulate water flows not quantified due to limitations of evidence base	û
Change in soil degradation rates	Increase in soil degradation and loss of capacity to store water	Chronic decrease in capacity of ecosystems to regulate water flows not quantified due to limitations of evidence base	û

Given the available evidence base, the impacts on flood regulation in the pilot NCST were focused on quantifying the chronic changes in the numbers of properties at risk of flood events and the change in the extent and magnitude of acute flood events by 2050. More specifically, the pilot exercise looked at the potential scale of the impact of a one-off repeat of the winter floods of 2013/14 given the greater numbers of people and properties at risk of flooding due to ongoing changes in the climate system and population by 2050.

Step 4. Identify and value economic impacts

Having developed the assumptions about changes in ecosystem services, the final part of the pilot was to carry out the economic impact analysis.

In the case of the two provisioning ecosystem services (crops and livestock and water supply), a model was developed and applied specifically for this pilot. The model is a static input-output model that calculates the

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[67] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[68] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[69] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[70] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.

economy-wide impacts of changes in demand. These economy-wide impacts arise from effects transmitted through industrial supply chains and changes in income that drive changes in consumption.[71] Having identified the output reductions that follow from a change in ecosystem services, it is up to the user to specify how any supply restrictions fall on individual industries; the model then calculates the extent to which this reduced demand from the (direct and indirect) users of crops and livestock or water is consistent with the assumption for reduced supply. The user can either specify the level of reductions themselves (e.g. '£5bn of output would be affected in the accommodation services industry') or impose assumptions that set the distribution of any reductions across industries (e.g. '7% of whatever output reduction is required is assumed to come from the fruit and vegetable processing industry').

The analysis of shocks to, and chronic degradation of, natural capital is largely uncharted territory and historical experience gives an incomplete picture as to how these effects might play out and how people and the economy might react. As such, a natural capital stress test is subject to a much wider range of uncertainties than a financial stress test. The analysis presented in this pilot is necessarily reliant on assumptions. Moreover, changes in provisioning ecosystem services mostly concern supply effects. These are distinct from demand effects and industrially-disaggregated analysis of supply effects is much less explored as an area of research than demand effects. Few existing models capture such supply impacts adequately and models that do will still be subject to parameters based on historical experience, which may be less suited to the analysis of adverse events. Given the complexity of the possible effects, and given that this is a pilot project, a simple model was preferred to explore the problem of ecosystem service change and its implications for the UK economy.

Because of the preference for simplicity/transparency, the model does not embody automatic responses of demand to changes in price (to bring demand into line with supply). Instead, it is up to the analyst to specify a change in output (translated from a change in ecosystem services, from the evidence) and a change in prices that together form a coherent scenario. This makes it easier to isolate different effects. The model therefore has a separate module to calculate the impacts on the consumer price index of price changes in the UK and the rest of the world.

The input-output model itself is based on the latest UK input-output table, for 2010. The underlying input-output table has been aggregated to 67 industries in a way that still permits analysis at broader industry groupings (corresponding to the individual sections of SIC 2007). Appendix C provides a table that lists the full name of each industry and its correspondence to the SIC Sections. The impact model itself, implemented in a Microsoft Excel workbook, contains a more-detailed mapping between the industries and other industry groupings. The input-output table is for 2010 and the 2050 baseline has been constructed by combining that data with output and employment projections from Cambridge Econometrics' MDM-E3 model of the UK economy. The projections are consistent with Cambridge Econometrics' November 2016 forecast and extrapolated to 2050. Unless otherwise stated, all monetary values reported in the macroeconomic analysis are in real terms (2010 prices).

Because uncertainty pervades the entire stress test approach, the quantitative estimates that follow are necessarily imprecise. Further, as will be seen in the case of the first two ecosystem services (crops and livestock, and water supply), the size of the impact depends critically on which industries are assumed to absorb the reductions in ecosystem service flows, and the extent to which industries might be able to adapt to the losses in service flows while maintaining production.

While the model is a substantive output of this pilot project, it is important to understand its role as an aid to a stress test analysis. Its value to analysts and decision makers comes from the ability to run meaningful

[71] The model incorporates a set of Type II output, GVA and employment multipliers.

scenarios and interpret the results. As the approach in Section 3 and the discussion in Section 4 make clear, different approaches will be necessary to examine different scenarios and ecosystem services. Hence, the results in this section should be viewed as an illustration of the kind of approach that might inform a stress test and, as importantly, how those results should be interpreted when drawing conclusions from the analysis.

For hazard regulation, a lack of data prevented a detailed assessment and modelling along the lines set out above. Instead, a different kind of analysis was conducted in which assumptions were applied to analyse what the impacts of a past series of flood events would be if they were to happen in the future (when the socio-economic structure of the UK would be different and perhaps more vulnerable to such events).

5.2 Headline results

Having identified three ecosystem services from the earlier prioritisation exercise, the NCST piloted here considered three questions:

- **Crops and livestock:** What is the potential scale of the impact of a reduction in the output of agricultural crops and livestock in 2050 due to a combination of acute tail-end shock events such as floods and disease outbreaks, and chronic declines such as falling soil productivity and a loss of natural pollinators?
- **Water supply:** What is the potential scale of the impact of a reduction in water availability due to an acute drought event in 2050 that is made more severe by chronic growth in demand that exceeds the natural replenishment of water resources?
- **Flood regulation:** What is the potential scale of the impact of a one-off repeat of the winter floods of 2013/14 given the greater numbers of people and properties at risk of flooding due to ongoing changes in the climate system and population by 2050?

The answers to these three questions are summarised in Table 10. Headline results from the pilot NCST exercise are explained in more detail in the following sections.

Table 10. Headline results from the pilot NCST exercise

Ecosystem service	Scenario	Estimated impacts in 2050
Crops and livestock	**Output shock in 2050** from disease outbreaks, flood events, wildfires, poor weather events, and heatwaves	0.9% reduction in GDP 347,000 jobs lost
	Productivity losses over time to 2050 from changes in growing conditions and land use, declines in pollinators, and falling soil productivity	0.2% reduction in GDP 66,000 jobs lost
Water supply	**Three-month UK wide drought in 2050, continued depletion** of water reserves	1.0% reduction in GDP 354,000 jobs lost
	Three-month UK wide drought in 2050, water reserves protected and maintained at current levels	0.5% reduction in GDP 156,000 jobs lost
Flood regulation	**Repeat in 2050 of the 2013/14 winter floods** with continued population growth and limited action on climate change	70% increase in damages to £2.2bn (2013/14 prices)

Crops and livestock

Change in service provision

The scenario tested in the pilot NCST aimed to quantify the potential scale of the impact of a reduction in the output of agricultural crops and livestock in 2050 due to a combination of acute tail-end shock events and chronic changes in productivity. An overview of the estimates of ecosystem service change is set out in Table 11 and further details are available in Appendix A.

Table 11. Cumulative change in crops and livestock

Service	Current output (2015 prices)	Acute change in output for shock event in 2050 (%)	Chronic change in output by 2050 (%)
Crops	£7,595,000,000	-34.6%	-7.7%
Livestock	£10,811,000,000	-1.2%	-19.6%

These results suggest that a combination of acute tail-end shock events including disease outbreaks, flood events, wildfires, poor weather events, and heatwaves occurring in the year 2050 could lead to a 34.6% and 1.2% reduction in crops and livestock output respectively. In addition, a chronic change in productivity resulting from improved growing conditions for certain crops, loss of agricultural land through coastal erosion, declines in natural pollinator populations, reduction in farming in upland areas, and falling soil productivity could lead to a 7.7% and 19.6% reduction in crops and livestock output by 2050.

However, it is important to note that existing studies do not provide a consistent overview of the cumulative impacts of various natural capital changes on crops and livestock provision by 2050. A number of different studies were drawn upon which used multiple different sets of assumptions and methodologies. This creates issues when trying to combine like with like; for instance some estimates for the extent of change in 2050 account for the change in magnitude of a particular impact (e.g. greater loss of milk yield from dairy cows due to an increase in the number of heatwave events), whereas others do not, instead assuming that events which have happened previously occur again in the future (e.g. replication of poor weather events in 2010/11).

The estimates do not account for the *likelihood* of an event occurring, and instead focus on the *magnitude* of the impact should an event occur. As such, some of the figures are likely to be over or under estimates of the actual magnitude. For example, the estimate of flood risk to agricultural land draws on CCRA 2017 work which suggests that 790,000 ha of BMV agricultural land could be at high risk of flooding by 2050. The estimates provided above look at the magnitude of the impact if all of this area was flooded within a single year, an event which has a low likelihood.

These issues mean that the pilot exercise should be taken as indicative of how the potential approach could be undertaken, rather than providing definitive estimates of what may actually happen in 2050. As a priority, research should be undertaken to build the evidence base around aggregate impacts of changes in ecosystem service provision.

Change in macroeconomic indicators

The narrative of an *acute* shock to crops and livestock supply is a series of impacts that falls largely on crops (as set out above): a confluence of events such as flooding, disease, and cold/wet weather. This reduces output in both the UK and (by assumption) abroad and causes a global price spike in 2050, the year of the shock. Countries do divert some of their exports to support domestic consumption and so importers of food face reduced supply. Both households (who purchase fruit and vegetables) and food manufacturers (who process crops) are affected.

The main features of this narrative for the quantitative economic analysis are, in 2050, as follows:

- A **reduction in agriculture output** in that year, of £2.9bn in real terms (2010 prices).[72] This represents around 6% of the industry's gross output in 2050. This is the direct impact of the change in ecosystem services that is transmitted into the economy.
- This reduction is associated with **higher prices**. Global agriculture prices in 2050 are assumed to double from the supply shock. This is discussed further below.
- Of that total reduction in output, £0.5bn of UK **exports are reduced (diverted to maintain domestic sales)**. This is around 12.5% of total exports. The percentage reduction is assumed to be twice the scale of the reduction in UK production, to reflect diversion to the domestic market.
- Despite the diversion of supply from exports, **households still bear some reduction in consumption**. It is assumed that direct sales to households are reduced by just over 3%: half the overall percentage reduction in UK supply.
- As it is assumed that the crisis occurs in multiple countries, it is also assumed that (temporary) **import substitution is not possible**. Moreover, producers in other countries adopt a similar policy as in the UK, diverting some of their exports to domestic consumption. This amounts to a 12.5% reduction in the supply of foreign agricultural products to UK households in 2050: around £1.7bn in real terms. The reduction in imports is larger than that of exports because the UK is relatively more dependent on food imports than other countries are on UK food exports. The overall lower availability of food to consumers is therefore the combination of lower domestic consumption and the lower availability of imported food. This represents a reduction in households' material circumstances (they are not able to consume as much as before) though only the first is reflected in a reduction in GDP.[73]

Because the purpose of the stress test was to analyse tail-risk (and therefore extreme adverse) events, the changes in ecosystem services identified in earlier parts of the stress test are necessarily of a scale that is either at the extreme of, or beyond, historical experience. Deep uncertainty characterises many of the possible future changes in natural capital and leads, in turn, to uncertainty about how the flow of ecosystem services might change and the consequences for the economy. Because of this uncertainty, and reflecting the resources available for this pilot stress test, the analysis aims to be as simple and as transparent as possible. This is reflected in the reliance on key assumptions at various points in the process and the need to carefully interpret results in light of those assumptions.

It is for these reasons that the economic impact model was developed for this scoping study, to test the approach on two of the selected ecosystem services (crops and livestock, here; and water supply, presented later). As explained earlier in this report, because of the lack of evidence/experience to properly understand all the effects, it was not clear that there would be much initial benefit in the pilot from immediately deploying a more sophisticated economic model. This is particularly the case in the analysis of supply restrictions (as is required here), which are not so well-represented in existing models. Moreover, in the narratives developed here, supply restrictions are imposed as combinations of price effects (to curb demand) and quantitative rationing (so that the burden is shared among households rather than borne by those with least ability to pay higher prices). In winter 2016/17, when rain and cold weather in Europe reduced the availability of certain kinds of produce, both higher prices and rationing (by food retailers) were applied. Finally, in the kinds of tail-risk scenarios of interest here, the impacts are more likely to lie outside of the historical experience on which

[72] The figures in nominal terms from the previous section have been converted to 2010 real terms as this is the base year of the underlying input-output table.
[73] In national accounting terms, the assumption of a reduction in the direct supply of imports to households (with no domestic alternative) requires changes in both domestic consumption and the foreign production to meet it. This appears as a simultaneous reduction in both the consumption and imports components of GDP as measured by the expenditure approach. There is no net change in GDP though it does represent lower expenditure by households.

existing models are based. This makes it less clear that the relationships that underpin these models will continue to hold under more extreme conditions.

Consequently, and in the interests of simplicity and transparency, the model developed and applied here does not attempt to simultaneously model changes in demand/supply and prices. Changes in supply do not lead to changes in price, nor do changes in price lead to changes in demand; as might be incorporated in a model with a set of price elasticities. Instead, it was necessary to develop a set of supply and price assumptions that, together, formed a coherent scenario.

The reductions in agricultural output that might occur in the event of an acute shock are detailed above, based on a range of sources. The nature of these changes in ecosystem services is largely uncharted territory and the evidence on how these might affect (increase) prices is even sparser. Given the limited state of knowledge in this area, the global price spike modelled in the analysis assumes a doubling of global food prices. The basis for this assumption is the international food price hike of 2007-08. During this period, a combination of supply-demand imbalances in food, increases in the oil price, and depreciation of the US Dollar contributed to increases in commodity prices of 80-105% for the main traded cereal crops. The UN Food and Agriculture Organisation's cereals price index shows a near-doubling over the period.[74] In the pilot stress test, this doubles the cost of imports to industry (with the size of the effect depending on each industry's import dependence). As price-takers, prices of UK agriculture output also double, increasing producers' profits. Prices are modelled under the assumption of full cost-price pass-through and the results are, in that sense, towards the upper bound of the likely impacts.

As set out in Table 12, the economic analysis of the acute shock involves a combination of price effects (reflecting *some* market forces to curb demand) but also some rationing. Of the overall £2.9bn reduction in agricultural output, £0.9bn is met by reductions in direct sales to households (£0.4bn) and for export (£0.5bn). The remaining loss of £2bn of crops and livestock production is met by reductions in output in industries that depend on that produce. This generates further impacts in downstream industries, ultimately reducing the availability of other goods and services for purchase by households etc. For example, a lower availability of crops can affect the supply chain by reducing the availability of wheat. This restricts flour production and, in turn, the production of baked goods. Economy-wide, the lower industrial output generates further effects by lowering household incomes and therefore leading to lower consumption on top of the original restrictions in purchases of fruit and vegetables.

Table 12. Economic assumptions for an acute shock to crops and livestock in 2050

	£2010bn	Share of 2050 baseline (%)
Reduction in agriculture industry gross output	-2.9	-6.2 (of gross output)
Of which met by reduced consumption by households	-0.4	-3.1 (of domestic consumption of agricultural products)
Of which diverted from exports	-0.5	-12.4 (of exports of agricultural products)
Remainder met by lower supply to industry	-2.0	-
Reduction in imports (from similar shocks abroad)	-1.7	-12.4 (of consumption of imported agricultural products)
Note: This scenario also assumes a doubling in global prices of agricultural products.		

[74] This mirrors the assumption in United Nations Environment Programme (2016) ERISC Phase II: How food prices link environmental constraints to sovereign risk [online] available at http://www.footprintfinance.org/portfolio/erisc2-report/ (last accessed 27 February 2017).

How the £2bn reduction in agricultural output falls on downstream industries (i.e. which industries bear more/less in the way of restrictions) is a critical final assumption in the analysis and a further source of uncertainty.[75] The analysis that follows considers two alternative assumptions about which industries see reductions in the availability of agricultural products. This is to illustrate the sensitivity of the results to such assumptions but also to show how an analyst might interpret the results from the pilot stress test.

The first set of assumptions comprises a set of reductions by individual industry based on the analyst's own judgment. The analyst must manually specify the industries that might be most affected by a reduction in the availability of agricultural products. In the input-output model developed for the pilot, these changes must be specified as reductions in the availability of goods and services for purchase by final users such as households. This is, in practice, an iterative process in which the analyst would continue to adjust the changes in demand until the model yields a set of results consistent with those required by the scenario; in this case, until the model produces results consistent with the outcomes specified in Table 12. This approach is amenable to stakeholder engagement/participation to develop a plausible, industry-tested piece of analysis. In a future stress test, such an approach is potentially time- and resource-intensive, but may yield substantial benefits if it can take advantage of such industry expertise. For this pilot, Table 13 reports the reductions in final demand by this approach.

Table 13 presents the amount by which production in specific industries is assumed to fall. These reductions achieve the overall reduction in agriculture industry output of £2.9bn. Alongside the monetary values, the table also reports how large these reductions are as a percentage of final demand in 2050. This gives an indication of the extent to which the availability of these products might need to fall to be consistent with a £2.9bn reduction in agricultural production. The £0.9bn reduction in agriculture in the first row follows directly from the narrative of the scenario. All other reductions in industry production had to be specified by the analyst.

Table 13. Analyst-led distribution of output reductions by industry for an acute shock to crops and livestock in 2050

	£2010 bn	Share of 2050 final demand (%)
Agriculture (Crop and animal production, hunting and related service activities)	-0.9	-4.5
Processing and preserving of fish, crustaceans, molluscs, fruit and vegetables	-2.0	-40.0
Grain mill products, starches and starch products	-1.5	-40.1
Bakery and farinaceous products	-4.9	-39.9
Other food products	-4.8	-40.0
Prepared animal feeds	-1.3	-39.8
Accommodation	-5.1	-7.4
Food and beverage service activities	-9.9	-7.5

The non-agriculture reductions in Table 13 were set in a way that reduced the availability of:

- Certain food products that depend on crops. The changes were chosen to achieve similar percentage reductions, which ended up being around 40%. These reductions in the availability of such goods to

[75] More sophisticated economic models might, for example, apply a set of price elasticities to simulate how the market might reconcile this problem but, as already mentioned, it is difficult to say whether this is a valid approach in an adverse scenario and, in any case, at least some restrictions would come about through rationing rather than prices.

households are clearly substantial under the assumption of fixed coefficients but this seems reasonably plausible as an implication because these products simply could not be manufactured without the crops.

- Accommodation and food/beverage services, by around 7.5%. The percentage reductions were smaller here to reflect some combination of: greater scope for substitution (these industries might serve alternatives if other products are not available) and/or a likely greater acceptance of any price increases (such firms may be willing to pay higher prices as long as they can keep serving their customers, because food inputs represent a smaller proportion of their overall costs).

The alternative set of assumptions is derived from the historical data on industrial usage of agricultural products. The model's underlying input-output table (for 2010, the latest available year of data) identifies transactions between industries, depicting the supply-chain dependencies of the UK economy. The table therefore shows the value of, for example, purchases of agricultural products by the fruit and vegetable-processing industry and how these purchases of inputs compare to those by the grain industry. Using this information, it is possible to develop a set of assumptions that constrain industry output in a way that reflects how significant each industry is as a purchaser of agricultural products.

For example, in the data, fruit and vegetable processing[76] accounts for 7% of industrial demand for agricultural products. In modelling the economy-wide impacts of the reduction in agricultural output, fruit and vegetable processing would account for 7% of the overall reduction in final demand. Because the raw data show meat[77] and dairy[78] products to dominate industrial purchases of agricultural products (and remembering that the acute ecosystem service shock falls largely on crops), in this case, these shares were set to zero (these industries faced no direct constraint on their production) and re-allocated to the other food-production industries.[79]

The only other modification to what would otherwise have been a set of assumptions derived entirely from the data, was to set the share of oils and fats production[80] to zero. This final adjustment was made because this industry is small and any direct constraints on output would quickly become implausibly large. The (small) share was re-allocated to other food-production industries in a similar manner. The clear advantage of this approach is that it is quick and transparent. However, it will not necessarily be as good a reflection of the specificities of any particular scenario. This is because this data-derived approach simply applies behavioural responses consistent with the idea that industry output is constrained according to historical usage of agricultural products.

In the results that follow, the estimated impacts from the assumptions based entirely on analyst judgment are labelled as 'analyst-led' and should be considered to be the central headline results from the pilot stress test. The results using assumptions based on the historical data are labelled 'data-derived'. While not a comprehensive sensitivity test, the results from this second set of assumptions give some sense of the possible range of outcomes.

One other sensitivity test carried out during the pilot was to see what the economic impacts might be if all the reduction in agricultural output was met by restricting sales to households and for export. Such a decision minimises the economic impacts by avoiding any downstream constraints on the supply chain. In fact, it is the

[76] In the model, strictly, Industry 6: 'Processing and preserving of fish, crustaceans, molluscs, fruit and vegetables'.
[77] Industry 5: 'Processing and preserving of meat and production of meat products'.
[78] Industry 8: 'Dairy products'.
[79] Specifically, Industries 6 ('Processing and preserving of fish, crustaceans, molluscs, fruit and vegetables'), 9 ('Grain mill products, starches and starch products'), 10 ('Bakery and farinaceous products'), 11 ('Other food products') and 12 ('Prepared animal feeds'). This re-allocation was done in proportion to these industries' relative shares of agricultural purchases.
[80] Industry 7: 'Vegetable and animal oils and fats'.

lowest possible economic impact that is still consistent with a reduction in agricultural output. The impacts on GVA/GDP and employment were small (barely 0.1%). But the possibility that households and foreign purchasers might bear the entirety of any production losses was considered unrealistic and so these results are not presented below. Table 14 summarises the economic impacts from the analyst-led and data-derived versions of the analysis.

Table 14. Summary economic impacts of an acute shock to crops and livestock in 2050

	Analyst-led	Data-derived
Change in GVA (£2010bn) (% of projected UK total in 2050; approximately equal to percentage of GDP)	-29.5 (-0.9%)	-15.2 (-0.5%)
Change in domestic final demand (£2010bn) (% of projected UK total in 2050)	-30.4 (-0.8%)	-16.3 (-0.4%)
Change in imports (£2010bn) (% of projected UK total imports for final use)	-1.7 (-0.3%)	
Change in employment ('000s) (% of projected UK total in 2050)	-347 (-1.1%)	-158 (-0.5%)
Change in CPI (%) (from the doubling in agricultural product prices)	+3.4%	

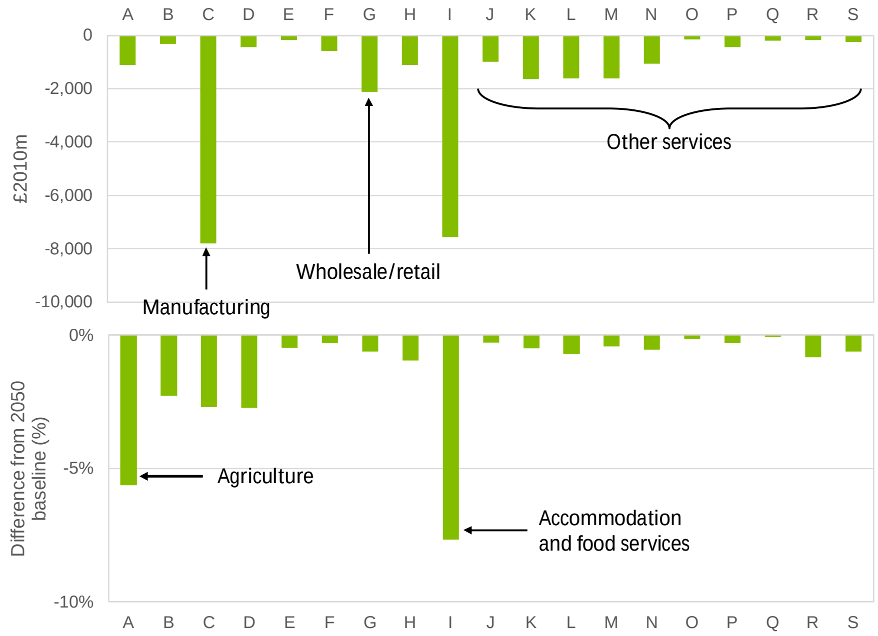
The results in Table 14 give a range of GDP impacts in 2050, with the largest estimated reduction approaching 1% (analyst-led results) and the smaller (data-derived) one around half that, at 0.5%.[81] The scale of the employment impacts is in a similar range (0.5% to 1.1%); or between 158,000 and 347,000 jobs. The overall macroeconomic effect is relatively small although some industries do see larger impacts than others.

The estimated impact on the CPI as a result of the doubling in global agriculture prices is an increase of 3.4%. While not modelled in the analysis above, the distributional impacts of this price increase would fall harder on lower-income households. These households spend a larger proportion of their budget on food (food has a larger weight in the basket of goods for these income groups). Consequently, these households will see a larger increase in the average price of goods and services that they buy. Conversely, higher-income groups will be relatively less affected, because food makes up a smaller proportion of their budget.

Figure 7 and Figure 8 report the gross value added (GVA) impacts by broad industry (SIC Section) for the two cases. Figure 7 reports the impacts from the analyst-allocated industry reductions, spread across elements of food processing and catering/hospitality. The distribution of the impacts follows largely from that allocation with reductions in GVA in manufacturing and accommodation/food services of close to £8bn. Wholesale/retail sees a fall in GVA of around £2bn and some other services in the wider economy (finance, business and professional services etc.) see similar reductions. These reductions in services were not specified by the analyst and are instead the consequence of supply-chain effects and how lower output reduces household incomes and consumption. However, in percentage terms, the industries most affected are agriculture (which is small but the scenario involves a reasonably-sized reduction in crop output) and accommodation and food services. Manufacturing is relatively less affected in percentage terms because food is only a part of the whole UK manufacturing industry.

[81] Strictly, the results reported are for GVA. GDP is GVA plus taxes less subsidies on products. The taxes/subsidies component varies by product but, in aggregate, and for the purposes of this exercise, the share is usually small and stable enough to interpret percentage changes in GVA as percentage changes in GDP.

Figure 7. GVA impacts of an acute shock to crops and livestock in 2050 by SIC Section (analyst-led)



In contrast, the data-derived approach leads to much lower impacts on accommodation and food services but also a somewhat lower reduction on manufacturing (see Figure 8). This can be explained by the way in which these assumptions constrain production among direct purchasers of agricultural products (such as food production) over industries whose dependence is less direct (accommodation and food services will tend to buy more from food production than directly from agriculture). This difference in the length of the supply chains also explains why the analyst-led results generates larger economic impacts than this data-derived case: longer supply chains require larger reductions in output to eventually transmit changes in demand back to the agriculture sector. Moreover, GVA tends to account for a larger proportion of gross output in services than in manufacturing. A given reduction in output will reduce GVA by relatively more in services (like accommodation and food services). Indeed, most of the difference in GVA impact between the two sets of results comes from the reductions in accommodation and food services.

Figure 8. GVA impacts of an acute shock to crops and livestock in 2050 by SIC Section (data-derived)

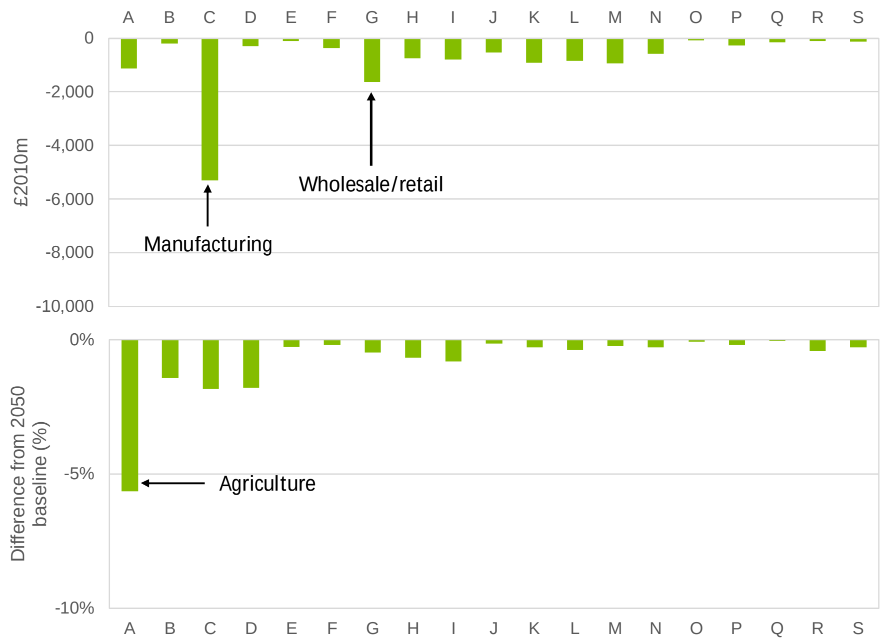
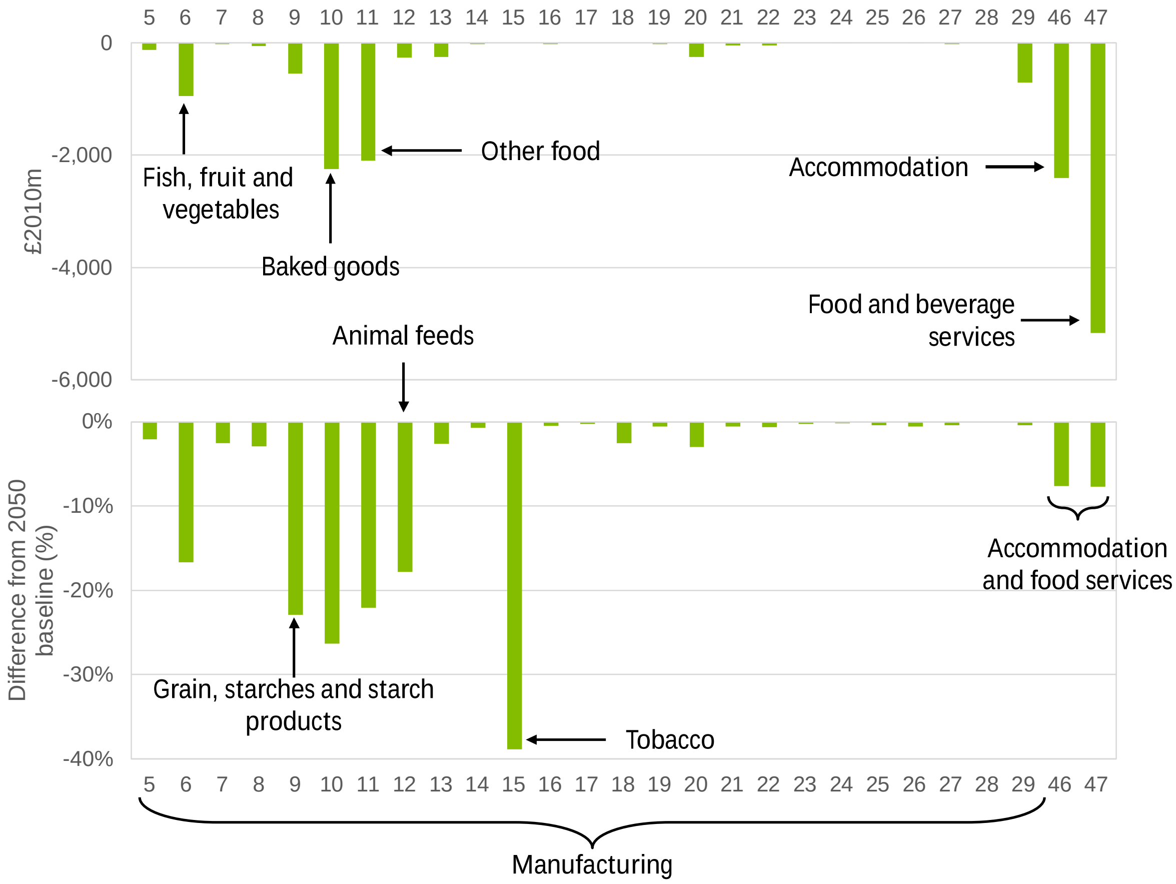


Figure 9 and Figure 10 present more detailed results for individual industries in the model. Figure 9 shows the results for manufacturing, and accommodation and food services from the analyst-led assumptions. While the monetary value of the reductions in accommodation and food services is large, because these industries are themselves large, the percentage reductions are comparatively mild.

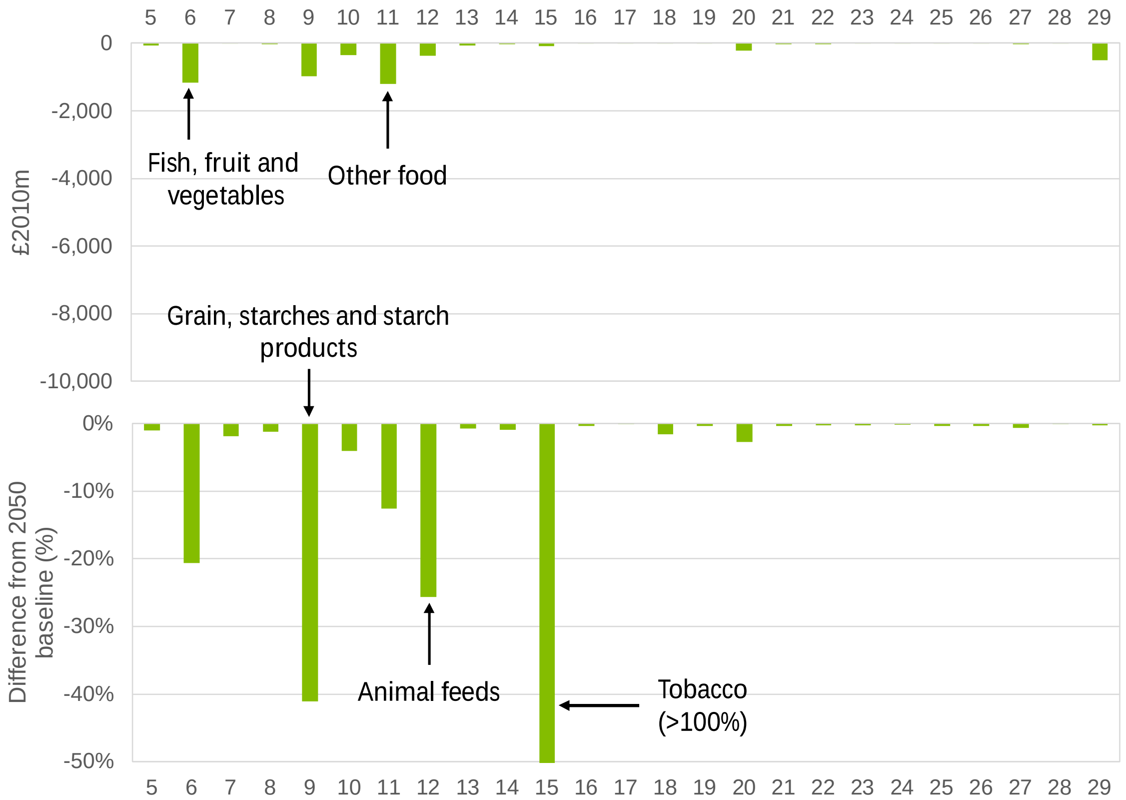
In manufacturing, small reductions in GVA can represent much larger proportions of the industries' output; 20% or more in some cases. These are large impacts and serve to highlight industries that would be exposed were such reductions in crop output to feed through to food production. No specific reduction was applied to the tobacco industry but the GVA reduction is large in percentage terms because the industry is projected to be so small in economic terms by 2050. At this scale, even small changes in output in monetary terms will generate large percentage changes.

Figure 9. GVA impacts of an acute shock to crops and livestock in 2050 for selected industries (analyst-led)



In comparison, Figure 10 shows a narrower range of industries affected. This allocation rule largely ignores downstream services like accommodation and food services and concentrates more of the impacts in fish, fruit and vegetables; grain, starches and starch products; and animal feed. The impacts on tobacco are, again, large in percentage terms owing to the small size of that industry by 2050.

Figure 10. GVA impacts of an acute shock to crops and livestock in 2050 for selected industries (data-derived)



In comparing the two sets of results it is clear that some industries will have to bear heavy reductions in output. Which industries will bear those reductions is an assumption that warrants further testing but the size of the GVA reductions in individual industries under the data-derived rule would seem to suggest that, without action, some of the impacts could be substantial (25-40% of these industries' GVA).

While these reductions follow from the previously-described analysis of the historical data, the scale of the effects makes it hard to believe that these effects could be allowed to happen without further responses.[82] In that sense, the figures reported here highlight the importance of action and/or response measures. However, some of those measures are likely already available as options in some industries, and a further question in a future stress test would be how large the difference is between the likely actions undertaken and the required actions.

From the analysis above, it seems reasonable to conclude that:

- The impact of an acute shock to crops and livestock in 2050 could reduce UK GDP by up to 1%, with an alternative set of assumptions (derived from the historical data) suggesting a somewhat lower impact of around 0.5%.
- By industry, the largest percentage losses in GVA are likely to be in the food-production industries; perhaps as large as 20% in some cases (from the analyst-led results). Smaller percentage reductions

[82] Remembering that the modelling framework assumes that inputs and outputs move in fixed proportions, precluding substitution or other ways to mitigate the effects.

could occur in catering and hospitality services but, because these are much larger industries, any losses in economic activity here would lead to larger reductions in GVA and jobs.

- Which industries bear the reductions most matters. Greater reductions in food production industries rather than catering/hospitality lead to relatively smaller economy-wide impacts. However, such an outcome implies substantial losses in individual industries, probably beyond the point where they might continue to be viable. Conversely, catering and hospitality services are larger industries, such that the necessary reductions constitute a smaller proportion of total output. However, the supply chains that lead back to the agriculture industry are longer, leading to an overall larger reduction in economic activity.

- Assuming a doubling of global agriculture prices in response to the shocks in multiple countries, an upper-range estimate for the increase in the CPI is around 3.5%. Lower-income households would likely face a larger average price increase than higher-income households.

In contrast to the acute case, the narrative for *chronic* degradation focuses mainly on livestock, as a result of land-use change (particularly the loss of upland livestock farming). Reductions in pollinators and soil quality contribute to some losses in crop output over time but the overall impacts on crops are much less than those on livestock. No additional costs were modelled to account for the possibility of attempts to maintain output in the face of these trends.

As with the acute scenario, lower production in the UK and abroad leads to higher prices. Because the input-output model is static and only looks at one year, the modelling approach is similar to the acute case in that it only looks at one year: 2050. However, the interpretation differs because the impacts examined in 2050 are assumed to have accumulated steadily over time rather than to have occurred suddenly in 2050. The analysis of chronic degradation should be interpreted as the impact *by* 2050, rather than *in* 2050. As in the acute scenario, the UK also diverts some exports to support domestic consumption. Unlike the acute scenario, there may be some scope to compensate with higher imports.

The narrative of the chronic decline in crops and livestock comprises, by 2050:

- A **reduction in agriculture output** that increases to £2.9bn in real terms (2010 prices), representing around 6% of the industry's gross output in 2050. As it happens, this is a similar scale of reduction to that in the acute case, but is assumed to be the cumulative impact by 2050, rather than the effect of a shock in 2050.

- Declining supply around the world leads to **persistent increases in prices**. As with the acute shock, in the absence of any further evidence to inform an assumption, global agriculture prices are assumed to grow to double what they might otherwise have been in 2050. This is, again, based on the experience of 2007-08 and the outcome for 2050 will be the same as in the analysis of an acute effect, though here it will have arisen steadily over time.

- Of that total reduction, £0.5bn of **exports are reduced (diverted to maintain domestic sales)**. This is around 12.5% of total exports. The percentage reduction is assumed to be twice that of the overall reduction to reflect UK producers' preference and attempts to support their domestic market.

Table 15 summarises these assumptions and, as with the acute shock to crops and livestock, the analysis considers both an analyst-led set of assumptions about how changes in agricultural output constrain other industries' output (implying reductions in final demand of around 25% in meat and dairy products; see Table 16) and a data-derived set based on the historical economic data. Because the historical data already reflects the dominance of meat and dairy products as purchasers of agricultural output, the only adjustment to the original calculation was to, again, set the share of oils and fats production to zero, reallocating it to the other food-production industries.

Table 15. Economic assumptions for chronic degradation to crops and livestock by 2050

	£2010bn	Share of 2050 baseline (%)
Reduction in agriculture industry gross output	-2.9	-6.2 (of gross output)
Of which diverted from exports	-0.5	-12.4 (of exports of agricultural products)
Remainder met by lower supply to industry	-2.4	-
Note: This scenario also assumes a doubling in global prices of agricultural products.		

Table 16. Analyst-led distribution of output reductions by industry under chronic degradation of crops and livestock by 2050

	£2010bn	Share of 2050 final demand (%)
Agriculture (Crop and animal production, hunting and related service activities)	-0.5	-2.4
Processing and preserving of meat and production of meat products	-4.2	-24.4
Dairy products	-2.2	-24.1

The model has nothing to say about the extent to which the UK might import additional food to maintain consumption. Assuming chronic decline in crops and livestock elsewhere in the world, it may not be plausible for the UK to make up the entire implied deficit with imports. In the analysis that follows, the results include an indicative figure for the additional imports that would be required to maintain household consumption. In a future stress test, the proportion of that figure that could reasonably be met in this way would be a matter of judgment on the part of the analyst.

The main results are presented in Table 17. These impacts are generally smaller than in the acute shock because supply chains for meat and dairy products are shorter and, compared to other food production, agricultural products make up a larger share of the meat and dairy industries' inputs to production. In this case, the analyst-led results suggest a reduction in GDP of 0.2% and a similar percentage reduction in employment (equivalent to 66,000 jobs). In contrast to the analysis of acute impacts, the results using the assumptions derived from the historical data are slightly larger than those from the analyst-led estimates: 0.3% of GDP and employment (just over 100,000 jobs).

Table 17. Summary economic impacts of chronic degradation to crops and livestock in 2050

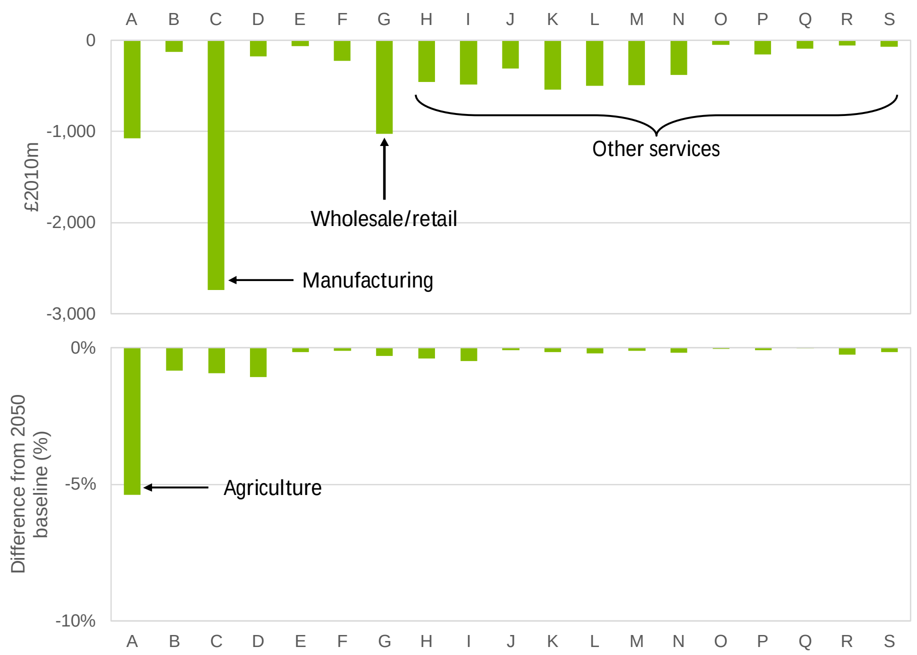
	Analyst-led	Data-derived
Change in GVA (£2010bn) (% of projected UK total in 2050; approximately equal to percentage of GDP)	-6.1 (-0.2%)	-9.0 (-0.3%)
Change in domestic final demand (£2010bn) (% of projected UK total in 2050)	-6.9 (-0.2%)	-9.9 (-0.2%)
Change in employment ('000s) (% of projected UK total in 2050)	-66 (-0.2%)	-102 (-0.3%)
Change in CPI (%) (from the doubling in agricultural product prices)	+3.4%	
Food imports required to compensate for lost domestic production (£2010bn) (% of projected UK total imports for final use)	6.4 (1.2%)	7.1 (1.3%)

The analyst-led set of results are somewhat larger than the data-derived ones because the data-derived assumptions spread out more of the impacts across the economy. The analyst-led assumptions concentrate the impacts in two industries (as listed in Table 16). This is clear at both:

- The broad industry level (Figure 11 and Figure 12) at which the data-derived assumptions generate more impacts beyond manufacturing, including wholesale/retail and other services.
- Within manufacturing (Figure 13 and Figure 14), with the analyst-led approach limiting the reductions to two food production industries while the data-derived approach applies reductions to a range of industries, not all of which might plausibly bear such reductions in a scenario of livestock decline (such as tobacco, as highlighted previously).

Figure 11. GVA impacts of chronic degradation to crops and livestock by 2050 by SIC Section (analyst-led)

Figure 12. GVA impacts of chronic degradation to crops and livestock by 2050 by SIC Section (data-derived)



To the extent that the analyst-led assumptions are arguably more plausible for the current narrative (of chronic decline in livestock), these results are perhaps closest to what could happen under this scenario. In any case, the two sets of impacts are quite small in aggregate though, again, GVA reductions approaching 20% would suggest that some industries could be left quite exposed if no further action is taken (or is possible).

Figure 13. GVA impacts of chronic degradation to crops and livestock by 2050 for selected industries (analyst-led)

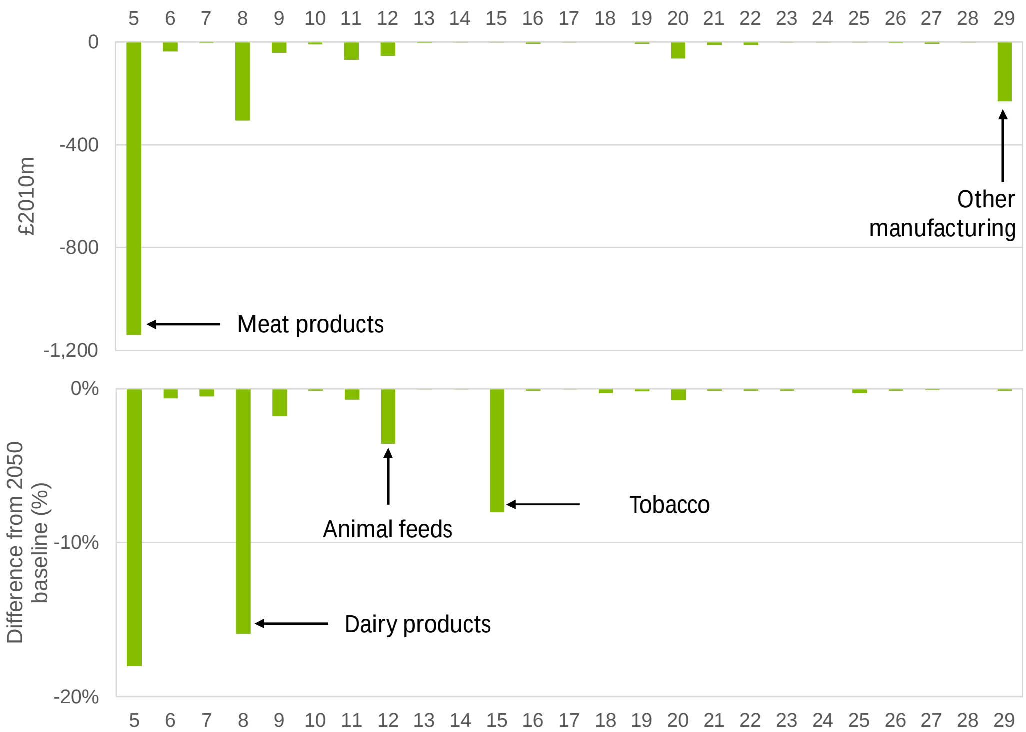
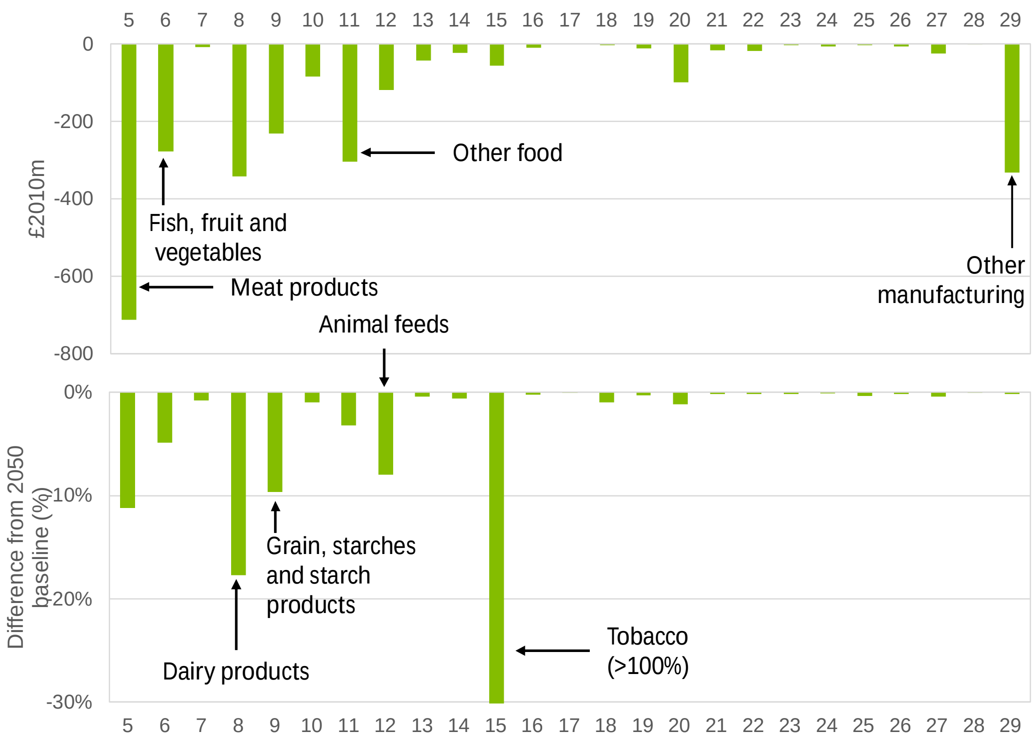


Figure 14. GVA impacts of chronic degradation to crops and livestock by 2050 for selected industries (data-derived)



From the results of the chronic crops and livestock analysis, one might conclude that:

- The reduction in GDP by 2050 is likely to be no more than 0.5%. This is smaller than the estimated impacts from an acute shock to crop production because supply chains for meat and dairy products tend to be shorter, limiting the wider economic impacts.
- Individual industries, however, could see moderate-to-large reductions in GVA. In the meat processing and dairy industries, the reduction could be 15-20% lower if chronic degradation is allowed to occur.
- A possible (adaptation) effect not captured in the analysis is the extent to which industries might restructure to produce alternatives such as less land-intensive livestock (e.g. poultry) or vegetable proteins. The analysis above assumes a simple reduction in productive potential under existing business models. While the impacts are small, they may be smaller still if industries shift their focus to alternative products.
- As with an acute shock, an eventual doubling of global agriculture prices as production falls could increase the CPI by as much as 3.5%. Again, lower-income households would likely face a larger average price increase than higher-income households.

Discussion and scope for improvement

The results from the analysis of acute and chronic effects on crops and livestock suggest that the overall impact in or by 2050 would be small at the level of the whole economy. There is no strong evidence to suggest that the impact could much exceed 1% of GDP or employment, although this is perhaps more a feature of the structure of the UK economy (the rest of the economy, particularly services, is just so much larger) than an observation about the unimportance of these ecosystem services. Moreover, at the level of individual industries, some of the impacts (assuming no action or response measures) could be large. Even if some of those impacts verge on implausibly large, the implication is clear that these industries are exposed to natural capital change and, one way or another, things could not continue as they are.

Of note with respect to the acute shock is that the 2007-08 crisis (the basis for the price effect analysed) was accompanied by socio-political unrest in countries in North Africa, the Middle East and South East Asia. The quantitative analysis did not attempt to interpret the results in the light of possible unrest. This is, however, a factor that that would need to be borne in mind were the stress test approach deployed in the future. The question here would be whether the impacts are likely to be of a magnitude that some threshold is crossed, leading to a social or political crisis.

Importantly, what the chronic analysis does not consider is the additional costs that agricultural producers might be willing to incur to offset at least some reductions in productivity. The scope for this is clearer for the small amount of lost crop output, for which farmers may choose to increase their use of pesticides and fertilisers. This would help to limit some of the output losses (at least for a time) and, depending on global price trends, such actions might squeeze profits (if higher costs cannot be passed on through higher prices) or lead to higher inflation (if costs are passed on to consumers).

Water supply

Change in service provision

The scenario tested in the pilot NCST aimed to quantify the potential scale of the impact of a reduction in water availability due to an acute drought event in 2050 made more severe by chronic growth in demand that exceeds the natural replenishment of water resources. Unlike crops and livestock, acute and chronic effects in water supply are not separable in this analysis. It is the chronic deterioration of the natural capital (paired with continued increases in water demand) that changes the severity of an acute shock, by reducing the capacity of the system to absorb that shock.

The chronic impact on water availability was estimated based on the CCRA 2017 projection that the balance of water supply relative to demand during low flow events will switch from a UK-wide surplus to a deficit by the 2050s[83] assuming: four degrees warming, a population increase of 10% to 83 million people, and a continuation of the current levels of adaptation. The figures are derived from an earlier piece of scenario analysis conducted by HR Wallingford. For the pilot stress test, the figures from the HR Wallingford analysis have been aggregated (approximately) to the twelve NUTS regions[84] of the UK. Water deficits by those twelve regions have then been calculated as the difference between projected supply and demand in 2050.

A summary of the results is set out in Table 18. The figures in the table set out the water deficit for a single day at low flows i.e. the level of river flow that is equalled or exceeded for 95% of the time (in this case calculated from 30-years of data). Zeroes indicate regions that would maintain a water surplus (i.e. incur no deficit) in the event of a low-flow event. The two columns of Table 18 correspond, respectively, to:

- A 'no degradation' case in which water reserves are maintained at their current levels to 2050.[85]
- A 'degradation' case in which water reserves are assumed to deteriorate over time, leading to progressively lower water availability to 2050.[86]

Water demand in 2050 is the same in the two cases and reflects an increase in demand over time from the assumed population growth in the overarching scenario, to 83 million people in that year. By holding demand constant in the two cases, the figures in Table 18 show how progressive degradation over time reduces the headroom (excess supply) in the system. In the event of a drought, the consequence of this chronic deterioration is more regions suffering a water deficit in the 'degradation' case compared to the 'no degradation' case. In this way, the chronic effect exacerbates the impacts of a drought. Were no degradation to occur, a drought in 2050 would push just four regions into deficit, implying a shortfall of just over 2,800 Ml/day (about 18% of projected daily water demand in that year). In contrast, were water reserves allowed to deteriorate, a drought in 2050 would push all but two regions into deficit, leading to an overall shortfall of almost 6,400 Ml/day (41% of daily demand).

The full set of calculations that underpins Table 18 is available in a separate Excel spreadsheet.

Table 18. Comparison of water availability in a low-flow event, with and without chronic degradation in water supply[87]

Region	No degradation: Water deficits during low flows in 2050 assuming water availability is maintained (Ml/day)	Degradation: Water deficits during low flows in 2050 assuming water availability declines (Ml/day)
East Midlands	-138	-387
East of England	-867	-1,196
London	-1,261	-1,292

[83] Hall et al. (2015), 'CCRA2: Updated projections for water availability for the UK Final Report.
[84] The Nomenclature of Territorial Units for Statistics (NUTS) is a geocode standard used by Eurostat for referencing the subdivisions of the United Kingdom of Great Britain and Northern Ireland for statistical purposes. There are 9 first level regions within England and one for each of Scotland, Wales and Northern Ireland.
[85] This case uses the water-availability figures from HR Wallingford's baseline/current analysis, based on data for 2014.
[86] This corresponds to Scenario 15 in the HR Wallingford analysis, representing a climate-change trajectory consistent with an eventual increase in global warming of four degrees Celsius and a continuation of current levels of adaptation.
[87] Hall et al. (2015), 'CCRA2: Updated projections for water availability for the UK Final Report.

Region	No degradation: Water deficits during low flows in 2050 assuming water availability is maintained (Ml/day)	Degradation: Water deficits during low flows in 2050 assuming water availability declines (Ml/day)
North East	0	-32
North West	0	-397
Northern Ireland	0	-54
Scotland	0	-532
South East	-549	-917
South West	0	-422
Wales	0	-1,162
West Midlands	0	0
Yorkshire and the Humber	0	0
Total	**-2,816**	**-6,392**
Deficit as % of total demand	**-18.1%**	**-41.0%**

By considering the change in water reserves only, the analysis that follows isolates the supply effect of a change in natural capital and how it alters the severity of a drought. In this way, the stress test applied here assesses the implications of no action to preserve UK water reserves. In this pilot case, the analysis assumes that a drought event in 2050 lasts three months.

Change in macroeconomic indicators

The changes in service provision above give the amount by which a drought in 2050 would create a water shortfall each day the drought continues. In the macroeconomic impact analysis, the annualised impact of a drought in 2050 is assessed on the assumption that a drought lasts for three months. Further, it is assumed that the drought is managed partly by some further depletion of water reserves, rather than wholly by a reduction in water supply to match the change in flow.[88] In percentage terms, were a drought to occur, the implied reduction in output of the water-supply industry in 2050 would be one-eighth of the deficits relative to total demand from Table 18.[89]

Table 19 summarises the input assumptions to the economic analysis. Reading from the top, Table 19 reproduces the totals and percentages from the earlier table of water deficits. The annual reduction in water-supply industry output is then given, at -2.3%, were a drought to occur but water reserves were maintained at current levels; and -5.1%, were a drought to occur and water reserves allowed to deteriorate. The impact of such a drought is roughly doubled by chronic degradation.

In monetary terms, the impact of a drought in 2050 without chronic degradation is a reduction in water-supply industry output of £234m (in 2010 prices). Chronic degradation would exacerbate the impact, leading to a real-terms reduction of £532m. Because water prices are regulated, no price changes have been modelled as

[88] This may further erode water reserves and reduce resilience to future droughts. The longer-term effects are, however, beyond the scope of the current pilot, which focuses on 2050 only.
[89] The percentages are divided by four, to reflect the three-month duration of the drought, and then halved, to represent the further depletion of water reserves to mitigate some of the reduced flow.

a response to supply restrictions. As mentioned previously, owing to a lack of data, the analysis excludes any increases in costs that might occur as water suppliers take steps to compensate for some of the degradation.

Table 19. Economic assumptions for an acute shock to water supply in 2050, with and without chronic degradation of water reserves

	No degradation	Degradation
Daily deficit (Ml/day)	-2,816	-6,392
Daily deficit as a share of total daily demand (%)	-18.1	-41.0
Annual change in water-supply industry output (%)[89] (Assumes a three-month drought and some mitigation by running down existing reserves)	-2.3	-5.1
Implied annual in water-supply industry gross output (£2010m)	-234	-532
Of which met by reduced household consumption (71%)	-167	-379
Remainder met by lower supply to industry (29%)	-67	-153

The historical data in the 2010 UK input-output table show that households account for 71% of the value of output of the water-supply industry, with industry accounting for the remaining 29%. This assumption is carried through to the impact analysis such that households bear a larger share of any restrictions, in line with their share of demand. This split is likely to be a strong assumption in the sense that industries are likely to bear relatively more in the way of reductions, much as they do now.

As with the analyses of crops and livestock, the economic impacts for water supply are estimated using the static input-output model developed for the pilot. This inherits the underlying assumption of fixed coefficients, implying no substitution and no scope for greater efficiency of water usage. From a behavioural/production perspective, industries are assumed to reduce their output in line with any restrictions in water usage. Industries are assumed to bear any reductions in proportion to their usage of water.

As explained above, the analysis of water supply involves a comparison of drought events in 2050 that differ in their severity. This difference in severity is the result of differences in total water reserves from (in)action with respect to climate change and adaptation. While there is always the possibility of a drought that restricts supply (the analysis in Table 18 suggests that some regions will see shortfalls in supply even if water reserves to 2050 are maintained at their current levels) the effects could be much worse without action to maintain these buffers (the headroom in the system). This is reflected in the implied reductions in output from the water-supply industry in the event of a drought, with and without degradation (Table 19), as well as the wider economic impacts from applying the input-output model (Table 20).

Table 20 shows the headline economic impacts of a drought in 2050 depending on the level of deterioration in water reserves. These are the results from two separate runs of the model. The table shows how a drought in 2050, *even if water reserves were somehow protected* ('no degradation') could reduce UK GVA by around £15bn and employment by some 156,000 jobs. This represents around 0.5% of UK GDP and a similar proportion of employment in 2050. The table also shows the impact of a drought if water reserves *were* allowed to deteriorate ('degradation'), around £35bn of GVA and 354,000 jobs. This is around 1% of GDP and employment.

The difference between the 'no degradation' and 'degradation' gives an indication of how much worse a future drought could be in economic terms if steps are not taken to maintain UK water reserves at their current levels. The impacts are more than doubled, from 0.5% of GDP and employment, to 1% or more. The results show how chronic degradation can exacerbate the economic impacts of an acute shock. A failure to act on diminishing water reserves exposes the UK to larger economic impacts: a further 0.5 percentage points of GDP, and almost 200,000 jobs would be at risk.

Table 20. Summary economic impacts of an acute shock to water supply in 2050, with and without degradation of water reserves

	No degradation	Degradation	Difference
Change in GVA (£2010bn) (% of total UK GVA in 2050; approximately equal to % change in GDP)	-15.2 (-0.5%)	-34.5 (-1.0%)	-19.3 (-0.5 percentage points)
Change in domestic final demand (£2010bn) (% of UK total in 2050)	-15.6 (-0.4%)	-35.4 (-0.9%)	-19.8 (-0.5 percentage points)
Change in employment ('000s) (% of projected UK total in 2050)	-156 (-0.5%)	-354 (-1.1%)	-198 (-0.6 percentage points)

A feature of these results that should be noted is the size of the overall economic impact compared to the initial shock. Depending on the case, the total GVA impact is a reduction of £15-35bn, from an initial change in water-supply output of £0.2-0.5bn (representing £0.2-0.4bn of GVA). The economy-wide GVA impact is almost 100 times larger than the initial GVA losses in the water-supply industry. The reasons for this are straightforward to identify in the modelling approach and rest on the underlying assumptions about how restrictions on water availability constrain production. What is less straightforward (and will be discussed in more detail later) is how some of these assumptions might be relaxed in future stress tests.

By broad industry group, Figure 15 shows the largest percentage reductions in GVA in Mining and quarrying (Section B), Electricity and gas (Section D), and Agriculture (Section A). However, these sectors are quite small in GVA terms and therefore contribute relatively little to the overall reduction in monetary terms. Larger GVA reductions in monetary terms take place in Manufacturing (Section C; £2.5-5.6bn), which is perhaps not surprising, depending on the specific industries, but also some services:

- Financial and insurance activities (Section K): £1.6-3.7bn.
- Public administration and defence; compulsory social security (Section O): £1.3-2.9bn.
- Education (Section P): £1.3-3.0bn.

Other services to see relatively larger GVA impacts from a drought include real estate, and various professional and business services (Sections L, M and N).

Because the economic model applied in this assessment is linear, chronic degradation of water reserves accentuates the industry-level impacts such that a doubling in size of the initial shock doubles each of the industry-level impacts.

Figure 15. GVA impacts of a drought in 2050, with and without degradation of water reserves, by SIC Section

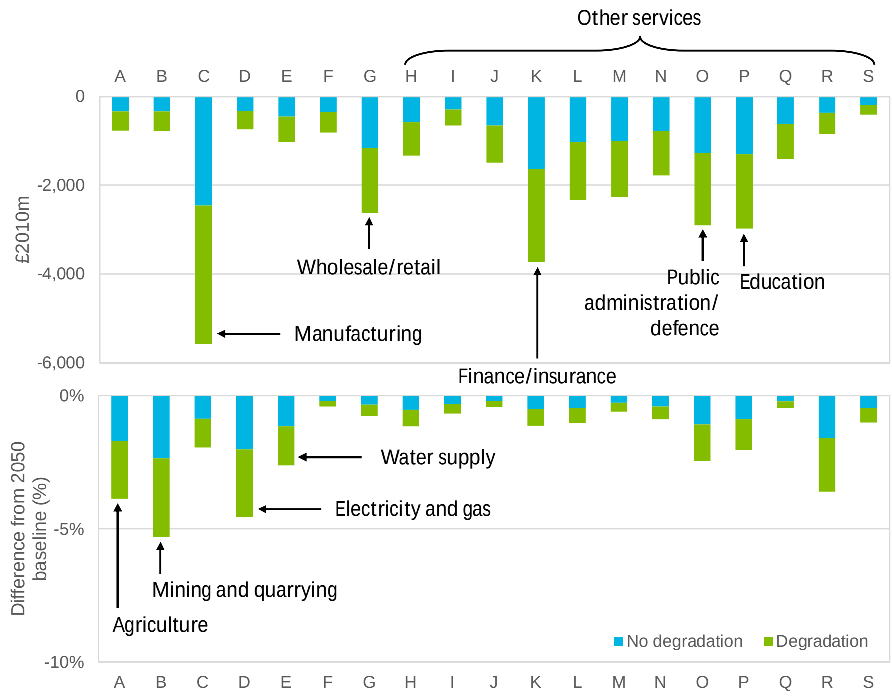
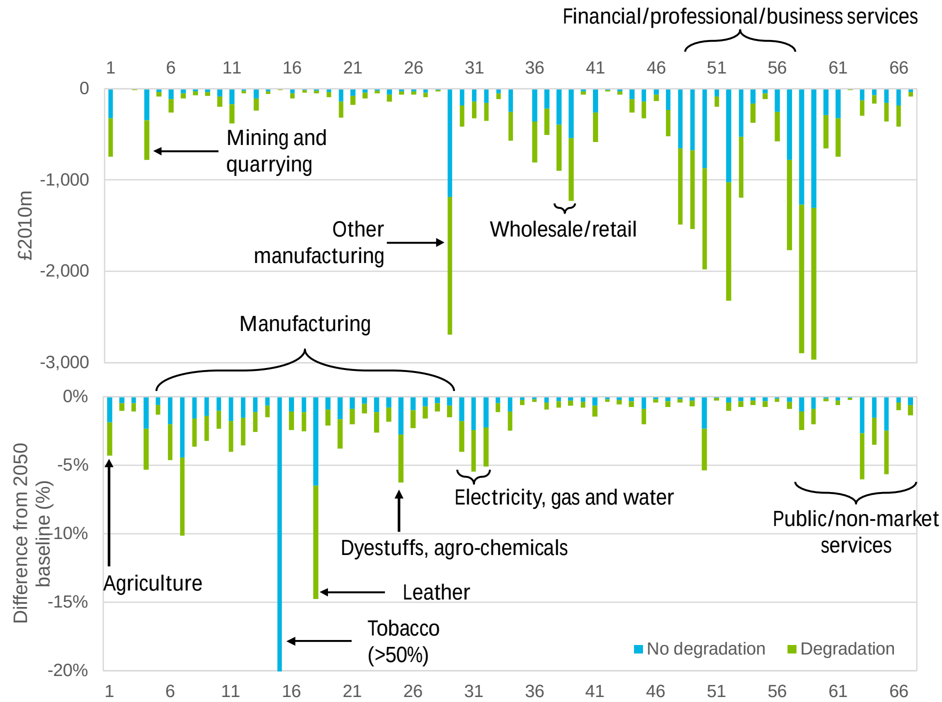


Figure 16 shows the more-detailed distribution of GVA impacts by individual industry from the input-output model. This chart shows how the GVA impacts in monetary terms are concentrated in the 'Other manufacturing' industry and various private and public services (consistent with the results by broad industry grouping). As with the earlier analysis of crops and livestock, the baseline that underpins the analysis projects sustained decline in the tobacco industry such that, by 2050, the industry is so small that even slight changes in output (of a few millions of pounds sterling in real terms) can represent large percentage changes.

Figure 16. GVA impacts of a drought in 2050, with and without degradation of water reserves, by industry



Discussion and scope for improvement

The review of possible changes in this ecosystem service yielded relatively little evidence on how some changes in natural capital might affect water supply. Just three of the eight possible impacts could be quantified (see Table 35 of Appendix A). Of those impacts, there was insufficient evidence to identify the need for, and associated costs of, additional water storage and treatment measures to compensate for natural capital losses. However, while the range of ecosystem-service changes quantified in this pilot might be narrow, there are reasons to think that those effects that were subsequently modelled yield estimates for the economic impacts that are at the upper end of the likely range.

On the face of it, the analysis of water supply above suggests that a relatively small change in water supply (up to £0.5bn or 5% of the water-supply industry's output in 2050) can lead to much larger impacts in the economy as a whole. The implied initial change in water-supply industry GVA (up to £0.4bn) can have an economy-wide impact almost 100 times larger (some £35bn), based on the idea that water is an essential input. Moreover, as mentioned previously, the assumption here is that households bear more of the restriction in water supply (71%) than businesses, in line with households' share of total water demand. This is a strong assumption because it is likely that businesses would bear relatively more of the reductions, as they do now. This would further increase the total economic impact by generating even larger knock-on effects through supply chains.[90]

Further investigation would be worthwhile, most likely with stakeholders, to better understand how supply restrictions might fall on businesses (particularly on specific industries) and households in the event of future droughts. This would improve on the treatment of supply restrictions used here (derived purely from the data) and give a better idea as to precisely where the initial impacts might fall, based on regulatory factors and the kinds of arrangements with water suppliers that different industries might have. The application of an input-output model could then be applied, as it was here, to identify the wider economic impacts.

Even without a more stakeholder-informed distribution of restrictions, the scale of the impacts seems on the large side, but is straightforward to explain in modelling terms. In a modelling approach in which changes in industry output are proportional to changes in the availability of inputs to production (the fixed-coefficients assumption), a restriction in supply for a small input can generate very large changes in output. Water is one such input, accounting for less than 1% of the value of any individual industry's output, and with just two industries for which that share exceed 0.5%. It therefore takes a large reduction in output across the economy to meet quite modest water-supply restrictions. This result is striking in the way that it yields large output reductions in industries like financial and public services; industries that one would not normally imagine as being dependent on water in the way that say beverage production is.

Despite the explanation from a modelling perspective, given the large size of the impacts for such a modest restriction on water-supply industry output, it is worth considering the economic logic of the underlying fixed-coefficients assumption. As already stated, the assumption of fixed coefficients (an assumption embedded in the input-output model) means that a change in the availability of an input to production translates, one for one, into a change in output. Such an assumption precludes:

- Substitution: In the absence of an input (or an increase in its price), firms in an industry cannot switch to alternative production methods that make use of more readily-available resources. Firms could not, for example, employ more labour to compensate for reductions in other inputs.

[90] At the other extreme, the water-supply restriction could fall entirely on households, leading to GVA impacts of £0.2-0.5bn and between 1,000 and 2,000 jobs. Impacts of this scale barely register at an economy-wide level. However, such an outcome does not constitute a plausible lower bound because water-supply restrictions that protect businesses at the expense of households in this way would be untenable.

- Increases in the efficiency with which firms use inputs to production or better management of resources in the event of a disruption: If these were options, firms would be able to produce the same amount of output for a smaller quantity of input(s) e.g. by taking steps to reduce waste or stockpile some resources.

In both cases, the fixed-coefficients assumption means that a reduction in the availability of an input forces firms to ratchet down their production. Of the two, a lack of substitutability could be reasonable for many provisioning ecosystem services. Crops are necessary to produce and sell certain fruit and vegetables. It is the second effect that seems harder to justify. This is because the fixed-coefficients assumption suggests that firms have no way of responding to a reduction in supply, not even on a temporary basis. In this situation, firms would have to reduce production rather than, for example, encouraging staff to work from home or, longer term, find ways to use water more efficiently.

While there is uncertainty as to how much efficiency is possible in the use of water (both in terms of the efficiency of supply through the network as well as by individual water consumers), it is hard to see there being no way at all to improve efficiency or manage an interruption in the ecosystem service. Given the regulated nature of water supply and the pricing of water, market forces to encourage efficiency are likely to be weaker and less able to incentivise agents to economise on usage. This is what sets water supply apart from crops and livestock, and why it seems harder to accept that there is little-to-no scope for efficiency gains.

Moreover, because the analysis concerns a heavy drought in over 30 years' time, it seems unlikely that the economy would be completely unprepared for such an event. Smaller droughts in the intervening years would surely signal the (growing) need for adaptation measures. It is for this reason that the impacts presented above are likely to be at the upper end of the possible range, by showing the potential losses of economic activity in the absence of any action on the part of businesses (or Government on their behalf) to cope with water shortages of growing frequency and severity over time. By assuming fixed coefficients in the analysis, the results would seem to highlight the need for action though, realistically, one would expect businesses to have at least some means to manage through a drought, and to be able to take some actions to lessen the impacts.

In this light, future work to improve the economic analysis of water supply carried out in this pilot could include:

- Improvements in the treatment of how water supply restrictions would fall on different consumers in the event of a drought, to identify more specifically, who would bear more or less of the initial impact.

- An extended modelling approach to relax the assumption that precludes the possibility of firms improving the efficiency of their water usage, whether generally (as it becomes apparent that water supplies are dwindling over time) or in the event of a drought. While the analysis here is able to show the potentially large impacts of no change in behaviour on the part of businesses, it would be useful to capture the response measures already available and used by businesses, so as to better gauge how much more action would be required to withstand a future drought.

- Work to better understand the scope for water efficiency at a system level (e.g. the extent of leakage) and the associated costs, to see where intervention on the part of the Government or Ofwat might be necessary.

- As was briefly mentioned before, one action included in the modelling is further depletion of water reserves to maintain at least some supply during the drought. This may have longer-term consequences by further eroding water reserves and increasing vulnerability to future droughts. Indeed, were this a standard response in the years leading up to 2050, the drought in that year could be worse than the modelling here indicates. It might be worth considering how a dynamic model of water stocks and flows could be linked to an economic impact model, or if there are ways to carry out the assessment using a wider range of methods.

In conclusion, while the analysis does suggest potentially large impacts relative to the modelled changes in water supply, these impacts represent a case in which no action is possible by firms to economise on water usage. The results therefore represent estimates towards the upper end of the likely range and should be treated with some caution in that respect. Given the remit of this pilot work, a relatively simple and transparent approach sheds some light on the issue but there is clear scope for improvement in the future. Future analysis to develop the approach would benefit from work to better understand what efficiency measures are already feasible and explore the implications of the fixed-coefficients assumption in the analysis carried out here. This further work would help to identify the need for further coordinated action, beyond what is already possible/likely.

Hazard regulation

Change in service provision

The scenario piloted in the pilot NCST aimed to quantify the chronic changes in the numbers of properties at risk of flood events and the change in the extent and magnitude of acute flood events by 2050. This was estimated based on the CCRA 2017 projections[91] of the changes in flood risk by 2050 assuming four degrees warming, a population increase of 10% to 83 million people, and a reduction in the current levels of adaptation.[92]

The results are set out in Table 21 and represent a combination of the change in the likelihood of acute flood events due to changes in the climate system, and a change in the magnitude of the associated impacts due to population growth, a reduction in the level of planned adaptation, and changes in the climate system.

Table 21. Cumulative change in flood regulation[93]

Aspect	Current	2050s	% change
No. residential properties at high risk of flooding[94]	1,073,286	2,454,715	129%
No. non-residential properties at high risk	533,590	772,041	45%
No. clean and wastewater sites at high risk	299	185	-38%
No. rail stations at high risk	580	685	18%
Length of road at high risk (km)	6,585	11,115	69%
Length of railway at high risk (km)	2,397	3,703	54%
No. power stations at high risk	24	16	-33%
No. substations at high risk	327	277	-15%
No. mobile phone masts at high risk	1,753	2,829	61%

[91] Sayers et al (2016). The analysis of future flood risk in the UK using the Future Flood Explorer (FFE). Proceedings of Floodrisk2016. Paul Sayers, Matt Horritt, Edmund Penning-Rowsell, Andrew McKenzie and David Thompson. E3S Web Conf., 7 (2016) 21005 DOI: http://dx.doi.org/10.1051/e3sconf/20160721005

[92] This scenario assumes that the adaptation effort as a whole reduces. Investment in traditional defences reduces (reflecting a reduction in the willingness to pay for defences from national tax revenues as flooding is increasingly seen as less of a national risk and more of a local one, but local funding fails to replace centralised investments). There is little take up of innovative catchment-based or urban run-off measures occurs, spatial planning becomes less rigorous (resulting in new development on the floodplain than currently is the case), and flood forecasting and warning systems and receptor level protection see low(er) levels of effectiveness and performance.

[93] Sayers et al (2016). The analysis of future flood risk in the UK using the Future Flood Explorer (FFE). Proceedings of Floodrisk2016. Paul Sayers, Matt Horritt, Edmund Penning-Rowsell, Andrew McKenzie and David Thompson. E3S Web Conf., 7 (2016) 21005 DOI: http://dx.doi.org/10.1051/e3sconf/20160721005

[94] 'High risk' defined as at risk of flooding more frequent than 1:75 years.

Aspect	Current	2050s	% change
No. care homes at high risk	438	780	78%
No. schools at high risk	1,112	1,652	48%
No. emergency services at high risk	249	410	65%
No. hospitals at high risk	94	127	36%
No. GP surgeries at high risk	563	993	76%
No. landfill sites at high risk	398	423	6%

Change in macroeconomic indicators

The original narrative for the hazard regulation analysis involved one or more flood events that cause damage to physical assets (housing, business premises, infrastructure etc.), leading to damage (and possibly insurance/financial) costs. The damage to these economic assets, in turn, disrupts productive and connective capacity in the impact area, leading to reductions in economic activity. A further source of costs would likely arise from emergency responses in the aftermath of the event(s) and the costs of recovery and reconstruction.

As Section 4.5 made clear, flooding is a local issue and a comprehensive assessment would likely involve case-by-case analyses of areas prone to flooding. This was a larger exercise than could be undertaken for this pilot. The alternative, adopted here, was to examine the economic impacts from a repeat of a past event, under assumptions about the future socio-economic structure of the economy. This contrasts with the analyses of the other two ecosystem services, which examined the impact of a natural capital shock, rather than the transmission mechanism. Across the three ecosystem services, there is therefore some analysis that tries to assess both sources of natural capital exposure (patterns of shocks from the environment, and transmission of shocks through the economy).

The analysis took, as its starting point, the impacts identified in a study for the Environment Agency on the impacts of the 2013/14 winter floods in England and Wales.[95] This impact is the result of a flood in a particular locality over a particular time period. The question the analysis then sought to ask was: 'under assumed changes in the configuration of the local economy (more houses and businesses on the floodplain), how might the impacts of the 2013/14 differ were an event of that magnitude to occur again?'.

A comprehensive assessment would likely apply GIS techniques to map out the area affected by the floods and then overlay the economic assets. From there, it would be possible to project a future version of that area, accounting for new build etc. and to (re)simulate the flood. In lieu of that, the analysis presented in Table 22 applies the growth assumptions from analysis for the 2017 CCRA[96] (as in Table 21), at the UK level, rather than at the level of regions affected by the 2013/14 floods. As an example, the analysis for the Environment Agency suggested a cost of damage to residential properties of £320m. The CCRA 2017 analysis in the selected scenario (four degrees warming; a population increase of 10% to 83 million people, and a reduction in the current levels of adaption) projects an increase in the number of properties of 129%. Assuming no

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[95] Chatterton, J., Clarke, C., Daly, E., Dawks, S., Elding, C., Fenn, T., Hick, E., Miller, J., Morris, J., Ogunyoye, F., Salado R. (2016), 'The costs and impacts of the winter 2013 to 2014 floods', Report for the Environment Agency, **SC140025/R1**: https://www.gov.uk/Government/uploads/system/uploads/attachment_data/file/501784/The_costs_and_impacts_of_the_winter_2013_to_2014_floods_-_report.pdf

[96] Sayers et al (2016). The analysis of future flood risk in the UK using the Future Flood Explorer (FFE). Proceedings of Floodrisk2016. Paul Sayers, Matt Horritt, Edmund Penning-Rowsell, Andrew McKenzie and David Thompson. E3S Web Conf., 7 (2016) 21005 DOI: http://dx.doi.org/10.1051/e3sconf/20160721005

change in the (real) average value of those properties[97], the potential damage of a similar series of floods in 2050 is estimated at £733m. Put another way, if the number of at-risk properties increases by 129%, the damage of a similar series of floods also increases by 129%.

This approach gives an indication of the likely change in impact as economic exposure increases. Moreover, the composition of that change in damage may also be revealing.

The first column of Table 22 reports the estimates directly from the analysis for the Environment Agency. The second column then reports the growth rates (change in extent) from the 2017 CCRA. The third column is the result of applying the growth rates to the historical damage estimates i.e. the estimated damage projected in 2050. The final two columns then calculate the share of each damage category in the final totals, in 2013/14 and 2050.

The results in the table suggest an overall increase in damage of 71%, from £1.3bn to £2.2bn (in 2013/14 prices). The two rightmost columns in the table compare the distribution of that damage across categories. The figures show that more of the damage is concentrated in housing (rising from 25% to 33%). The growth is similar for businesses but starting from a lower base (21% to 29%). Table 22 does, however, only apply growth rates to some element of the 2013/14 impacts. It is likely that some other components would also grow over time, such as those costs that relate to emergency measures.

Discussion and scope for improvement

Impacts that are not captured in this approach because of a lack of data/evidence are:

- The consequent losses in economic activity from the damage/disruption to economic assets.
- Increases in insurance costs (in effect, the annuitised version of the insurable damage costs).

It is important to note that this analysis does not show the impact of a UK-wide flood event. Instead, the analysis essentially replays the flooding seen previously in the south of England but with a different composition of economic assets on the floodplains. It is this that yields the alternative damage measure.

Table 22. Comparison of economic impacts of a flood in 2013/14 and 2050[98,99]

Category	2013/14 (£m)	Change in extent (%)	2050 (£m)	2013/14 (%)	2050 (%)
Residential properties	320	129	733	25	33
Businesses	270	135	635	21	29
Temporary accommodation	50	-	50	4	2
Motor vehicles, boats, caravans	37	-	37	3	2
Local authorities/local Government infrastructure	58	-	58	4	3

[97] This is fine to the extent that no inflation figures are applied on top of these impacts.
[98] Chatterton, J., Clarke, C., Daly, E., Dawks, S., Elding, C., Fenn, T., Hick, E., Miller, J., Morris, J., Ogunyoye, F., Salado R. (2016), 'The costs and impacts of the winter 2013 to 2014 floods', Report for the Environment Agency, **SC140025/R1**: https://www.gov.uk/Government/uploads/system/uploads/attachment_data/file/501784/The_costs_and_impacts_of_the_winter_2013_to_2014_floods_-_report.pdf
[99] Sayers et al (2016). The analysis of future flood risk in the UK using the Future Flood Explorer (FFE). Proceedings of Floodrisk2016. Paul Sayers, Matt Horritt, Edmund Penning-Rowsell, Andrew McKenzie and David Thompson. E3S Web Conf., 7 (2016) 21005 DOI: http://dx.doi.org/10.1051/e3sconf/20160721005

Category	2013/14 (£m)	Change in extent (%)	2050 (£m)	2013/14 (%)	2050 (%)
Emergency services	3.3	65	5.5	0	0
Flood risk management infrastructure/service	147	-	147	11	7
Utilities: energy	0.8	-24	0.6	0	0
Utilities: water	29	-38	18	2	1
Transport: road	180	69	304	14	14
Transport: rail	110	36	150	8	7
Transport: ports	1.8	-	1.8	0	0
Transport: air	3.2	-	3.2	0	0
Other communications (telecom)	-	61	-	-	-
Public health and welfare	25	63	41	2	2
Education	1.6	48	2.4	0	0
Agriculture	19	39	26	1	1
Wildlife sites	2.4	27	3.1	0	0
Heritage sites	7.4	-	7.4	1	0
Tourism and recreation	3.5	-	3.5	0	0
TOTAL	**1,300**	**71**	**2,226**	**100**	**100**

5.3 Supplementary analysis

For the first two ecosystem services considered in the pilot (provisioning services for crops and livestock, and for water supply), the analysis used input-output tables from the Office for National Statistics (ONS) to model the interdependencies between industries. It was by this approach that the analysis examined how changes in ecosystem services could have wider economic impacts through supply chains and from income/expenditure effects. The ONS only publishes such tables at the UK level and, consequently, the model developed for this project only generates impacts at a UK level. The model does not, by itself, provide estimates of any economic impacts at a regional level.

The first two pieces of analysis in this section show how the UK-level impacts from the main analysis could be disaggregated by region. This is shown for the acute shock to crops and livestock, and the effects of drought on water supply. The final piece of analysis assesses the sensitivity of the CPI in the crops and livestock cases to alternative price effects. This shows how the impacts in the model are (by design) linear such that a 50% increase in prices leads to a CPI impact that is half that from a doubling (100% increase) in prices.

Regional impacts of an acute shock to crops and livestock in 2050

Using ONS data on regional GVA and employment (for 2010), Table 23 and Table 24 disaggregate the GVA and employment impacts from the analysis of the acute shock to crops and livestock (the analyst-led results). The implicit assumption is that the impact by region is proportional to each region’s share of industry GVA. For example, in 2010, Scotland accounted for 16% of GVA in agriculture, forestry and fishing (SIC Section A). In the disaggregation of the UK-level results, that means that 16% of the UK reduction in agriculture GVA is assumed to occur in Scotland. The method is the same for employment, but using regional employment data, rather than regional GVA.

This is, of course, a relatively unsophisticated approach. A more detailed analysis would distinguish the different kinds of activity within agriculture, forestry and fishing in each region and form judgements about the relative exposure of each activity to the type of shock that is being tested, but this is beyond the scope of the present pilot.

As regions that account for higher shares of UK agriculture, areas like Scotland and the East of England bear larger reductions in agriculture GVA and employment than regions in which agriculture is smaller (such as the North East, and especially London). However, the UK-level analysis earlier in this report highlighted the supply-chain effects of the shock to crops and livestock. A region may still be exposed to economic impacts through these supply chains, even if there is relatively little agriculture in that region. This can be seen in the small reductions in agriculture GVA and employment in London but larger impacts in manufacturing (which includes food and beverage production) and especially accommodation / food services. The results for the North West tell a similar story, with a greater impact in manufacturing (the food, drink and tobacco component) than in accommodation / food services.

Based on the (proportional) disaggregation approach applied here, the column totals at the bottom of Table 23 and Table 24 suggest that, while agriculture-heavy regions in the UK could see large impacts on their agriculture industries, other regions may be indirectly exposed because of the way in which reductions in the availability of agriculture products have knock-on effects to other industries. The results suggest that, while the impacts on agriculture are larger in Scotland and the East of England (because their agriculture industries are larger), other regions might ultimately see larger total impacts, especially those that have large hospitality and catering industries.

Table 23. GVA impacts of an acute shock to crops and livestock in 2050, by industry and region (£2010m)

	London	South East	East of England	South West	West Midlands	East Midlands	Yorkshire and The Humber	North West	North East	Wales	Scotland	Northern Ireland
A - Agriculture, forestry and fishing	-6	-128	-173	-138	-98	-109	-111	-67	-36	-25	-183	-52
B - Mining and quarrying	-3	-3	-1	-6	-1	-3	-3	-3	-3	-1	-35	-1
C – Manufacturing	-601	-591	-750	-563	-650	-875	-851	-915	-231	-364	-1,007	-397
D - Electricity, gas, steam and air conditioning supply	-55	-65	-20	-37	-44	-36	-42	-37	-27	-21	-54	-7
E - Water supply; sewerage, waste management/remediation	-18	-27	-20	-18	-18	-13	-14	-17	-6	-11	-19	-4
F – Construction	-95	-93	-63	-48	-46	-38	-43	-57	-18	-22	-50	-14
G - Wholesale and retail trade	-315	-350	-219	-167	-168	-154	-154	-231	-62	-67	-160	-63
H - Transportation and storage	-241	-157	-106	-76	-83	-80	-86	-109	-31	-32	-86	-21
I - Accommodation and food service activities	-1,659	-1,056	-581	-716	-575	-373	-503	-792	-221	-279	-658	-159
J - Information and communication	-370	-223	-66	-52	-56	-31	-41	-70	-22	-17	-42	-11
K - Financial and insurance activities	-776	-163	-86	-99	-88	-44	-88	-115	-27	-29	-113	-21
L - Real estate activities	-499	-234	-149	-136	-101	-64	-87	-110	-33	-59	-116	-27
M - Professional, scientific and technical activities	-562	-268	-150	-103	-78	-68	-72	-144	-29	-30	-106	-19
N - Administrative and support service activities	-270	-160	-95	-76	-77	-71	-70	-104	-27	-29	-74	-16
O - Public administration and defence; compulsory social security	-22	-20	-11	-16	-9	-9	-11	-13	-6	-7	-13	-5
P – Education	-71	-70	-39	-34	-40	-29	-35	-46	-17	-19	-36	-12
Q - Human health and social work activities	-30	-26	-16	-16	-17	-13	-17	-23	-9	-10	-20	-6
R - Arts, entertainment and recreation	-50	-28	-18	-12	-11	-11	-12	-19	-5	-5	-18	-4
S - Other service activities	-53	-43	-25	-21	-18	-15	-15	-25	-7	-8	-16	-5
Total	**-5,697**	**-3,704**	**-2,590**	**-2,334**	**-2,178**	**-2,037**	**-2,255**	**-2,897**	**-817**	**-1,035**	**-2,805**	**-846**

Table 24. Employment impacts of an acute shock to crops and livestock in 2050, by industry and region (‘000s)

	London	South East	East of England	South West	West Midlands	East Midlands	Yorkshire and The Humber	North West	North East	Wales	Scotland	Northern Ireland
A - Agriculture, forestry and fishing	0.0	-2.1	-2.5	-3.6	-3.0	-1.4	-1.6	-1.8	-0.6	-1.7	-3.6	-2.0
B - Mining and quarrying	0.0	-0.1	0.0	-0.1	0.0	-0.1	-0.1	0.0	0.0	0.0	-0.6	0.0
C – Manufacturing	-3.1	-3.5	-4.0	-4.3	-4.8	-6.6	-6.1	-6.6	-1.8	-2.5	-5.5	-1.5
D - Electricity, gas, steam and air conditioning supply	-0.1	-0.6	-0.1	-0.4	-0.3	-0.3	-0.3	-0.4	-0.2	-0.2	-0.6	0.0
E - Water supply; sewerage, waste management/remediation	-0.1	-0.1	-0.1	-0.1	-0.1	0.0	0.0	-0.1	0.0	0.0	-0.1	0.0
F – Construction	-0.9	-1.4	-0.9	-0.7	-0.7	-0.6	-0.7	-0.9	-0.3	-0.4	-0.7	-0.3
G - Wholesale and retail trade	-2.9	-3.5	-2.5	-2.2	-2.2	-1.8	-2.0	-2.7	-0.8	-1.1	-1.9	-0.7
H - Transportation and storage	-2.4	-1.7	-1.4	-1.0	-1.2	-1.1	-1.2	-1.6	-0.4	-0.5	-1.1	-0.3
I - Accommodation and food service activities	-25.6	-20.2	-12.0	-16.5	-11.3	-9.4	-11.8	-16.0	-5.1	-8.0	-14.4	-4.1
J - Information and communication	-1.5	-0.9	-0.4	-0.3	-0.3	-0.2	-0.3	-0.4	-0.1	-0.1	-0.3	-0.1
K - Financial and insurance activities	-1.1	-0.4	-0.2	-0.3	-0.2	-0.1	-0.3	-0.3	-0.1	-0.1	-0.3	-0.1
L - Real estate activities	-1.1	-0.6	-0.5	-0.4	-0.3	-0.3	-0.3	-0.4	-0.2	-0.1	-0.3	-0.1
M - Professional, scientific and technical activities	-4.1	-2.6	-1.5	-1.2	-0.9	-0.9	-0.9	-1.6	-0.5	-0.5	-1.1	-0.2
N - Administrative and support service activities	-2.9	-1.9	-1.4	-1.0	-1.1	-1.1	-1.1	-1.6	-0.5	-0.5	-1.2	-0.3
O - Public administration and defence; compulsory social security	-0.3	-0.2	-0.1	-0.1	-0.1	-0.1	-0.1	-0.2	-0.1	-0.1	-0.2	-0.1
P – Education	-1.0	-1.2	-0.7	-0.7	-0.7	-0.5	-0.7	-0.8	-0.3	-0.4	-0.5	-0.2
Q - Human health and social work activities	-0.3	-0.4	-0.2	-0.3	-0.2	-0.2	-0.3	-0.4	-0.1	-0.1	-0.3	-0.1
R - Arts, entertainment and recreation	-1.0	-0.7	-0.5	-0.6	-0.4	-0.3	-0.4	-0.6	-0.2	-0.2	-0.5	-0.1
S - Other service activities	-0.9	-0.8	-0.5	-0.5	-0.4	-0.4	-0.4	-0.6	-0.2	-0.2	-0.4	-0.1
Total	**-49.3**	**-42.9**	**-29.5**	**-34.1**	**-28.3**	**-25.3**	**-28.6**	**-36.9**	**-11.5**	**-16.8**	**-33.5**	**-10.3**

Regional impacts of a drought in 2050, depending on degradation to water reserves

The regional disaggregation of the economic impacts of droughts applies a different method based on the pattern of water deficits in the 'degradation' and 'no degradation' cases. Table 25 reproduces the analysis of water deficits by region from the previous section (Table 17) and also reports:

- Each region's share of the water deficit in a drought, with and without degradation of water reserves.
- The GVA impacts by region from sharing out the UK-level results (from the analyst-led approach) using the deficit shares.

Note that the underlying assumption of this approach is that the economic impacts of a drought are confined to the regions that incur a water deficit. In practice this is an oversimplification: it is unlikely that the two regions that appear able to withstand a drought regardless of deterioration to water reserves would see no economic impact whatsoever, because its firms may form part of the supply chain related to producers in regions that are directly affected.

As an example, a reduction in water supply in the East of England would certainly reduce beverage production in the region, but the consequent reduction in beverage supply could affect a hotel or restaurant in the West Midlands, say. However, as a first approximation it seems reasonable to focus on the regions with the most severe water deficit.

Table 25. GVA impacts of a drought in 2050, with and without degradation of water reserves, by region

	Water deficit (Ml/day)		Share of total deficit (%)		GVA impact (£2010m)	
	No degradation	Degradation	No degradation	Degradation	No degradation	Degradation
East Midlands	-138	-387	4.9	6.1	-744	-2,087
East of England	-867	-1,196	30.8	18.7	-4,671	-6,451
London	-1,261	-1,292	44.8	20.2	-6,794	-6,968
North East	0	-32	0.0	0.5	0	-173
North West	0	-397	0.0	6.2	0	-2,141
Northern Ireland	0	-54	0.0	0.8	0	-291
Scotland	0	-532	0.0	8.3	0	-2,869
South East	-549	-917	19.5	14.3	-2,958	-4,946
South West	0	-422	0.0	6.6	0	-2,276
Wales	0	-1,162	0.0	18.2	0	-6,267
West Midlands	0	0	0.0	0.0	0	0
Yorkshire and the Humber	0	0	0.0	0.0	0	0
Total	**-2,816**	**-6,392**	**100.0**	**100.0**	**-15,172**	**-34,476**

By the method set out above, Table 25 highlights London's largely-unchanged (but also large) exposure to the economic consequences of a drought, whether or not local water reserves are protected at their current levels. In both cases, London seems exposed to the largest regional impact. In contrast, if water reserves were not maintained then most other regions see either an increase in the size of the GVA impact (a near-tripling for the East Midlands) or move from no exposure to some exposure. The impacts on Wales are particularly striking: -£6.3bn if water reserves are allowed to deteriorate. This impact would place it third, after London and the East of England. What makes this results striking is that Wales has a much smaller regional economy than the aforementioned areas, representing a larger impact relative to its size. These results follow from the initial analysis of water deficits.

Sensitivity of the UK CPI to changes in global agriculture prices

In the crops and livestock analyses, a doubling of global agriculture prices was modelled, based on the 2007-08 food crisis. This led to an increase in the CPI of 3.4%; an estimate at the upper end of the range owing to the assumption of 100% cost-price pass-through. The response of the CPI in the model to changes in prices is linear such that:

- A doubling (100% increase) in global agriculture prices (as in the main analysis for this pilot) increases the CPI by 3.4%, with 0.4 percentage points of that increase attributable to increases in import prices. The rest comes from domestic producers also doubling their prices.
- A 50% increase in global agriculture prices increases the CPI by 1.7%, with 0.2 percentage points of the increase coming from import prices. This is half the effect of the doubling in the main analysis.

In terms of the plausibility of any sensitivities, there is little evidence on the potential increases in prices as a result of the kinds of effects modelled above. What evidence is available from past reviews and modelling studies suggests that a doubling of prices as seen in 2007-08 is currently among the most extreme examples of global price increases. The effect of larger price increases would follow linearly but the extent to which such increases are likely, and might accompany such shocks, remains an area of further research.

6. Conclusions and recommendations

6.1 Conclusions

The development and piloting of an NCST approach in this study demonstrates that the loss or degradation of UK's natural capital could lead to significant impacts on the national economy by 2050 if actions are not undertaken to curb or adapt to the potential changes. These impacts could be particularly significant for the most at risk sectors, such as the food and beverages sector.

The study also demonstrates proof of concept for a stress test type approach to gauging the impacts of changes in natural capital on the economy. In particular, it demonstrates a method to prioritise the impact pathways selected for analysis; map the logic of cause-and-effect between changes in natural capital and economic impacts; establishes a model to trace through those impacts to macroeconomic indicators such as GDP and employment; and identifies the challenges posed to comprehensive quantitative modelling imposed by limitations on the present state of knowledge.

Critically, the approach developed and piloted in this project could support decision making for a wide range of Government and private sector stakeholders (see Table 26).

Table 26. Potential users of an NCST

Potential user group	Decision-making in which an NCST could be of use
HM Treasury	Supporting annual budgetary decision-making e.g. informing budgetary allocations and measures as well as Spending Reviews and Comprehensive Spending Reviews
Department for Health	Supporting decision-making and budget allocations around preparation for natural capital related public health challenges and estimating the potential costs of such impacts
Department for Business, Energy & Industrial Strategy	Informing the UK national infrastructure plan and industrial strategy e.g. identifying the contribution of natural capital to productivity/growth and mitigating risks
Local Enterprise Partnerships	Identifying risks to the growth of local economies and local employment and developing local growth strategies which take into account resilience of natural capital stocks
Cabinet Office	Updating the UK National Risk Register to account for environmental change and informing mitigation planning decisions
Defra	Informing the 25 Year Environment Plan for restoring natural capital, and identifying areas where market failures might require intervention and identifying priority metrics for monitoring natural capital (including with respect to economic impacts)
Environment Agency	Supporting decision-making relating to crisis preparation and undertaking national level risk assessments which incorporate the economic impacts of flood events
Foreign & Commonwealth Office	Informing the formulation of international economic, trade, security, and environmental policies
National Infrastructure Commission	Understanding the level of resilience of national infrastructure schemes to future natural capital risks
UK and international business	Identifying key vulnerabilities in cross-sectoral supply chains and developing more resilient supply chains

In order to improve the applicability of the NCST developed and piloted in this project, a number of practical steps could be taken to communicate and refine the approach:

- Workshops could be organised with the relevant Government departments to identify the most significant potential applications of the NCST, who might use the approach and when, and any modifications that might improve its value for specific applications.
- Businesses and sector associations could be invited to comment on the development of scenarios relevant to particular sectors, explore how the approach could align with the Natural Capital Protocol, and collaborate in adapting the process for business use.
- A multi-lateral discussion (or study) could be initiated to assess the extent to which Government and business will be able to adapt and respond to the potential natural capital changes and economic impacts identified through the NCST, in order to identify appropriate policy responses.

The pilot NCST undertaken in this project also demonstrated that there are significant uncertainties involved in estimating and quantifying the extent of natural capital risks and the impacts they could have on the economy. It should be emphasised that only a small selection of ecosystem services were examined in the pilot exercise and it was not possible to aggregate the various impacts across the three ecosystem services explored (due to the different assumptions and approaches used). As such, each estimate only represents a portion of the aggregate impact on the UK economy of changes in natural capital and the estimates should not be interpreted as a comprehensive estimate of the cumulative consequences of natural capital loss or degradation.

One of the lessons from this exercise has been that particular pathways of impact of ecosystem services change on the economy call for bespoke modelling that is tailored to the particular circumstances envisaged in each case. With the current state of knowledge, no single model seems capable of capturing the key features of the narrative for different ecosystem service changes. The analysis also encountered uncertainties over:

- The scale of loss of ecosystem services that should plausibly be considered.
- The possible breach of tipping-points or thresholds beyond which there would be a sharp deterioration in service provision.
- The ease with which firms can adapt to temporary or longer-term changes in resource availability or productivity.

As a result, the quantitative estimates produced by the modelling are inevitably subject to a degree of uncertainty. Drawing an analogy with financial stress testing, which assesses the resilience of financial institutions to tail-risk economic shocks, the aim of the exercise was to identify the potential exposure of the economy to a decline in ecosystem services that, as far as present knowledge permits, represents an eventuality that society should plan for. Unlike a financial stress test, this analysis cannot rely significantly on historical events to determine the parameters for the test because this is likely to be entering uncharted territory. Also, the set of potential impacts and interactions with regard to natural capital is far more complex.

Further work could be undertaken to begin to address some of these uncertainties and resolve some of the issues identified through the piloting. This might include, for example:

- Improving the evidence base to better describe the risks to the UK's natural capital and ecosystem services. This could involve undertaking primary research or aligning with existing research projects (such as the Climate Change Risk Assessment) to fill in key gaps in understanding.
- Creating a framework for the development of stress test scenarios. Such a framework may not only provide useful guidance for those involved in deploying an NCST, but may also facilitate consistent assessments that could be repeated periodically in the same way as financial stress tests are applied to banks.
- Expanding the scope of the NCST by piloting additional ecosystem services and exploring the extent

to which adaptation and behavioural responses on the part of businesses could be incorporated to provide a more realistic assessment of the economic impacts of changes in ecosystem service provision.

6.2 Limitations and caveats

While progress has been made through this study, particularly in linking impact metrics to existing economic indicators, it is important to clearly acknowledge that natural capital stress testing is a relatively novel concept and the approach set out here is necessarily exploratory. The process of designing and testing the approach has revealed a number of challenges, not all of which could be resolved within the scope of the current project, but none of which are considered insurmountable. Some of the key limitations with the approach set out in this report are identified below.

Step 1. Determining the scope of the stress test

- As it stands, the stress test is not designed with any one particular user in mind. Rather, it was designed to demonstrate proof of concept more generally. Future users of the NCST approach might therefore wish to tailor the approach to meet their specific needs.
- The pilot was limited to exploring three ecosystem services, which were selected through a rapid prioritisation process. This process assessed the magnitude of potential impacts or sector dependencies using a high, medium, low scale informed by a review of the literature and on the basis of expert judgment.
- The criteria used to determine the relevance of each ecosystem service to the economy, while all relevant, may unintentionally bias the selection of services to be included in the quantitative assessment. This is because only one criterion relates to the importance of the ecosystem service to the economy while four criteria relate to the availability of methodologies and data that allow for the quantification of impacts on ecosystem services. The current approach to scoring each ecosystem service using the criteria therefore introduces a bias towards including those ecosystem services (typically provisioning services) which are relatively well studied and more straightforward to model.
- There are generally few examples in the literature of analyses which identify the full range of natural capital impacts/dependencies relevant to a particular sector. In the absence of this understanding, it may be that important ecosystem service impacts/dependencies were missed with implications for the prioritisation of services for investigation through the modelling.
- Sectors were only assessed for vulnerability at the Standard Industrial Classification sector level. However, as noted in Section 5.5, it is at the individual industry level that the scale of impacts begins to clearly emerge. Using sub-sectors rather than top-tier sectors in the qualitative assessment would also provide a more detailed picture of relative exposure and, more importantly, a more accurate representation of the overall dependence of the sector (and overall economy) on each ecosystem service.

Step 2. Formulating the stress test scenario

- Formulating a ‘tail-risk’ scenario for natural capital is a highly subjective task. Professional/expert judgement must be applied to maintain the plausibility of the scenario, but the severity of the scenario must ultimately be set by the NCST user. The risk of subjectivity was addressed in the pilot through the application of already documented scenarios or projections, but this approach limits the scope of the scenarios where existing estimates of ‘tail-risk’ impacts are not available.
- The scenario development process drew on various projections for the 2050s. This decade was selected (rather than 2080s) for its greater anticipated relevance to decision-makers. However, this may risk ignoring longer-term impacts of current natural capital degradation trends.

- The scenario did not include anticipated responses from policy-makers or sectors. This approach was taken in order to limit the amount of speculation involved in the scenario development process, but might mean that some of the consequences associated with changes in natural capital are somewhat overstated. Nonetheless, it serves to highlight the scale of impact that might occur in the absence of adaptation responses, which, in turn, shows the importance of implementing those measures. The NCST therefore has an important role to play in highlighting the risks that policy-makers and businesses need to be aware of so they can put in place measures to manage those risks.

Step 3. Quantifying ecosystem service changes

- No modelling of the physical changes in ecosystem service provision was undertaken for the purposes of this project. Rather, this project drew on the findings of published scientific studies that have devoted significant resources to understanding and modelling the relationships between natural capital and ecosystem service flows. The quantification of changes in ecosystem service provision in this study is therefore limited to the information that is readily available in the published literature.

- The available literature rarely documents the likelihood of declines in ecosystem services occurring in a systematic fashion. While the stress test does not require an indication of likelihood, an indication of probability is important to select ecosystem service changes that are compliant with the 'tail-risk' criteria and consistent with the plausible-worst case scenario.

- Changes to ecosystem service provision over time were assumed to be linear and therefore ignore any potential threshold effects or tipping points, for example, where ecosystems are stressed beyond the point from which they are able to recover, or where there is a step-change in ecosystem service productivity as a result of a shock or stress.

- Due to data limitations, it was not possible to quantify all of the potentially significant changes to the piloted ecosystem services. Likewise, the loss of biodiversity and the related loss of resilience are not represented in the quantification due to the complexity of the task and the paucity of data.

- The scenario assumes the occurrence of several different negative effects taking place in one particular year (e.g. agricultural disease outbreak, flooding etc.). The likelihood of these events occurring simultaneously is not quantified and may be low.

Step 4. Valuing economic impacts

- International ecosystem service change impacts are less well documented than UK ecosystem service changes. Given the UK trade balance, these changes could have significant impacts on the UK economy. However, there are few robust projections of how such changes would affect world markets and import availability.

- The allocation rules (that is, how reductions in outputs are distributed across final consumers) were kept purposefully simple for this exercise. The allocation rules can, however, make a large difference to the overall impacts and therefore further work to develop the sophistication and realism of the allocation rules based on additional market information is warranted. Likewise, the economic impact modelling (for water supply) assumes that there are no substitution effects and no changes to the efficiency with which water supplies are used as an input to production.

- In a more comprehensive stress test, the allocation rules and assumptions with regard to substitutability would ideally better reflect regulatory factors (for example, some industries might come to arrangements or be required to bear more or less of the burden associated with ecosystem service change) or other behavioural factors (in the event of extreme changes, firms might find substitutes or economise on inputs).

- The range and extent of behavioural responses (including adaptation) included in the modelling and analysis are limited, largely by the availability of data. As noted in Section 3.2, certain actions (behavioural responses) could mitigate or amplify certain effects which means that some of the impacts reported in the pilot exercise may be somewhat overstated. However, this is offset by the fact that many aspects of risk have been excluded in the analysis, due to lack of information as discussed above, and which would lead the analysis to under-estimate potential economic impacts.

6.3 Recommendations

The results of the pilot exercise (Section 5) demonstrate that an NCST is a feasible approach for exploring the scale of the impacts on the economy associated with changes in natural capital, although there are limitations. An overview of the key recommendations for addressing these limitations is set out below.

Step 1. Determining the scope of the stress test

- As the ability to model ecosystem service changes improves, the feasibility of modelling should become less of a priority when selecting the ecosystem services to include. The full value of an NCST will be realised with the inclusion of progressively more ecosystem services.
- The sector review process might be conducted more robustly if sector associations or businesses from several sectors were involved in the scoping process.
- The sector review would be improved by splitting sectors into sub-sectors, as exposure to natural capital risk can vary significantly within sectors.
- The lack of sector-specific natural capital risk assessments (at time of writing) makes the scoping process more labour-intensive. Such assessments would be valuable resources for sectors, and could contribute to the individual efforts of businesses applying the Natural Capital Protocol.

Step 2. Formulating the stress test scenario

- The scenario used for the purposes of the NCST should be developed to be able to address the specific interests of the user. These should be clarified at the outset, and the scope of the test (in terms of the plausibility and severity of the changes) should be similarly fixed. An expert workshop might offer an effective and efficient way of defining the parameters of the scenario and, as noted previously, can help to establish credibility.

Step 3. Quantifying ecosystem service changes

- The CCRA and other assessments that are conducted and published on a regular basis and that make use of consistent approaches have the potential to provide an ideal evidence base for a NCST. Where there are specific policy questions to be addressed by an NCST that could be evidenced through these routine assessments, there may be an opportunity to ascertain whether the scope and outputs of these assessments could be adjusted in such a way that they could provide the data necessary to inform more routine application of stress testing.
- Future research commissioned on UK ecosystem service change could be encouraged, where appropriate, to include projections or scenarios that are compatible with CCRA evidence.

Step 4. Valuing economic impacts

- The current assumptions around substitution effects (and potentially substitution between forms of capital) and resource efficiency could be refined to provide a more realistic assessment of the economic impacts of changes in ecosystem service provision.
- More sophisticated allocation rules could be developed to represent more accurately the distribution of reductions in outputs across final consumers.
- More work is required to understand and model behavioural responses of different users to changes in ecosystem service provision.

Next steps

Following the release of this report, and the NCST approach which it contains, an appropriate next step may be for the intended users of the NCST to pilot the approach, report back on its fitness-for-purpose, and recommend how the approach could be fine-tuned to better address their specific needs.

In addition, there are several areas of work that could be undertaken more immediately to refine the approach prior to its uptake by decision-makers. These include:

- Holding a meeting/workshop to present and discuss the report findings with UK Government departments, and discuss next steps that could be taken. For example, this could involve the UK Government (perhaps led by HM Treasury and/or the NCC) setting up an initiative to explore how the NCST developed in this project could be further developed/adapted by Government departments.
- Undertaking further piloting with all of the eight identified priority ecosystem services. This would better demonstrate the capacity of the NCST to comprehensively describe potential impacts of changes in ecosystem service provision that happen in combination.
- Developing a framework for formulating stress test scenarios. This might involve the design of expert workshops and a process for systematically reviewing recent peer-reviewed and grey literature. Such a framework could not only provide useful guidance for those involved in deploying an NCST, but might also facilitate consistent assessments that could be repeated periodically in much the same way as financial stress testing is applied to banks.
- Undertaking ecological modelling to better describe the non-linearity in UK ecosystem service delivery as natural capital deteriorates (this could align with any existing projects).
- Adapting the approach to better address the needs of business users, perhaps through a joint collaboration with the Natural Capital Coalition.
- Developing guidance for research institutions to better steer natural capital and ecosystem services-related research towards generating outputs that facilitate natural capital stress testing.

It is clear that more work is required to develop the natural capital stress testing approach further, to improve the robustness of results and increase its applicability. However given that the economic risks highlighted in this first pilot testing exercise are quite significant, some additional investment in this approach appears to be warranted.

Appendix A. Methodology for developing the approach

Overview

This section provides a more detailed overview of the method taken in this project to develop and pilot an approach to undertaking an NCST.

Initial review

In order to inform the design of the approach to undertaking an NCST and identify where it might be useful to decision makers, a review of the literature was undertaken drawing on the following key sources:

- Anger et al. (2014), 'UK National Ecosystem Assessment Follow-on. Work Package Report 2: Macroeconomic implications of ecosystem service change and management: A scoping study'.
- eftec (2016), 'Developing a UK national economy natural capital stress-test'.
- HSBC (2013), 'Natural Capital: Identifying implications for economies'.
- Natural Capital Declaration (2015), 'Towards including natural resource risks in cost of capital: state of play and the way forward'.
- Nous Group (2014), 'The Future Economy Project: The economic impact of diminishing natural capital in Victoria'.
- Ofwat (2016), 'Monitoring financial resilience'.
- Stern (2007), 'The Economics of Climate Change: The Stern Review'.
- The Bank of England financial stress testing reports.
- The Natural Capital Committee 'State of Nature' natural capital reports.
- Trucost reports on natural capital exposure risk for various economic sectors.

In addition to the literature review, a series of semi-structured interviews were held with key stakeholders and technical experts including:

- **Annela Anger-Kraavi** – Lecturer in Economics at Cambridge University and lead author of the UKNEA-FO work package on macroeconomic implications of ecosystem service change.
- **Colin Smith** – Economic Advisor, Defra.
- **Helen Dunn** – Former Economic Advisor, Defra.
- **Mark Gough** – Executive Director, Natural Capital Coalition.
- **Paul Ekins OBE** – Professor of Energy and Environment Policy, University College London.
- **Peter Costigan** – Former Deputy Director and Science Co-ordinator for Natural Environment Evidence, Defra.

Two workshops were held on 13 December 2016 and 23 January 2017, respectively, to discuss the proposed scope and methodology with key stakeholders from a range of Government departments, academic institutions, private sector organisations, and NGOs. A full list of attendees is set out in Table 27.

Table 27. Workshop attendees

No.	Name	Organisation
1	Karen Ellis	WWF-UK
2	Toby Roxburgh	WWF-UK
3	Steve Smith	AECOM
4	Petrina Rowcroft	AECOM
5	Chris White	AECOM
6	Max Heaver	AECOM
7	Richard Lewney	Cambridge Econometrics
8	Chris Thoung	Cambridge Econometrics
9	Annela Anger-Kraavi	University of Cambridge
10	Julian Harlow	Natural Capital Committee Secretariat
11	Peter Costigan	Former Deputy Director at Defra
12	Colin Smith	Defra
13	Alastair Johnson	Defra
14	Henry Leveson-Gower	Defra
15	Neha Dutt	Defra
16	John Ayre	Defra
17	Phil Cryle	eftec
18	Eoin Sinnott	Valuing Nature Initiative
19	Steve Arnold	Environment Agency
20	Hannah Pitts	World Business Council on Sustainable Development
21	Ulrike Hotopp	Simetrica
22	Katherine Bolt	RSPB
23	Michael Sheren	Bank of England
24	Richard Hardwicke	Trucost / Standard & Poor's

The results of this exercise confirmed that natural capital stress testing is a new and emerging area which could be undertaken in a number of different ways and could have a range of different policy applications and potential users.

The broad consensus that emerged from the scoping exercise was that there is currently a gap in the evidence in terms of establishing clear, quantifiable links between changes in natural capital and macroeconomic indicators. This was raised in eftec (2016) 'Developing a UK national economy natural capital stress-test', in the UKNEA-FO report on the macroeconomic implications of ecosystem service change, as well as by the NCC in their advice to the Government on research priorities which stated:

"The impact of changes in natural capital upon conventional measures of UK economic performance remains an open empirical question…this topic explicitly focusses upon conventional financial measures of jobs, growth, and economic activity. It therefore excludes non-market economic and socio-cultural measures of wellbeing.

Key questions:

- *How do changes in our natural capital affect measures such as national income, growth and jobs both directly and indirectly?*
- *What sort of frameworks do we need to examine, measure and model these links effectively?*
- *How do these changes vary across the short- and long-term?"*[100]

It was also identified during the scoping phase that understanding the impact of potential changes in natural capital on macroeconomic indicators would be a useful and important policy question to answer for decision makers in Defra, Treasury, and other Government departments; with one of the workshop respondents stating that, *"ultimately, the issues that keep decision makers awake at night are GDP, unemployment, and inflation".*

From this exercise it was decided that the primary focus of an NCST for the UK should be on developing a method that could be used to assess how future changes in natural capital could potentially affect the headline macroeconomic indicators for the UK economy.

A further issue that was raised during the scoping phase was that one of the challenges with this approach is that it may be difficult to identify observable impacts on macroeconomic indicators at a UK wide level from natural capital change, and that relying on UK wide indicators might mask important impacts on particular economic sectors. Providing more detailed analysis on a sectoral level was therefore identified as being useful in providing a clearer picture of the risks. It was also identified that this might encourage businesses operating within high risk sectors to undertake more detailed stress testing to identify the extent of the risks to their operations. As such, in addition to the headline figures provided for the UK economy, it was decided that sectoral impacts of changes in natural capital would also be explored using the stress test approach.

Identifying sector dependence on ecosystem services

Alongside the literature review, interviews, and workshops, a mapping exercise was undertaken to identify the level of ecosystem service dependence by economic sector. This task was based on a recommendation set out in the UKNEA-FO which states:

"Given the complexity of ecosystems and the economic system and that the stocks and flows of natural capital are still largely unknown, a reasonable first step would be identifying the links between final ecosystem services and economic sectors. This could be done by constructing a matrix with ecosystems services (rows) and economic sectors (columns) in order to map the potential inputs from ecosystem services to economic sectors."[101]

Following the UKNEA-FO guidance, a matrix was developed using the Common International Classification of Ecosystem Services (CICES) Version 4.3[102] (note this does not include abiotic services from natural capital

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[100] Natural Capital Committee (2015), 'Advice to Government on research priorities'.
[101] Anger et al. (2014), 'UK National Ecosystem Assessment Follow-on. Work Package Report 2: Macroeconomic implications of ecosystem service change and management: A scoping study', UNEP-WCMC, LWEC, UK.
[102] Available to download at: http://cices.eu/

such as minerals or fossil fuels) and the UK Standard Industrial Classification of Economic Activities 2007.[103] The dependence of each economic sector on each ecosystem service was then assessed using a simple scoring system: High = 2; Medium = 1; and Low = 0.

The scores were aggregated across the services to give a total score for each economic sector. The sector was ranked as 'high' if the score was in the top tertile, medium if in the middle tertile, and low if in the bottom tertile. A similar process was also used to identify the aggregate level of dependence of the UK economy on each ecosystem service.

The assessment was undertaken using professional judgement, with rapid literature reviews being undertaken for sectors for which there was a significant degree of uncertainty. The scores were then reviewed and sense-checked internally. A summary of the results is provided in Table 28 and the full results are available in Appendix B.

Table 28. Economic sectors with high (l) or medium (l) dependence on ecosystem services

Economic sector
l = Agriculture, forestry and fishing
l = Water supply; sewerage, waste management and remediation activities
l = Manufacturing
l = Accommodation and food service activities
l = Arts, entertainment and recreation

The findings were presented at the workshop on 13 December 2016 and there was a general consensus that, while this is a simplistic, qualitative scoring approach, the findings nonetheless provided a reasonable reflection of the dependence of the UK economy on ecosystem services.

In order to build on this approach it was noted that future assessments could be undertaken which disaggregated each economic sector by sub-sector. Further assessments could also be undertaken which move beyond a simplistic high, medium, low scoring system and draw more heavily on quantitative data to establish sector dependence; potentially drawing on the results of the quantitative stress test model once developed.

Identifying priority services

Once a high level overview of the dependence of each economic sector on ecosystem services in the UK had been established, the next step was to draw on this information to identify which services should form the starting point for developing and piloting the NCST approach. Identifying a core number of priority services to focus on in more detail was important at this stage given that CICES v4.3 includes 48 distinct ecosystem services, some of which have limited relevance to the UK economy and some of which are relevant but are difficult to quantify in economic terms.

A prioritisation exercise was therefore undertaken using the method set out in Khan et al. (2013)[104] and White

[103] Available to download at: https://www.gov.uk/Government/publications/standard-industrial-classification-of-economic-activities-sic
[104] Khan, J., Greene, P. and Wei Hoo, K. (2013) Measuring UK Woodland Ecosystem Assets and Ecosystem Services [online] available at http://www.ons.gov.uk/ons/guide-method/user-guidance/well-being/publications/measuring-the-uk-woodlands-ecosystem.pdf

et al. (2015).[105] This approach involved assigning a score to each ecosystem service of: High (2); Medium (1); and Low (0) against the following criteria:

- Whole-economy relevance (drawing on the results from Step 1).
- Policy relevance.
- Relative risk to future provision.
- Availability of methods for physical terms analysis.
- Availability of methods for monetary terms analysis.
- Availability of data for physical analysis.
- Availability of data for monetary analysis.

An aggregate score was calculated and each service was ranked as 'high' if the score was between 9 and 14; 'medium' if between 5 and 9; and 'low' if between 0 and 5. The scoring was based on professional judgement and was 'sense checked' through an internal review process.

As set out in Table 29, the results of the prioritisation exercise identified eight 'high' priority services (note, for ease of interpretation a simplifying classification framework has been used to present the results, the full results using the CICES v4.3 classification, are available in Appendix B). A further prioritisation exercise was then undertaken to identify three services to focus on for the purposes of piloting the NCST approach. The selected services were identified as: crops and livestock; water supply; and flood regulation. The reasoning for the selection of these three services is set out in Table 29.

Table 29. Ecosystem services prioritised for inclusion in the pilot stress test

Ecosystem service	Further prioritisation exercise	Selected for piloting?
Crops and livestock	High policy relevance, significant impacts on future provision, good approaches for quantification, and demonstrated impact on macroeconomy (2007/08 food price spikes)	ü
Fisheries	Similar type of service to 'crops and livestock' although more challenging to detect an impact on the wider economy and more difficult to quantify impacts on future provision	û
Timber	Challenging to identify a scenario leading to a change in timber provision that is detectable at an economy wide level	û
Water supply	Significant impacts on future provision of service and potential for diffuse impacts whereby the whole economy becomes more vulnerable as a result of water scarcity	ü
Air quality regulation	Growing policy interest in this service although challenging to link to macroeconomic indicators	û
Flood regulation	Key issue for a range of economic sectors, significant future impacts on this service from a changing climate, and likely to be possible, although challenging, to quantify	ü
Global climate regulation	While an important service, a stress test would be unlikely to add value given previous and ongoing efforts in this area	û

[105] White et al. (2015), 'Developing ecosystem accounts for protected areas in England and Scotland: Main Report', Department for Food, Environment & Rural Affairs/The Scottish Government.

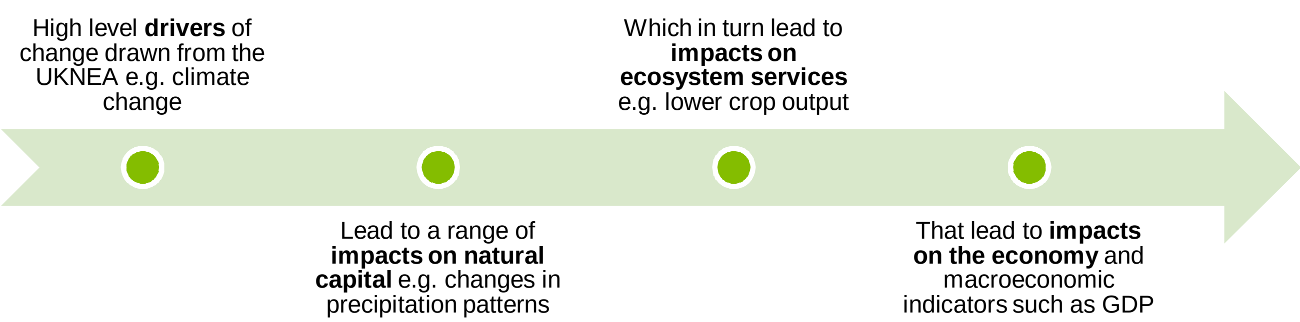
Ecosystem service	Further prioritisation exercise	Selected for piloting?
Tourism and recreation	Significant economic sector although challenging to identify natural capital scenarios which impact the ‘quantity’ rather than the ‘quality’ of the service	û

The findings were presented at the workshop on 13 December 2016 and there was a general consensus that the three services identified for inclusion within the NCST approach were reasonable given that they reflected both chronic and acute effects and are associated with relatively un-contested approaches to monetary valuation and, as such, would allow demonstration of proof of concept.

Developing an underlying structure for the NCST

With the priority services identified for inclusion within the model, the next step was to develop a framework for linking high level drivers of change in natural capital (under various scenarios) to macroeconomic impacts in order to provide the underlying logical structure for developing the NCST approach. An outline of the framework developed is set out in Figure 17.

Figure 17. Outline of underlying logic framework



Using this structure, impact pathways were developed for each of the three services as set out in the diagrams overleaf.

The proposed logical structure of the approach using the three impact pathways was presented at the workshop on 13 December 2016 and there was a general consensus that it provided a coherent underlying logic to the development of the NCST approach and that there were no fundamental gaps in the pathways identified.

However, it was noted that it is important to recognise that the linear impact pathways set out in the diagrams are more likely to be circular in practice as economic impacts and responses generate feedbacks to natural capital. As such, it was stressed that it is important to separate out ‘impacts’ and ‘responses’ when developing the scenarios. For example, providing clarity over whether policy decisions are included as drivers of natural capital change or responses to such changes.

Figure 18. Impact pathway for ‘crops and livestock’ service

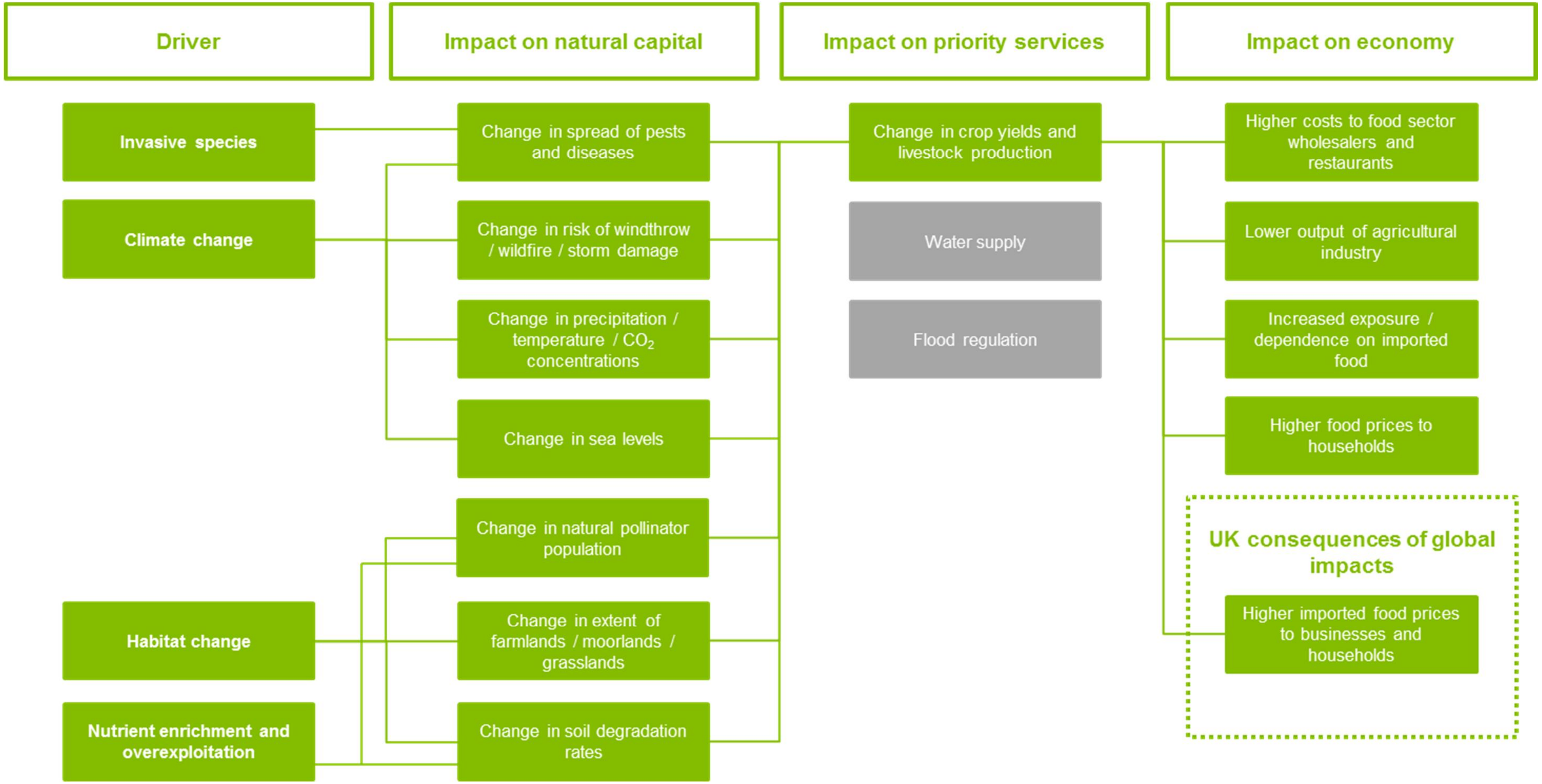


Figure 19. Impact pathway for 'water supply' service

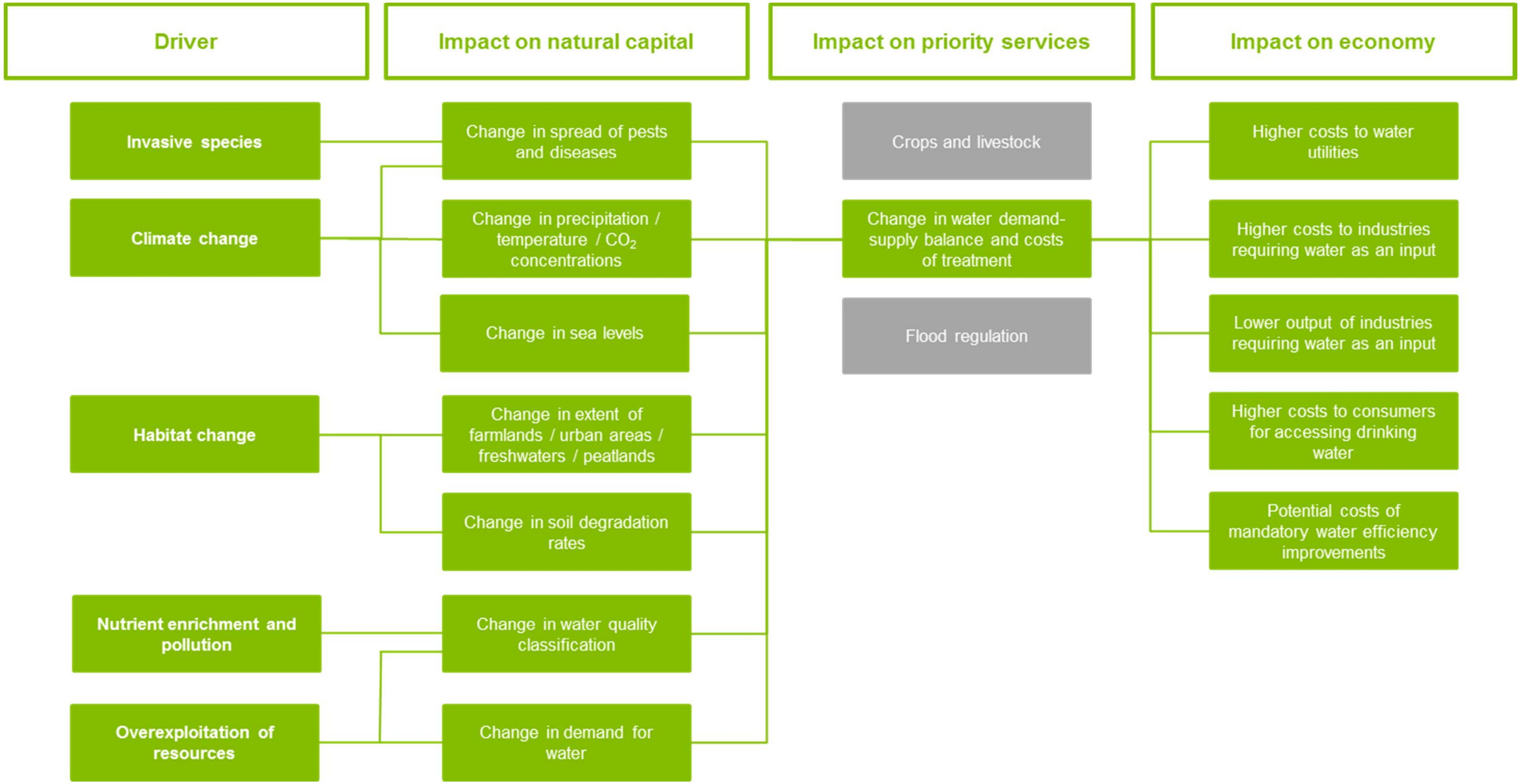
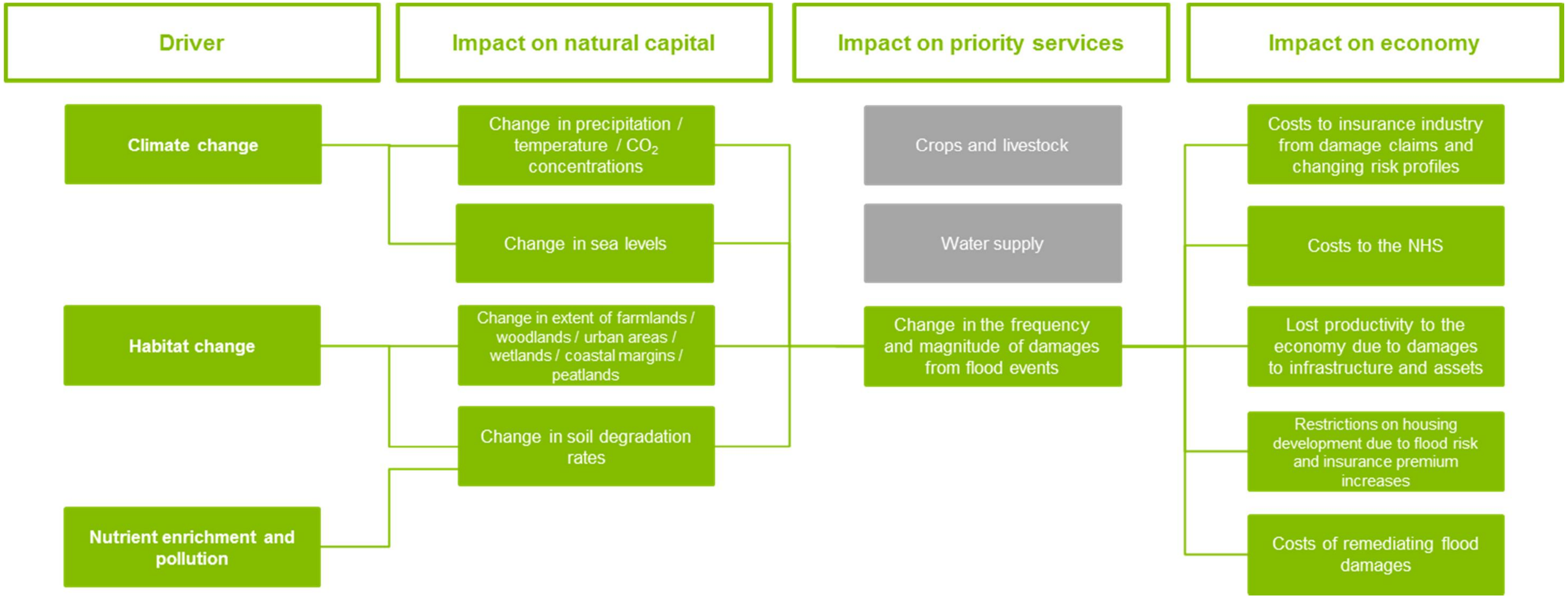


Figure 20. Impact pathway for 'hazard regulation' service



Developing scenarios

In addition to the issue of separating out impacts and responses, a number of additional points were also raised during the interviews and workshops for consideration when developing the scenarios. Some of the key points included:

- **Capturing the cumulative impacts on the economy** when developing scenarios due to the interactions of multiple factors affecting output of a particular service, and the cumulative effect of changes in multiple services on economic output. For example, a scenario focusing solely on modelling the impacts of a reduction in water availability on crop output and the agricultural sector would fail to capture important interactions such as the impact of crop pests and diseases or changes in flood risk on crop output, as well as important cumulative effects across multiple services, such as the combined impact on the economy from a loss of crop output and a reduction in water availability for other uses such as residential and industrial.

- **Considering both acute and chronic impacts** such as a gradual ongoing change in service provision as well as changes in the extent and frequency of acute 'shock' events. For example, scenarios should capture both an ongoing decline in crop output due to factors such as declining soil productivity, as well as changes in shock events such as lost output due to flooding or drought events. The combined impacts on overall resilience (i.e. chronic degradation may make the economy more vulnerable to acute events), could also be captured within the scenarios.

- **Clarifying the time horizons which the pilot will consider** bearing in mind that departments such as Treasury tend to work in 5-year cycles while bodies such as Defra, the National Infrastructure Commission, DfT, and DCLG tend to plan over longer term horizons.

- **Designing scenarios which are plausible to decision makers** in order that the outputs are seen as credible and usable.

In light of this feedback on the underlying structure and development of the scenarios, the approach to developing the scenarios began with the five broad drivers of ecosystem change identified in the UKNEA: invasive species, climate change, habitat change, nutrient enrichment and pollution, and overexploitation of resources. For each of these drivers a literature review was undertaken to identify high level, qualitative narratives on the extent to which they might change in the future. In order to design scenarios that were likely to be seen as credible, they were largely drawn from existing scenarios and projections developed for the UK context including:

- Beddington (2012), 'Food, Energy, Water and the Climate: A Perfect Storm of Global Events?'.

- Committee on Climate Change reports on risk assessment, projections of future flood risk, projections for water availability, assessment of climate change impacts on natural capital, and the development of climate scenarios.

- Environment Agency (2006), 'Environment Agency Scenarios 2030'.

- Environment Agency and Natural Resources Wales (2013) 'Current and future water availability – addendum. A refresh of the Case for Change analysis'

- Foresight Land Use Futures Project (2010), 'Final Project Report'.

- Lloyds (2015) 'Food System Shock: The insurance impacts of acute disruption to global food supply'.

- McKenzie & Rosenthal (2012), 'Developing scenarios to assess ecosystem service tradeoffs: Guidance and case studies for InVEST users'.

- UKNEA chapters on 'Drivers of change' and 'Scenarios: Development of Storylines and Analysis of Outcomes'.

An outline of the proposed scenario was presented at the workshop on 23 January 2017. Based on the feedback gathered it was decided that, for the purposes of the pilot, a time horizon of 2050 would be used which aligned with several of the reports set out above.

In terms of distinguishing between impacts and responses, it was decided that the scenario would encompass the 'first order' impacts of broad policy changes on natural capital such as potential relaxation of environmental legislation or changes in land-use cover in the UK. It was further decided that the scenario would include assumptions around 'second order' effects i.e. how the economy might respond to such changes in natural capital such as through changes in the quantity of food imported from international markets. Finally, it was also decided that the scenario would not include 'third order' policy responses to any of the ecosystem service changes captured within the model such as increasing subsidies in response to a decline in agricultural output or changing the level of adaptation.

Based on the initial literature review and the discussions at the workshop, the finalised scenario narrative for each of the five drivers was developed as follows:

- **Climate change:** Globally, the international community fails to meet the required reductions in greenhouse gas emissions to limit warming to two degrees. The resulting climate scenario in the UK follows the projections set out in the UKCP09 'High Emissions' scenario on the four degrees of warming path. The subsequent impacts cause significant reductions in the amount of water in the environment that can be sustainably withdrawn, while also increasing the demand for water during the driest months. The frequency and magnitude of floods in the UK also rise significantly and cause growing costs to a range of economic sectors. Globally, changes in the climate system lead to a doubling of international food prices.

- **Invasive species:** Increasing demand for global imports and a more diverse supply chain, together with changes in the climate and land use, lead to a significant increase in the frequency and severity of pest and disease outbreaks in the UK and growing costs for the agriculture industry.

- **Habitat change:** Greater emphasis on competing in the international market and securing trade deals leads to cuts in public subsidies for UK agriculture and there is a marked shift from subsidising food production towards allowing the market to determine the level of agricultural output. This shift leads to a widespread abandonment of agricultural land in upland areas with limited agricultural productivity. At the same time, the UK population continues to grow which leads to growing demand for housing resulting in the relaxation of Green Belt restrictions and widespread urban expansion into farmland areas surrounding cities, increased development of housing infrastructure on floodplains and coastal margins, and the creation of new towns on areas previously used for agriculture.

- **Nutrient enrichment and pollution:** Environmental regulations are also relaxed in order to support intensification of the remaining farms to allow them to compete with less constrained international producers. This leads to increases in livestock stocking densities and a spike in the use of pesticides and fertilisers which cause short term productivity boosts and longer term increases in soil degradation, water pollution, and loss of natural pollinators. Combined, this creates rising costs for agricultural productivity and water treatment, and reduced capacity of ecosystems to regulate surface water flows during flood events.

- **Overexploitation of resources:** Demand for residential water use grows in line with the increase in population and creates additional pressures on already-stretched water resources in some parts of the country. In the drier areas of the country water shortages become commonplace leading to frequent restrictions. These pressures are further exacerbated by increasing demand for irrigation water due to the changing climate and the growing demand for water to meet the energy needs of a growing population.

- **Quantifying impacts on natural capital and ecosystem services:** A more detailed literature review was then undertaken in order to quantify the extent of change in natural capital and the resulting change in service provision. An outline of the results for each of the three services: crops and livestock, water supply, and flood regulation is set out below.

Crops and livestock

Defra statistics on the value of production of different crop and livestock outputs in 2015 were combined with a series of assumptions and calculations to estimate the resulting change in the provision of crops and livestock resulting from each of the natural capital impacts identified in the impact pathway. An overview of the results is set out in Table 30.

Table 30. Overview of impacts on natural capital from high level drivers and resulting impacts on crops and livestock

Key impacts	Impact on natural capital by 2050s	Impact on crops and livestock	Quantified
Change in spread of pests and disease	Increased impacts on winter wheat and barley from diseases such as Barley Yellow Dwarf virus due to climatic changes and increased activity of aphid vectors[38]	- Assuming a 28% reduction in affected wheat yields and a 75% reduction in affected barley yields due to an outbreak of the Barley Yellow Dwarf virus[106] - Assuming that 95% and 40% of yields (i.e. winter output) are affected[107,108] - Leads to acute reduction in crop yields of 10.3% of total value by 2050 per disease outbreak	ü
	Increased impacts on livestock due to diseases such as bluetongue and liver fluke[109]	- Assuming a bluetongue mortality rate of 0.06% of dairy and beef cows and 1.25% of sheep[110] - Assuming 76% exposure of cows to liver fluke [111] and loss of milk yield of 3.2% for affected cows[112] - Leads to acute reduction in livestock production of 1.0% of total value by 2050 per disease outbreak	ü
Change in risk of windthrow / wildfire / storm damage	Increase in wildfire risk[113] and loss of crops to fire damage	- Assuming repeat of wildfire damage in 2010/11 where 37,380 ha of land burned[114] - Assuming 18% of UK land under crops	ü

[106] Crop Bayer Science http://www.bayercropscience.co.uk/our-products/seed-treatment/redigo-deter/bydv/
[107] Farmers Weekly http://www.fwi.co.uk/arable/spring-wheat-now-makes-up-5-of-uk-wheat-area.htm
[108] Defra (2015) 'Provisional 2015 cereal and oilseed rape production estimates'.
[109] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[110] Veterinary Record http://veterinaryrecord.bmj.com/content/161/16/571.6
[111] Pfizer Animal Health http://beefandlamb.ahdb.org.uk/wp/wp-content/uploads/2013/06/Liver-fluke-in-cattle-costs-and-control.pdf
[112] AHDB Dairy https://dairy.ahdb.org.uk/market-information/farming-data/milk-yield/average-milk-yield/#.WH5PiNWLS71
[113] Gazzard et al. (2016), 'Wildfire policy and management in England: an evolving response from Fire and Rescue Services, forestry and cross-sector groups'
[114] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.

Key impacts	Impact on natural capital by 2050s	Impact on crops and livestock	Quantified
		- Leads to acute reduction in crop yields of 0.2% of total value by 2050 per fire	
Change in precipitation / temperature / CO_2 concentrations	Increase in the area of Best and Most Versatile (BMV) land at high risk of flooding to 790,000 ha[115]	- Assuming crop distribution on BMV land is equal to the national distribution and that all crops in high risk areas are flooded - Leads to acute reduction in crop yields of 18.3% of total value by 2050 per flood	ü
	Increase in water supply deficits during low flow events and restrictions on agricultural water use	- Assuming impacts on agricultural output due to drought events are captured in the 'water supply' service	û
	More frequently waterlogged soils in winter and reduced soil moisture in summer leading to increase in weather patterns seen in 2012 where poor weather (wet winter/spring, dry summer) led to reduced wheat and potato yields[116]	- Assuming replication of weather events in 2012 which lead to 15% reduction in wheat and 26% reduction in potatoes[117] - Leads to acute reduction in crop yields of 5.9% of total value by 2050 per year with poor weather event	ü
	Increase in wheat and sugar beet yields due to better growing conditions together with decrease in potato yields[118]	- Assuming increased wheat yields of 79%, sugar beet 39%, and potatoes -5%[119] - Assuming climate conditions account for 5% of yields[120] - Leads to chronic increase in crop yields of 1.1% of total value by 2050	ü
	Increase in heatwave events which lead to loss of milk yield from livestock[121]	- Assuming 20% reduction in milk yields during heatwaves and number of heat stress days increases to 10 per year[122] - Leads to acute reduction in livestock production of 0.2% by 2050 due to heatwaves	ü

[115] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[116] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[117] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[118] CCRA (2012), 'Climate Change Risk Assessment for the Agriculture Sector'.
[119] CCRA (2012), 'Climate Change Risk Assessment for the Agriculture Sector'.
[120] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[121] Dunn et al. (2014), 'Analysis of heat stress in UK dairy cattle and impact on milk yields'.
[122] Dunn et al. (2014), 'Analysis of heat stress in UK dairy cattle and impact on milk yields'.

Key impacts	Impact on natural capital by 2050s	Impact on crops and livestock	Quantified
Change in sea levels	Average increase in sea levels of 0.34 metres[123] leading to loss of 0.1% of BMV land through costal erosion[124]	- Assuming that 40% of agricultural land is BMV and that crop output is distributed similarly across BMV land and total national output - Leads to chronic reduction in crop yields of 0.04% of total value by 2050[125]	ü
Change in natural pollinator population	Decline in natural pollinator populations and distributions to the extent that pollinator visits to crops fall[126]	- Assuming 29% fall in pollinator populations[127] - Assuming 25% oilseed rape, 85% field beans, 45% fresh vegetables, and 65% fresh fruit yields dependent on pollination[128] - Leads to chronic reduction in crop yields of 4.9% of total value by 2050	ü
Change in extent of farmlands / moorlands / grasslands	Subsidy reductions take all Less Favoured Areas (LFA) land in England out of production	- Assuming average of 82 cows and 683 sheep per LFA farm[129,130] - Leads to chronic reduction in livestock production of 19.6% of total value by 2050	ü
	Increase in development of agricultural land to meet growth in housing demand	- Chronic reduction in crop yields and livestock production not quantified due to limitations of evidence base	û
Change in soil degradation rates	Widespread deterioration in soil quality due to erosion, loss of soil organic content, and compaction[131,132,133]	- Assuming total cost of soil degradation relating to agriculture of £290 million[134] - Leads to chronic reduction in crop yields of 3.8% of total value by 2050	ü

[123] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[124] Ramsbottom et al. (2012), 'UK 2012 Climate Change Risk Assessment for the Floods and Coastal Erosion Sector'.
[125] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[126] Brown et al. (2017) UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.
[127] Biesmiejer et al. (2006), 'Parallel Declines in Pollinators and Insect-Pollinated Plants in Britain and the Netherlands'.
[128] UK NEA (2011), 'Chapter 14: Regulating Services'.
[129] RBR (2016), 'Farm Business Survey 2014/2015 Hill Farming in England'.
[130] Defra Soil Research Programme 'Review of the weight that should be given to the protection of best and most versatile (BMV) land Technical Report SP1501/TR Final Report'.
[131] UK National Ecosystem Assessment Follow-On (2014), 'Work Package Report 1: Annex 4 – Case studies'.
[132] Cranfield University (2013) for the Adaptation Sub-Committee. Work for the 'Managing the land in a changing climate' report
[133] Graves et al. (2015), ' The total costs of soil degradation in England and Wales'.
[134] Graves et al. (2015), ' The total costs of soil degradation in England and Wales'.

The impacts where then aggregated to estimate the cumulative potential change if all of the potential acute shocks occurred in the year 2050 i.e. a UK wide flooding of agricultural land, an outbreak of various diseases, a heatwave event etc.; and the cumulative chronic change given the ongoing impacts on output due to changes such as pollinator decline and land use change etc. The results are set out in the tables below.

Table 31. Acute impact on crops

Crop type	Current output (2015 prices)	Impact of flooding	Impact of wildfires	Impact of weather	Impact of disease	Change in output (2015 prices)	Change in output (%)
Wheat	£2,033,000,000	-4.9%	-	-4.0%	-7.0%	-£1,207,331,074	-15.9%
Barley	£824,000,000	-2.0%	-	-	-3.3%	-£398,799,827	-5.3%
Oats	£86,000,000	-0.2%	-	-	-	-£15,705,039	-0.2%
Oilseed rape	£706,000,000	-1.7%	-	-	-	-£128,927,416	-1.7%
Linseed	£9,000,000	-0.02%	-	-	-	-£1,643,551	-0.02%
Sugar	£173,000,000	-0.4%	-	-	-	-£31,592,695	-0.4%
Peas	£13,000,000	-0.03%	-	-	-	-£2,374,018	-0.03%
Field beans	£97,000,000	-0.2%	-	-	-	-£17,713,823	-0.2%
Fresh vegetables	£1,277,000,000	-3.1%	-	-	-	-£233,201,572	-3.1%
Plants and flowers	£1,149,000,000	-2.8%	-	-	-	-£209,826,630	-2.8%
Potatoes	£547,000,000	-1.3%	-	-1.9%	-	-£242,111,355	-3.2%
Fresh fruit	£681,000,000	-1.6%	-	-	-	-£124,361,997	-1.6%
Total	**£7,595,000,000**	**-18.3%**	**-0.2%**	**-5.9%**	**-10.3%**	**-£2,625,242,915**	**-34.6%**

Table 32. Acute impact on livestock

Livestock type	Current output (2015 prices)	Impact of bluetongue	Impact of liver fluke	Impact of heatwaves	Change in output (2015 prices)	Change in output (%)
Dairy cows	£3,663,000,000	-0.02%	-0.8%	-0.2%	-£112,168,090	-1.0%
Beef cows	£2,739,000,000	-0.02%	-	-	-£1,643,400	0.0%
Pigs	£1,078,000,000	-	-	-	-	-
Sheep	£1,105,000,000	-0.13%	-	-	-£13,812,500	-0.1%
Poultry	£2,226,000,000	-	-	-	-	-
Total	**£10,811,000,000**	**-0.16%**	**-0.8%**	**-0.2%**	**-£127,623,990**	**-1.2%**

Table 33. Chronic impact on crops

Crop type	Current output (2015 prices)	Impact of climate	Impact of pollina-tion	Impact of coastal erosion	Impact of soil decline	Change in output (2015 prices)	Change in output (%)
Wheat	£2,033,000,000	1.1%	-	-0.01%	-	£79,490,300	1.0%
Barley	£824,000,000	-	-	-0.004%	-	-£329,600	-0.004%

Crop type	Current output (2015 prices)	Impact of climate	Impact of pollina-tion	Impact of coastal erosion	Impact of soil decline	Change in output (2015 prices)	Change in output (%)
Oats	£86,000,000	-	-	-0.0005%	-	-£34,400	-0.0005%
Oilseed rape	£706,000,000	-	-0.7%	-0.004%	-	-£51,467,400	-0.7%
Linseed	£9,000,000	-	-	-0.00005%	-	-£3,600	-0.00005%
Sugar	£173,000,000	0.04%	-	-0.001%	-	£3,304,300	0.044%
Peas	£13,000,000	-	-	-0.0001%	-	-£5,200	-0.0001%
Field beans	£97,000,000	-	-0.3%	-0.001%	-	-£23,949,300	-0.3%
Fresh vegetables	£1,277,000,000	-	-2.2%	-0.01%	-	-£167,159,300	-2.2%
Plants and flowers	£1,149,000,000	-	-	-0.01%	-	-£459,600	-0.01%
Potatoes	£547,000,000	-0.02%	-	-0.003%	-	-£1,586,300	-0.02%
Fresh fruit	£681,000,000	-	-1.7%	-0.004%	-	-£128,640,900	-1.7%
Total	**£7,595,000,000**	**1.1%**	**-4.9%**	**-0.04%**	**-3.82%**	-£581,154,524	**-7.7%**

Table 34. Chronic impact on livestock

Livestock type	Current output (2015 prices)	Impact of land-use change	Change in output (2015 prices)	Change in output (%)
Dairy cows	£3,663,000,000	-	-	-
Beef cows	£2,739,000,000	-16.9%	-£1,832,289,703	-16.9%
Pigs	£1,078,000,000	-	-	-
Sheep	£1,105,000,000	-2.7%	-£291,072,339	-2.7%
Poultry	£2,226,000,000	-	-	-
Total	**£10,811,000,000**	**-19.6%**	**-£2,123,362,042**	**-19.6%**

It is important to note the lack of studies providing a consistent overview of the cumulative impacts of various natural capital changes on crops and livestock provision by 2050. As such a number of different studies were drawn upon which used multiple different sets of assumptions and methodologies. This creates issues when trying to combine like with like; for instance some estimates for the extent of change in 2050 account for the change in magnitude of a particular impact (e.g. greater loss of milk yield from dairy cows due to an increase in the number of heatwave events), whereas others do not, instead assuming that events which have happened previously occur again in the future (e.g. replication of poor weather events in 2010/11).

The estimates also not account for the likelihood of an event occurring, and instead focus on the magnitude of the impact should an event occur. As such, some of the figures are likely to be over or under estimates of the actual magnitude. For example, the estimate of flood risk to agricultural land draws on CCRA work which suggests that 790,000 ha of BMV land could be at high risk of flooding by 2050. The estimates provided above look at the magnitude of the impact if all of this area was flooded within a single year, an event which has a low likelihood.

These issues mean that the piloting exercise should be taken as indicative of how the potential approach could be undertaken, rather than providing prescriptive estimates of what may actually happen in 2050. As a priority, research should be undertaken to build the evidence base around aggregate impacts of natural capital change in service provision.

Water supply

A similar approach was adopted for the water supply service and the estimates of change in natural capital are set out in Table 35. Note for a number of the potential impacts it was not possible to develop quantitative estimates of change, again highlighting the limitations of the underlying evidence base and the fact that the quantitative estimates do not fully reflect the narrative of the scenario.

Table 35. Overview of impacts on natural capital from high level drivers and resulting impacts on water supply

Key impacts	Impact on natural capital by 2050s	Impact on water supply	Quantified
Change in spread of pests and disease	Increased incidence of invasive species (especially aquatic plants and invertebrates)[135]	Chronic increase in water treatment costs not quantified due to limitations of evidence base	û
Change in precipitation / temperature / CO_2 concentrations	Change in precipitation patterns contributes to lower flows in summer months[135]	Assuming chronic reductions in supply of water which increase the impacts of acute drought events based on the evidence base set out in the CCRA 2017	ü
		Assuming acute drought event occurs for a 3 month period	ü
Change in sea levels	Average increase in sea levels of 0.34 metres[136]	Chronic increase in groundwater saline intrusion into aquifers not quantified due to limitations of evidence base	û
Change in extent of urban areas/ freshwaters / peatlands	Increase in population leading to increase in intensification of remaining agricultural land and urbanisation of river catchment which reduces capacity of ecosystems to regulate water quality	Chronic increase in water treatment costs not quantified due to limitations of evidence base	û
Change in soil degradation rates	Continued erosion of sediments contributing to sedimentation of water	Chronic increase in water treatment costs not quantified due to limitations of evidence base	û
Changes in water quality classification	Intensified agriculture and wetter autumns and winters increases the severity of diffuse agricultural pollution and low summer river flows less effectively dilute pollutants	Chronic increase in water treatment costs not quantified due to limitations of evidence base	û
Change in demand for food / water / raw materials	Increase in population of 10% to 83 million people leading to the demand for water across the UK to increase by 9%[137]	Assuming chronic increase in demand for water which can emphasise the impacts of acute shocks during drought events based on the evidence base set out in the CCRA 2017	ü

[135] Dawson et al. (2016), 'Climate Change Risk Assessment 2017: Infrastructure'
[136] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[137] HY Wallingford (2015), CCRA2: Updated projections for water availability for the UK Final Report'.

Given the limitations of the evidence base, the impacts on water supply for the purposes of pilot NCST were focused on quantifying the chronic changes in the demand and supply of water, and how these ongoing chronic changes could lead to greater exposure to acute drought events in future. More specifically, the pilot aimed to answer the question, how much greater could the magnitude of impacts from a drought event in 2050 be due to chronic declines in water availability based on a comparison between:

- The impacts of a three month drought event in 2050 (assumed here to be a period where water levels are at low flows for three months) if water availability declines to the extent projected by the CCRA 2017.
- The impacts of a similar drought event in 2050 if water availability was maintained at its current levels.

The chronic impact on water availability was estimated based on the CCRA 2017 projection that the balance of water supply relative to demand during low flow events will switch from a UK-wide surplus to a deficit by the 2050s[138] assuming: four degrees warming, a population increase of 10% to 83 million people, and a continuation of the current levels of adaptation. The figures are derived from a scenario analysis conducted by HR Wallingford, which calculated deficits for each of twelve water catchments corresponding (approximately) to the twelve NUTS regions[139] of the UK. A summary of the results are set out in Table 36, the full set of calculations are available in a separate Excel spreadsheet.

Table 36. Comparison of water availability based on chronic changes in water supply and demand[140]

Region	Water deficits during low flows in 2050 assuming water availability is maintained (Ml/day)	Water deficits during low flows in 2050 assuming water availability declines (Ml/day)
East Midlands	-138	-387
East of England	-867	-1,196
London	-1,261	-1,292
North East	0	-32
North West	0	-397
Northern Ireland	0	-54
Scotland	0	-532
South East	-549	-917
South West	0	-422
Wales	0	-1,162
West Midlands	0	0
Yorkshire and the Humber	0	0
Total	**-2,816**	**-6,392**
Deficit as % of total demand	**-18.1%**	**-41.0%**

138 Hall et al. (2015), 'CCRA2: Updated projections for water availability for the UK Final Report.
139 The Nomenclature of Territorial Units for Statistics (NUTS) is a geocode standard used by Eurostat for referencing the subdivisions of the United Kingdom of Great Britain and Northern Ireland for statistical purposes. There are 9 first level regions within England and one for each of Scotland, Wales and Northern Ireland.
140 Hall et al. (2015), 'CCRA2: Updated projections for water availability for the UK Final Report.

The figures above set out the water deficit for a single day at low flows i.e. the level of river flow that is equalled or exceeded for 95% of the time (in this case calculated from 30-years of data). These chronic changes in water availability lead to impacts of different magnitudes during acute drought events. In this pilot case, it is assumed that a drought event lasting for a period of three months occurs meaning that a low flow event occurs for a three month period.

Flood regulation

The same approach was then adopted for the flood regulation service. The estimates of the change in natural capital are set out in Table 35.

Table 37. Overview of impacts on natural capital from high level drivers and resulting impacts on flood regulation

Key impacts	Impact on natural capital by 2050s	Impact on hazard regulation	Quantified
Change in precipitation / temperature / CO_2 concentrations	Average increase in peak river flows of 23%[141] and events of intense rainfall between 1 to 6 hours duration of 20%[142]	Assuming increase in risk of acute fluvial flood events based on the evidence base set out in CCRA 2017	ü
		Assuming increase in risk of surface water flood events based on the evidence base set out in CCRA 2017	ü
		Assuming increase in risk of acute groundwater flood events based on the evidence base set out in CCRA 2017	ü
Change in sea levels	Average increase in sea levels of 0.34 metres[143]	Assuming increase in risk of acute coastal flood events based on the evidence base set out in CCRA 2017	ü
Change in extent of woodland / urban areas / wetlands	Increase in population of 10% to 83 million people[144] leading to an increase in urbanisation mainly at the expense of agricultural land although some additional development on floodplains	Assuming chronic increase in number of properties at risk from flooding during acute events	ü
		Chronic decrease in capacity of ecosystems to regulate water flows not quantified due to limitations of evidence base	û
Change in soil degradation rates	Increase in soil degradation and loss of capacity to store water	Chronic decrease in capacity of ecosystems to regulate water flows not quantified due to limitations of evidence base	û

The impacts on flood regulation are focused on quantifying the chronic changes in the numbers of properties at risk of flood events and the change in the extent and magnitude of acute flood events by 2050. This was

[141] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[142] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[143] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.
[144] Sayers et al. (2015), 'Climate Change Risk Assessment 2017: Projections of future flood risk in the UK'.

estimated based on the CCRA 2017 projections[145] of the changes in flood risk by 2050 assuming four degrees warming, a population increase of 10% to 83 million people, and a reduction in the current levels of adaptation.

The results are set out in Table 38 and represent a combination of the change in the likelihood of acute flood events due to changes in the climate system, and a change in the magnitude of the associated impacts due to population growth, a reduction in the level of planned adaption, and changes in the climate system.[146]

Table 38. Cumulative change in flood regulation[147]

Aspect	Current	2050s	% change
No. residential properties at high risk of flooding[148]	1,073,286	2,454,715	129%
No. non-residential properties at high risk	533,590	772,041	45%
No. clean and wastewater sites at high risk	299	185	-38%
No. rail stations at high risk	580	685	18%
Length of road at high risk (km)	6,585	11,115	69%
Length of railway at high risk (km)	2,397	3,703	54%
No. power stations at high risk	24	16	-33%
No. substations at high risk	327	277	-15%
No. mobile phone masts at high risk	1,753	2,829	61%
No. care homes at high risk	438	780	78%
No. schools at high risk	1,112	1,652	48%
No. emergency services at high risk	249	410	65%
No. hospitals at high risk	94	127	36%
No. GP surgeries at high risk	563	993	76%
No. landfill sites at high risk	398	423	6%

Developing and applying the economic impact approach

Having identified the three ecosystem services to be analysed in the pilot, specified the scenario, and quantified the extent of change, the final step involved the development of approaches to assess the economic impacts. This began with some initial work to set out the framework by which changes in ecosystem services lead to economic impacts. This framework identified:

[145] Sayers et al (2016). The analysis of future flood risk in the UK using the Future Flood Explorer (FFE). Proceedings of Floodrisk2016. Paul Sayers, Matt Horritt, Edmund Penning-Rowsell, Andrew McKenzie and David Thompson. E3S Web Conf., 7 (2016) 21005 DOI: http://dx.doi.org/10.1051/e3sconf/20160721005

[146] This scenario assumes that the adaptation effort as a whole reduces. Investment in traditional defences reduces (reflecting a reduction in the willingness to pay for defences from national tax revenues as flooding is increasingly seen as less of a national risk and more of a local one, but local funding fails to replace centralised investments). There is little take up of innovative catchment-based or urban run-off measures occurs, spatial planning becomes less rigorous (resulting in new development on the floodplain than currently is the case), and flood forecasting and warning systems and receptor level protection see low(er) levels of effectiveness and performance.

[147] Sayers et al (2016). The analysis of future flood risk in the UK using the Future Flood Explorer (FFE). Proceedings of Floodrisk2016. Paul Sayers, Matt Horritt, Edmund Penning-Rowsell, Andrew McKenzie and David Thompson. E3S Web Conf., 7 (2016) 21005 DOI: http://dx.doi.org/10.1051/e3sconf/20160721005

[148] 'High risk' defined as at risk of flooding more frequent than 1:75 years.

- The components of the logic chain: translation of changes in ecosystem services into direct impacts; indirect impacts through economic dependencies; and behavioural responses.
- Factors that lead to changes in the impacts: changing patterns of natural capital shocks and changing socio-economic structure.
- The different channels (corresponding to the three categories of ecosystem services) by which changes in natural capital might alter the flow of benefits into the economy.

The framework was presented at the first workshop on 13 December 2016 alongside an example that set out the logic chain for a reduction in the availability of crops and livestock. The example elaborated the economic component of the impact pathway for that ecosystem service (extending the detail of the rightmost column of the impact pathway in Figure 18).

The workshop provided an opportunity for stakeholders to comment on the approach and logic chain and to say if the economic logic was missing any critical effects. The discussion did not highlight any specific elements that were missing from the draft economic pathway for crops and livestock although there was some discussion as to how best to incorporate financial and insurance impacts into the hazard regulation analysis and other scenarios that may involve some kind of crisis that leads to insurance claims etc.[149] Section 4 in the main body of the report sets out the economic logic of the approach to the impact analysis.

The discussion also emphasised the ways in which such economic assessments could be more challenging because of the characteristics of natural capital. These characteristics include the relatively low share of provisioning ecosystem services in inputs to production but typically a limited degree of substitutability, making such services essential even if they constitute a small proportion of total value. The implication is that ecosystem services and the industries that depend on them directly may not, at first glance, appear to contribute much to total economic activity. However, this is simply because the rest of the economy (in the UK, largely services) is so much larger.

Without much scope for substitution, the loss of ecosystem services like food and water could in fact cause substantial disruption because such services are ‘lifelines’. A breakdown of the results by industry was considered important to understand knock-on effects through the economy but also because some impacts are likely to affect some sectors much more than others. While the impacts of a stress test may not show up very clearly at the aggregate level, some sectors could be greatly affected.

Difficulties were also noted as to how to show the relative importance of these services given high levels of uncertainty about behavioural responses under severe environmental stress, the potential for technological change and adaptation in the long term, and the presence of non-linearities and threshold effects. There was relatively little of this that could be addressed in the pilot although the economic impacts have been reported in a way that attempts to convey approximate scale, rather than a precise estimate of the impacts.

The discussion during the workshop also supported the aim of the stress test to focus on observable economic indicators and to avoid non-market values, which are less robust and more contestable. Stakeholders felt that the use of the latter might undermine confidence in the results of a stress test. This also supported the earlier decision not to attempt an assessment of any cultural ecosystem services (which generally generate non-monetised amenity values).

Having agreed the logic/narrative of the crops and livestock analysis, an impact model was developed in Excel

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[149] In the end, data limitations prevented an assessment of these effects in the pilot but it is something that should be considered in more detail in future work.

to embed that economic logic. The model takes, as inputs:

- The anticipated reduction in an industry’s output that arises from a change in an ecosystem service.
- A set of assumptions to determine the extent to which the impacts are to be borne by final users (households, foreign purchasers etc.) and by individual industries. The industry-level impacts may be set either: by the analyst based on prior knowledge of how a scenario might constrain output in specific industries (the ‘analyst-led’ approach reported in the crops and livestock results); or by applying a set of assumptions to distribute the output constraints according to some rule (an example of this is the ‘data-derived’ approach reported in both crops and livestock, and water supply).
- If required, a set of changes to domestic prices (increasing industry profits) and import prices, to calculate the impact on the consumer price index.

The underlying model is quite general, so that it can be used in scenario analysis beyond the life of this project. However, because the model is so general, each scenario examined in the pilot took a version of that model as a template. The individual models were then tailored to the specific scenario, with a sheet of controls that only contained the key inputs for that ecosystem service.

Initial results from an early version of that model (that only incorporated the first two of the above) were presented at the second workshop on 23 January 2017, to show early results from an acute shock to crops and livestock. There was agreement that the work was going in the right direction. The remaining narratives for the other ecosystem services were also presented to broad agreement.

Following the second workshop, the model was further developed and applied to the scenario of chronic degradation of crops and livestock. A version of the model was then developed to analyse water supply.

Because of a lack of detailed spatial data, in the end, no model was developed for flood regulation. Ideally, such an analysis would have considered the location-specific impacts of a particular flooding event and traced through the consequences for economic activity and the costs of recovery. In lieu of this, the approach taken was less detailed and involved taking the estimated costs of the 2013/14 winter floods in England and Wales and scaling them up using assumptions about future economic development and climate change. Implicitly, this approach attempts to project the future impacts of a series of events like the 2013/14 floods were they to occur in the future (2050) when the structure of the economy in those areas (number of households compared to number of businesses etc.) might be different and the extent of flood magnitude might also change. This changes both the total costs but also the composition of those impacts.

The results of the stress test and the interpretation of those results are presented in Section 5 of the main report.

Appendix B. Scoping matrices

Overview

This section provides an overview of the scoping matrices used to develop and pilot the approach to natural capital stress testing. Copies of the Economic Sector Review and the Ecosystem Service Prioritisation matrices are set out in Figure 21 and Figure 22, respectively. Full versions are available separately in Excel spreadsheets.

Economic Sector Review matrix

The first step of the scoping process is to qualitatively assess the dependency of economic sectors on a range of ecosystem services in order to identify the services which are of most importance to the economy. This can be done using the Economic Sector Review matrix.

In this matrix a list of economic sectors (UK Standard Industrial Classification of Economic Activities 2007) is set on the horizontal axis against a list of ecosystem services (CICES, Version 4.3) on the vertical axis of the matrix. Scores on a three-point scale (High, Medium, Low) are then entered by the user to indicate the strength of interaction between each ecosystem service and each economic sector. This matrix is to be completed with the application of the best available evidence and preferably with the advice of sectoral and ecosystem service experts. Previous inputs from the piloting of this approach may be retained and updated where appropriate; this iterative revision of scores may continue throughout the application of the NCST to reduce the required effort for each application.

The strength of the service-sector interaction should not be assessed on the perceived risk of ecosystem service change, or the nature of the interaction, but on the extent to which a change in ecosystem service provision might cause significant impacts (positive or negative) on activities within economic sectors. For a sector-specific application, or more comprehensive application, the user might consider sub-sector classifications. This is because ecosystem service change can be expected to cause more severe impacts in certain sub-sectors (for example food supply impacts on food and beverage manufacturing may be significant while wider manufacturing impacts might be more limited).

Ecosystem Service Prioritisation matrix

The second step is to build on the economic sector review to further assess the list of ecosystem services in order to identify a priority list of services to be included within the NCST. This can be done using the Ecosystem Service Prioritisation matrix which sets out a range of criteria for prioritising services for inclusion.

In this matrix the user assigns a score to each ecosystem service of: High (2); Medium (1); and Low (0) against the following criteria: whole economy relevance (drawing on the results from Step 1); policy relevance; relative risk to future provision; availability of methods for physical and monetary analysis; and availability of data for physical and monetary analysis.

Each cell should be completed by the user, aside from those of the first criterion (whole economy relevance) which is automatically filled from the previous scoping step. Given the high level of this assessment, it can be completed on the basis of professional judgement and should be ‘sense checked’ through internal or external review processes. On completion of the matrix, an Ecosystem Service Priority Score will be presented. A higher score represents a higher priority for inclusion in the stress test. However, the interpretation and use of this score will depend on the user’s required scope. It is suggested that the user selects a greater number of services at this point than can be assessed in detail later, and then further narrows their selection of ecosystem services through more deliberative methods (for example, through a workshop for expert stakeholders).

Figure 21. Economic Sector Review matrix

UK Standard Industrial Classification of Economic Activities 2007			AGRICULTURE, FORESTRY AND FISHING	MINING AND QUARRYING	MANUFACTURING	ELECTRICITY, GAS, STEAM AND AIR CONDITIONING SUPPLY	WATER SUPPLY; SEWERAGE, WASTE MANAGEMENT AND REMEDIATION ACTIVITIES	CONSTRUCTION	WHOLESALE AND RETAIL TRADE; REPAIR OF MOTOR VEHICLES AND MOTORCYCLES	TRANSPORTATION AND STORAGE	ACCOMMODATION AND FOOD SERVICE ACTIVITIES	INFORMATION AND COMMUNICATION	FINANCIAL AND INSURANCE ACTIVITIES	REAL ESTATE ACTIVITIES	PROFESSIONAL, SCIENTIFIC AND TECHNICAL ACTIVITIES	ADMINISTRATIVE AND SUPPORT SERVICE ACTIVITIES	PUBLIC ADMINISTRATION AND DEFENCE; COMPULSORY SOCIAL SECURITY	EDUCATION	HUMAN HEALTH AND SOCIAL WORK ACTIVITIES	ARTS, ENTERTAINMENT AND RECREATION	OTHER SERVICE ACTIVITIES	ACTIVITIES OF HOUSEHOLDS AS EMPLOYERS	ACTIVITIES OF EXTRATERRITORIAL ORGANISATIONS AND BODIES	Ecosystem Service Materiality Score	Ecosystem Service Materiality Rating
CICES 4.3 Ecosystem Services	**UK Specific Example**	**Broad Classification**	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U		
Provisioning Services																									
Cultivated crops	Crops	Crops & livestock	High	Low	Medium	Low	Medium	Low	Medium	Low	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	7	Medium
Reared animals and their outputs	Livestock	Crops & livestock	High	Low	Medium	Low	Medium	Low	Medium	Low	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	7	Medium
Wild plants, algae and their outputs	Mushrooms & berries	Wild foods	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Wild animals and their outputs	Fisheries	Fisheries	High	Low	Medium	Low	Low	Low	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	5	Medium
Plants and algae from in-situ	Seaweed	Aquaculture	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Animals from in-situ aquaculture	Farmed salmon	Aquaculture	Medium	Low	Low	Low	Low	Low	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	3	Low
Surface water for drinking	Drinking water	Water supply	High	Medium	High	Medium	High	Medium	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	11	High
Ground water for drinking	Drinking water	Water supply	High	Medium	High	Medium	High	Medium	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	11	High
Fibres and other materials from	Timber	Timber	High	Low	Medium	Low	Low	Medium	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	5	Medium
Materials from plants, algae and	Fodder	Crops & livestock	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Genetic materials from all biota	Genetic resources	Genetic resources	High	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	2	Low
Surface water for non-drinking	Other water uses	Water supply	High	Medium	High	Medium	High	Medium	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	11	High
Ground water for non-drinking	Other water uses	Water supply	High	Medium	High	Medium	High	Medium	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	11	High
Plant-based resources (for energy	Woodfuel/biomass	Energy	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	1	Low
Animal-based resources (for energy	Manure/slurry	Energy	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Animal-based energy	Oxen	Energy	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Regulating Services																									
Bio-remediation by micro-organisms,	Bio-remediation	Soil quality regulation	Low	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	1	Low
Filtration/sequestration/storage/accu	Detoxification	Water quality regulation	Low	Low	Low	Low	High	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	3	Low
Filtration/sequestration/storage/accu	Pollution absorption	Air quality regulation	Medium	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	Low	Low	Low	Low	4	Low
Dilution by atmosphere, freshwater	Waste dilution	Water quality regulation	Low	Low	Low	Low	High	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	3	Low
Mediation of smell/noise/visual	Vegetation screening	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Mass stabilisation and control of	Erosion control	Soil quality regulation	Medium	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	2	Low
Buffering and attenuation of mass	Sediment transport	Water quality regulation	Low	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	2	Low
Hydrological cycle and water flow	Environmental flows	Water supply	High	Medium	High	Medium	High	Medium	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	11	High
Flood protection	Flood protection	Flood regulation	High	Low	Medium	Medium	Medium	High	Medium	Medium	Low	Low	High	Medium	Low	Low	Low	Low	Medium	Low	Low	Low	Low	13	High
Storm protection	Shelter belts	Storm regulation	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Ventilation and transpiration	Ventilation	Air quality regulation	Medium	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	Low	Low	Low	Low	4	Low
Pollination and seed dispersal	Pollination	Pollination	High	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	2	Low
Maintaining nursery populations and	Nursery habitats	Fisheries	High	Low	Medium	Low	Low	Low	Medium	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	5	Medium
Pest control	Pest control	Disease & pest control	High	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	3	Low
Disease control	Disease control	Disease & pest control	High	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	Low	Low	Low	Low	5	Medium
Weathering processes	Soil regulation	Soil quality regulation	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	1	Low
Decomposition and fixing processes	Soil regulation	Soil quality regulation	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	1	Low
Chemical condition of freshwaters	River water quality	Water quality regulation	Low	Low	Low	Low	High	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	3	Low
Chemical condition of salt waters	Bathing water quality	Water quality regulation	Medium	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	3	Low
Global climate regulation by reduction	Carbon sequestration	Global climate regulation	High	Low	Medium	Medium	High	Low	Low	Low	Low	Low	High	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	9	High
Micro and regional climate regulation	Temperature regulation	Local climate regulation	Medium	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	Low	3	Low
Cultural Services																									
Experiential use of plants, animals	Wildlife watching	Tourism & recreation	Low	Low	Low	Low	Low	Low	Low	Medium	Medium	Low	Low	Low	Low	Low	Low	Low	Medium	High	Low	Low	Low	5	Medium
Physical use of land-/seascapes in	Nature based recreation	Tourism & recreation	Low	Low	Low	Low	Low	Low	Low	Medium	Medium	Low	Low	Low	Low	Low	Low	Low	Medium	High	Low	Low	Low	5	Medium
Scientific	Scientific values	Science & knowledge values	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	Low	Low	Low	Low	Low	Low	Low	Low	2	Low
Educational	Educational values	Science & knowledge values	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	Low	Low	1	Low
Heritage, cultural	Cultural values	Cultural & spiritual values	Medium	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	High	Low	Low	Low	4	Low
Entertainment	Entertainment values	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	High	Low	Low	Low	2	Low
Aesthetic	Aesthetic values	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Medium	Low	Low	Low	Low	Low	High	Low	Low	Low	4	Low
Symbolic	Symbolic values	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Sacred and/or religious	Religious values	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Existence	Existence values	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Bequest	Bequest values	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	Low	0	Low
Total Score																									
Overall sector materiality score			41	5	17	9	29	8	12	3	14	0	6	2	2	0	0	1	10	16	0	0	0		
Overall sector materiality rating			High	Low	Medium	Low	High	Low	Low	Low	Medium	Low	Low	Low	Low	Low	Low	Low	Low	Medium	Low	Low	Low		

Figure 22. Ecosystem Service Prioritisation matrix

Criteria for Prioritisation			Whole-economy relevance	Policy relevance	Relative risk to future provision	Methods for physical terms analysis	Methods for monetary terms analysis	Availability of data for physical terms	Availability of data for monetary terms	Ecosystem Service Priority Score	Ecosystem Service Priority Rating
CICES 4.3 Ecosystem Services	**UK Specific Example**	**Broad Classification**	a	b	c	d	e	f	g	h	i
Provisioning Services											
Cultivated crops	Crops	Crops & livestock	Medium	High	Medium	High	High	High	High	12	High
Reared animals and their outputs	Livestock	Crops & livestock	Medium	High	Medium	High	High	High	High	12	High
Wild plants, algae and their outputs	Mushrooms & berries	Wild foods	Low	Low	Low	High	High	Low	Low	4	Low
Wild animals and their outputs	Fisheries & game	Fisheries	Medium	High	Medium	High	High	High	High	12	High
Plants and algae from in-situ	Seaweed	Fisheries	Low	Low	Low	High	High	Low	Low	4	Low
Animals from in-situ aquaculture	Farmed salmon	Fisheries	Low	Low	Low	High	High	High	High	8	Medium
Surface water for drinking	Drinking water	Water supply	High	High	High	High	High	High	Medium	13	High
Ground water for drinking	Drinking water	Water supply	High	High	High	High	High	High	Medium	13	High
Fibres and other materials from	Timber	Timber	Medium	Low	Medium	High	High	High	High	10	High
Materials from plants, algae and	Fodder	Crops & livestock	Low	Low	Low	Medium	Medium	Low	Low	2	Low
Genetic materials from all biota	Genetic resources	Genetic resources	Low	Medium	Low	Low	Low	Low	Low	1	Low
Surface water for non-drinking	Other water uses	Water supply	High	High	High	High	High	High	Medium	13	High
Ground water for non-drinking	Other water uses	Water supply	High	High	High	High	High	High	Medium	13	High
Plant-based resources (for energy	Woodfuel/biomass	Energy	Low	Medium	Low	High	High	Medium	Low	6	Medium
Animal-based resources (for energy	Manure/slurry	Energy	Low	Low	Low	Low	Low	Low	Low	0	Low
Animal-based energy	Oxen	Energy	Low	Low	Low	Low	Low	Low	Low	0	Low
Regulating Services											
Bio-remediation by micro-organisms,	Bio-remediation	Soil quality regulation	Low	Low	Low	Low	Low	Low	Low	0	Low
Filtration/sequestration/storage/accu	Detoxification	Water quality regulation	Low	Low	Low	Low	Low	Low	Low	0	Low
Filtration/sequestration/storage/accu	Pollution absorption	Air quality regulation	Low	High	High	High	Medium	High	Medium	10	High
Dilution by atmosphere, freshwater	Waste dilution	Water quality regulation	Low	Medium	High	High	Medium	Low	Medium	7	Medium
Mediation of smell/noise/visual	Vegetation screening	Cultural & spiritual values	Low	Medium	Medium	Low	Medium	Low	Low	3	Low
Mass stabilisation and control of	Erosion control	Soil quality regulation	Low	High	High	Low	Low	Low	Low	4	Low
Buffering and attenuation of mass	Sediment transport	Water quality regulation	Low	Low	Medium	Low	Low	Low	Low	1	Low
Hydrological cycle and water flow	Environmental flows	Water supply	High	Low	Low	Low	Low	Low	Low	2	Low
Flood protection	Flood protection	Flood regulation	High	High	High	Medium	High	Medium	Medium	11	High
Storm protection	Shelter belts	Storm regulation	Low	High	High	Medium	High	Low	Medium	8	Medium
Ventilation and transpiration	Ventilation	Air quality regulation	Low	Low	Low	Low	Low	Low	Low	0	Low
Pollination and seed dispersal	Pollination	Pollination	Low	High	High	Medium	Medium	Medium	Medium	8	Medium
Maintaining nursery populations and	Nursey habitats	Fisheries	Medium	Medium	Low	Medium	Low	Medium	Low	4	Low
Pest control	Pest control	Disease & pest control	Low	Medium	Medium	Medium	Medium	Low	Low	4	Low
Disease control	Disease control	Disease & pest control	Medium	Medium	Medium	Medium	Medium	Low	Low	5	Medium
Weathering processes	Soil regulation	Soil quality regulation	Low	Low	Low	Low	Low	Low	Low	0	Low
Decomposition and fixing processes	Soil regulation	Soil quality regulation	Low	Low	Low	Low	Low	Low	Low	0	Low
Chemical condition of freshwaters	River water quality	Water quality regulation	Low	High	Medium	High	Low	High	Low	7	Medium
Chemical condition of salt waters	Bathing water quality	Water quality regulation	Low	High	Medium	High	Low	High	Low	7	Medium
Global climate regulation by reduction	Carbon sequestration	Global climate regulation	High	High	Medium	High	High	High	High	13	High
Micro and regional climate regulation	Temperature regulation	Local climate regulation	Low	Low	Low	Medium	Medium	Low	Low	2	Low
Cultural Services											
Experiential use of plants, animals	Wildlife watching	Tourism & recreation	Medium	Medium	Low	High	High	High	High	10	High
Physical use of land-/seascapes in	Nature based recreation	Tourism & recreation	Medium	Medium	Low	High	High	High	High	10	High
Scientific	Scientific values	Science & knowledge values	Low	Low	Low	Low	Low	Low	Low	0	Low
Educational	Educational values	Science & knowledge values	Low	Medium	Low	High	Medium	High	Medium	7	Medium
Heritage, cultural	Cultural values	Cultural & spiritual values	Low	Medium	Medium	Medium	Medium	Low	Low	4	Low
Entertainment	Entertainment values	Cultural & spiritual values	Low	Low	Low	Medium	Low	Medium	Low	2	Low
Aesthetic	Aesthetic values	Cultural & spiritual values	Low	High	Medium	Medium	Medium	Medium	Medium	7	Medium
Symbolic	Symbolic values	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	0	Low
Sacred and/or religious	Religious values	Cultural & spiritual values	Low	Low	Low	Low	Low	Low	Low	0	Low
Existence	Existence values	Cultural & spiritual values	Low	Medium	High	High	Low	High	Low	7	Medium
Bequest	Bequest values	Cultural & spiritual values	Low	Medium	High	High	Low	High	Low	7	Medium

Appendix C. Industry groupings in the economic impact model

Table 39 below lists the 67 industries identified in the economic impact model that was developed for the pilot stress test and the correspondence between these industries and broader industry groupings. The broader groupings correspond to the sections of the Standard Industrial Classification (SIC) 2007.

The letters and numbers for the groups and industries below match those in the labels of the results charts in Section 5, in the main body of the report.

Table 39. Correspondence between SIC Sections and model industries

SIC Section		Industries in the model	
A	Agriculture, forestry and fishing	1	Crop and animal production, hunting and related service activities
		2	Forestry and logging
		3	Fishing and aquaculture
B	Mining and quarrying	4	Mining and quarrying
C	Manufacturing	5	Processing and preserving of meat and production of meat products
		6	Processing and preserving of fish, crustaceans, molluscs, fruit and vegetables
		7	Vegetable and animal oils and fats
		8	Dairy products
		9	Grain mill products, starches and starch products
		10	Bakery and farinaceous products
		11	Other food products
		12	Prepared animal feeds
		13	Alcoholic beverages
		14	Soft drinks; production of mineral waters and other bottled waters
		15	Tobacco products
		16	Textiles
		17	Wearing apparel
		18	Leather and related products
		19	Wood and products of wood and cork, except furniture; Articles of straw and plaiting materials
		20	Paper and paper products
		21	Printing and reproduction of recorded media
		22	Coke and refined petroleum products
		23	Industrial gases, inorganics and fertilisers (all inorganic chemicals) - 20.11/13/15

SIC Section		Industries in the model	
		24	Petrochemicals - 20.14/16/17/60
		25	Dyestuffs, agro-chemicals - 20.12/20
		26	Paints, varnishes and similar coatings, printing ink and mastics
		27	Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations
		28	Other chemical products
		29	Other manufacturing
D	Electricity, gas, steam and air conditioning supply	30	Electric power generation, transmission and distribution
		31	Gas; distribution of gaseous fuels through mains; Steam and air conditioning supply
E	Water supply; sewerage, waste management and remediation activities	32	Water collection, treatment and supply
		33	Sewerage
		34	Waste collection, treatment and disposal activities; materials recovery
		35	Remediation activities and other waste management services
F	Construction	36	Construction (construction of buildings, civil engineering, and specialised construction activities)
G	Wholesale and retail trade; repair of motor vehicles and motorcycles	37	Wholesale and retail trade and repair of motor vehicles and motorcycles
		38	Wholesale trade, except of motor vehicles and motorcycles
		39	Retail trade, except of motor vehicles and motorcycles
H	Transportation and storage	40	Rail transport
		41	Land transport services and transport services via pipelines, excluding rail transport
		42	Water transport
		43	Air transport
		44	Warehousing and support activities for transportation
		45	Postal and courier activities
I	Accommodation and food service activities	46	Accommodation
		47	Food and beverage service activities
J	Information and communication	48	Information and communication
K	Financial and insurance activities	49	Financial service activities, except insurance and pension funding
		50	Insurance and reinsurance, except compulsory social security; and pension funding
		51	Activities auxiliary to financial services and insurance activities
L	Real estate activities	52	Real estate activities
M	Professional, scientific and technical activities	53	Legal, accounting, head offices, and management consultancy
		54	Architectural and engineering activities; Technical testing and analysis
		55	Scientific research and development
		56	Other professional, scientific and technical activities

SIC Section		Industries in the model	
N	Administrative and support service activities	57	Administrative and support service activities
O	Public administration and defence; compulsory social security	58	Public administration and defence; Compulsory social security
P	Education	59	Education
Q	Human health and social work activities	60	Human health activities
		61	Social care services (residential care activities, and social work activities without accommodation)
R	Arts, entertainment and recreation	62	Creative, arts and entertainment activities
		63	Libraries, archives, museums and other cultural activities
		64	Gambling and betting activities
		65	Sports activities and amusement and recreation activities
S	Other service activities	66	Other service activities

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