VALUING NATURE RESEARCH

Trends in Natural Capital, Ecosystem Services and Economic Development in Dorset

Valuing Nature Research Project Report

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Chapmans Pool © Roger Holman

Wimborne Minster River © David Jeffrey Morgan

Summary

How does environmental degradation affect economic development and employment? This report presents the results of research that addressed this question. The research was conducted by the project *Tipping Points in Lowland Agricultural Landscapes (TPAL)*, which forms part of the Valuing Nature Programme. The research focused on the county of Dorset, situated on the south coast of England. Land use in Dorset is dominated by agriculture, yet the county is also of high value for wildlife, and has a burgeoning green economy. It therefore provides a valuable example of the potential synergies and conflicts between wildlife conservation, economic growth and development.

Specifically this research aimed to find out:

- **How has the environment of Dorset changed in the recent past?**
- **How might it change in the near future?**
- **What are the implications of such change for human society, and specifically for economic growth and employment?**

Three main approaches were employed to address these questions:

(i) **in the past, using analysis of historical and time-series data;**

(ii) **in the present, using assessments of gradients in the field; and**

(iii) **in the future, using scenario-building and modelling approaches.**

Key results are summarized below:

- Dorset's environment has been seriously degraded over the past 80 years. Measures of biodiversity value have undergone a substantial decline in this period, as illustrated by the 97% loss of neutral grassland and 70% loss of calcareous grassland. The condition of remaining semi-natural habitats has been reduced by nitrogen deposition and habitat fragmentation; for example the mean area of heathland patches has declined by 29% since 1978. These trends are primarily attributable to agricultural intensification and changing farming practices.

- Provision of most ecosystem services, or the benefits provided by ecosytems to people, has declined significantly since the 1930s. Some services, such as soil quality and carbon storage, have declined continuously over this interval, with no sign of recovery. Others, such as mitigation of flood risk, have increased in recent years owing to changing land use, particularly the transition from arable to livestock farming that occurred over large areas after the 1950s.

- The provision of ecosystem services is important to local businesses. Overall, 47% of the Dorset businesses surveyed stated that they were at least somewhat dependent on service flows. Economic sectors that were highly dependent on ecosystem services included tourism and travel, manufacturing, education and agriculture. The most important services to businesses were provision of freshwater, waste and water treatment, microclimate regulation, water quality and carbon storage.

- Economic analyses indicate that the further expansion of agriculture would provide limited benefits to the local economy. Even if all remaining land in Dorset that is suitable for agriculture were converted to farmland, Gross Value-Added (GVA) would increase by ≤ 0.3%. However, investment in natural capital, aiming to improve the extent and condition of semi-natural ecosystems, could have a much greater impact on the economy, with GVA increases of up to 5% in the scenarios explored. Such investment could deliver an £0.8 billion increase in GVA and create more than 25,000 jobs.

- Rural land use can significantly affect the wider economy by influencing the provision of ecosystem services to other business sectors. This influence of farming on the wider economy is ignored by conventional approaches to economic forecasting, but can substantially outweigh the value of the agricultural sector itself.

- We detected a number of ecological thresholds in relation to the status of natural capital assets. These suggest that future environmental degradation could lead to relatively abrupt changes in provision of ecosystem services, which could have a significant impact on the local economy and employment. Investment in natural capital could help mitigate these risks.

- Recommendations are provided regarding policy and management options for strengthening natural capital in the region, while supporting incomes to farmers.

Context

We live in an era of unprecedented environmental change. Examples include rapid changes in global climate and land cover, increasing pollution and biodiversity loss, and widespread environmental degradation. These trends are creating major societal challenges owing to declining natural resources, and increasing risks to human health and wellbeing. These challenges are illustrated by the UN's Sustainable Development Goals, more than half of which are explicitly linked to environmental degradation.

Although the importance of environmental change is widely appreciated, its impacts on human society are less well understood. In particular, there is uncertainty regarding how such changes might affect economic development and employment. Is environmental change something that we can readily live with, or adapt to? Or is it something that might threaten our economy, jobs and wellbeing?

This report describes research undertaken to help answer these questions. The project Tipping Points in Lowland Agricultural Landscapes (TPAL) formed part of the Valuing Nature Programme (http://valuing-nature.net/), a multi-disciplinary initiative designed to improve how the natural environment is represented in valuation analyses and decision making.

The research focused on the county of Dorset, which is situated on the south coast of England. Specifically we aimed to find out:

- **How has the environment of Dorset changed in the recent past?**
- **How might it change in the near future?**
- **What are the implications of such change for human society, and specifically for economic growth and employment?**

[1] Ash Futures (2015). *Dorset's Environmental Economy.* Report for Dorset County Council. Ash Futures, Devon.

Poppies Near Fontmell Down © Roger Holman

Dorset is exceptionally important for wildlife. The UK's richest grid squares for vascular plants and mammals are both found in Dorset, leading to its recognition as a "biodiversity hotspot". There are many habitats of international significance for conservation, including important cliff and maritime areas, chalk rivers, lowland heathland, calcareous grasslands and ancient woodlands. Dorset also possesses scenically attractive landscapes and coastline. These attract large numbers of tourists each year, who make a significant contribution to the local economy. Dorset's land use is dominated by agriculture, in a way that is typical of much of lowland north-west Europe.

In recent decades, the landscapes of Dorset have changed markedly in response to shifting patterns of land use. Many habitats that are valuable for wildlife have been lost or degraded, as a result of agricultural intensification and increasing development pressures. Notable species such as tree sparrows, wild asparagus and fan mussel are now close to extinction, whereas other species such as pearl-bordered and high brown fritillary butterflies have been lost altogether.

Do these changes matter? If the environment is deteriorating in this way, what are the implications for society? A recent report[1] attempted to estimate the value of Dorset's environment to the local economy, and found that the environment contributes about £1.5bn of GVA per annum and supports about 30,000 jobs in the county. This represents about 8-10% of total annual economic output and employment in Dorset. The current report aims to build on this analysis by further examining the links between the economy and the environment. Specifically, it explores how these relationships have changed in the past and how they might alter further in the future.

Natural Capital, Ecosystem Services and Tipping Points

Recent efforts to understand the links between the environment and the economy have focused on the concept of *natural capital*. This can be viewed as one of the five types of capital asset that are needed to support the economy, along with social, human, manufactured and financial capital. Natural capital can be defined as the elements of nature that directly and indirectly produce value or benefits to people[2]. Natural capital assets include different components of the environment, including species, ecological communities and ecosystems, and the ecological processes that influence their structure and dynamics.

These natural assets represent natural capital *stocks*. Whereas stocks of financial capital can provide flows of income or expenditure, stocks of natural capital provide flows of benefits to people. These are referred to as *ecosystem services,* and include many benefits on which human lives depend, including clean air and water, food, materials and energy, together with cultural and aesthetic benefits (**Figure 1**). Such ecosystem services can be valued in monetary or non-monetary terms, but they are generally omitted from traditional approaches to economic accounting and planning.

The relationships between natural capital stocks and provision of ecosystem services can change over time and place. In the context of understanding the impacts of environmental change on human society, the relationship between the condition of a natural asset and provision of ecosystem benefits is of particular importance. Environmental degradation may lead to a decline in natural asset status, which could reduce the benefits provided to people[3]. Potentially, this relationship could either be linear, or it could be non-linear (**Figure 2**). However, the form of this relationship is not well understood. One of the main objectives of the research described here was to determine the form of this relationship, as it applies to natural capital assets in Dorset.

[2] Natural Capital Committee (2014). *State of Natural Capital: Restoring Our Natural Assets.* 2nd report. NCC, London

[3] Mace, G.M. *et al.* (2015). *J. Appl. Ecol.* 52, 641-653.

[4] Groffman, P.M. *et al.* (2006). *Ecosystems* 9, 1-13.

[5] Natural Capital Committee (2014). *State of Natural Capital: Restoring Our Natural Assets.* 2nd report. NCC, London

[6] Mace, G.M. *et al.* (2015). *J. Appl. Ecol.* 52, 641-653.

View west from Eggardon Hill © Panglossian

Why is the form of this relationship important? If environmental change causes a decline in the condition of natural capital assets, then this might happen gradually. Alternatively, a small change in natural asset status might lead to a large decline in the flow of ecosystem benefits, which might happen abruptly and unexpectedly. This could occur if the relationship is non-linear, for example if it is characterised by an *ecological threshold*[4].

Some ecological thresholds are driven by positive feedback processes, which can increase the rate of change. An example is provided by the melting of ice caps and glaciers caused by global warming. Loss of ice reduces albedo, which increases the amount of solar energy absorbed, leading to more warming. There is currently great concern that processes such as this could lead to tipping points, or critical thresholds beyond which rapid changes will occur that might be difficult to reverse (**Figure 3**). Melting ice caps provide a powerful example of a tipping point.

Might there be thresholds or tipping points in natural capital? In other words, could environmental change lead to rapid declines in ecosystem service flows? Could the economy suffer as a result? The identification of such thresholds and tipping points, and their potential consequences, was a central objective of the research described here. Three approaches were employed to detect such changes:

(i) **in the *past*, using analysis of historical and time-series data;**

(ii) **in the *present*, using assessments of gradients in the field; and**

(iii) **in the *future*, using scenario-building and modelling approaches.**

Figure 1. Natural capital and provision of ecosystem benefits to people: a framework. (Adapted from the Natural Capital Committee, 2014)[5].

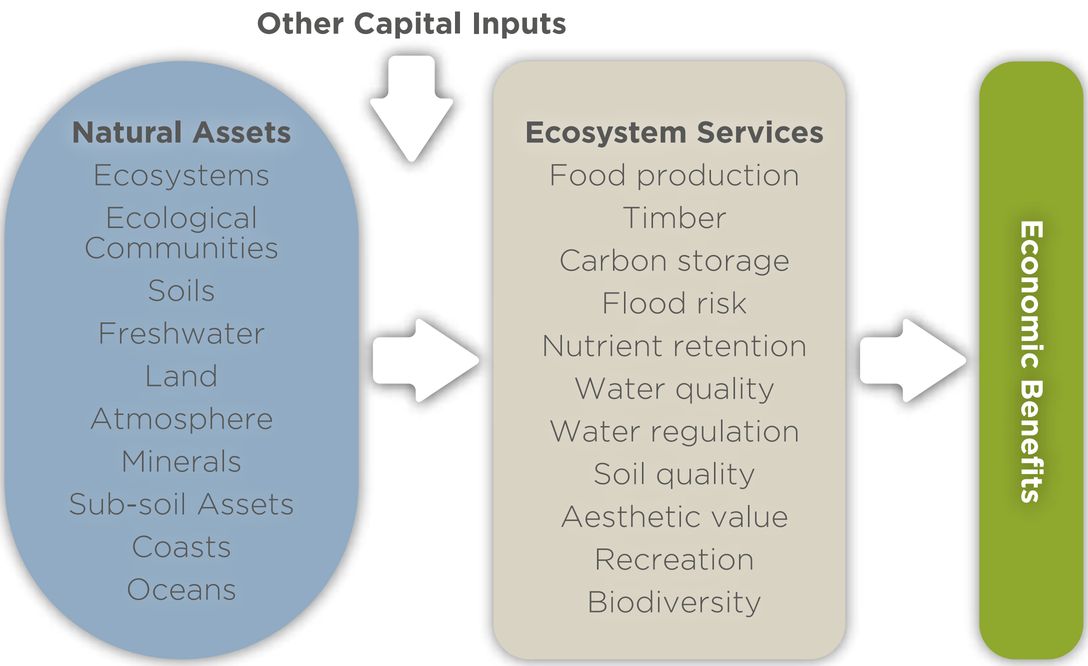


Figure 3. Tipping points in natural capital. Anthropogenic pressures, such as land cover change, pollution or climate change, can lead to a change in the condition or state of an ecosystem. These changes can happen abruptly, representing an ecological threshold. Where such thresholds are caused by a positive feedback mechanism, they are referred to as tipping points.

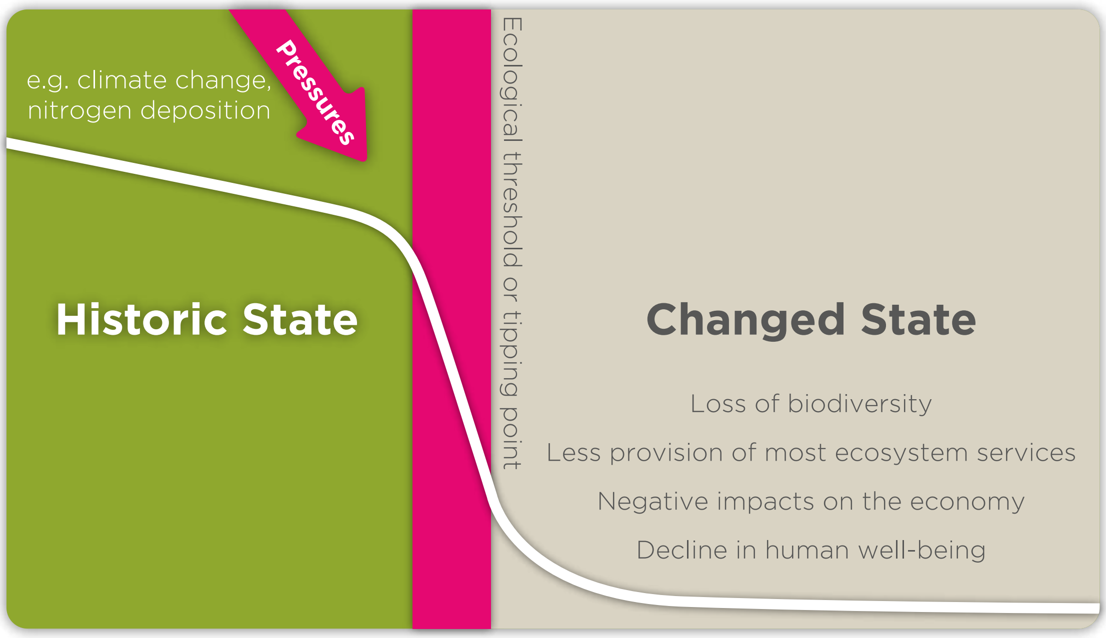


Figure 2. Possible relationships between the status of natural capital assets and the flow of ecosystem benefits[6]. (**2a**) The lines illustrate the how the flow of benefits might change in response to variation in the status or condition of natural assets, which could be caused by environmental degradation. The continuous line shows a threshold response (or tipping point).

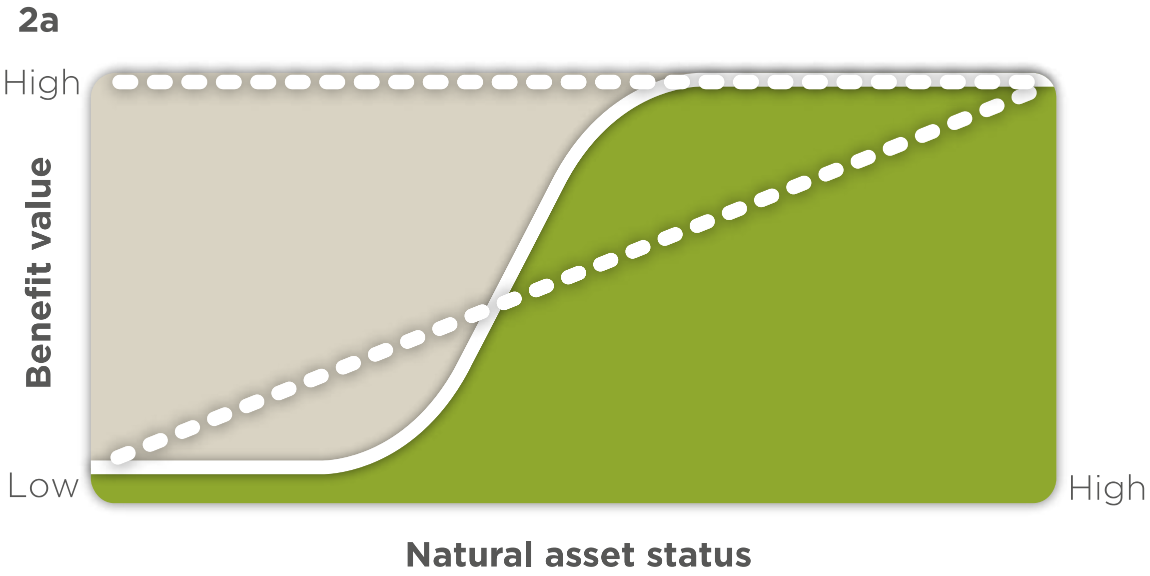
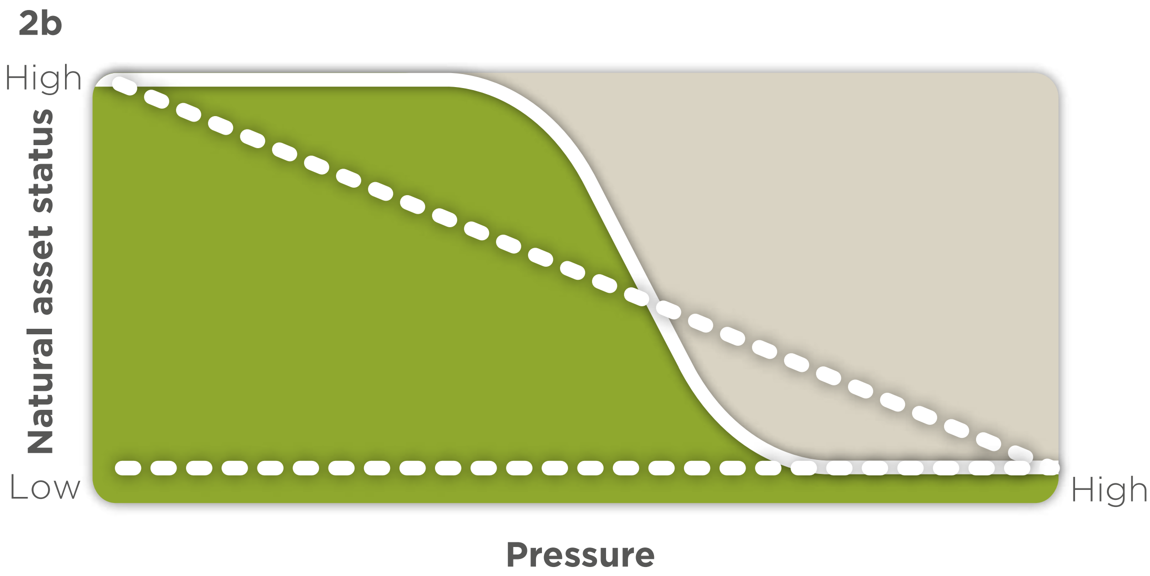


Figure 2. (**2b**) The relationship between anthropogenic pressures and natural capital status may also demonstrate a threshold response (continuous line).



Environmental Change in Dorset

Today, around 75% of Dorset's land area is farmed, of which about a third is arable farmland. In the UK as a whole, agriculture accounts for about 70% of land area, so Dorset can be considered as a fairly typical county in terms of patterns of land use. But how has this pattern changed over time?

To answer this question, we created a series of land cover maps for Dorset (**Figure 4**), which were based on available historical maps and land use data, together with historical vegetation surveys and resurveys. Results indicated that the total proportion of the land cover comprising agricultural land remained roughly constant over the past 80 years. However, there were significant changes in the extent and distribution of different agricultural land use practices. Arable land, for example, increased markedly in extent between 1930 and 1950, but declined steadily thereafter. Conversely, improved grassland remained limited in extent until 1950, but afterwards underwent a substantial increase, reaching a maximum value at the present day. Other vegetation types that increased in area over time included conifer plantations, ranging from a value close to zero in 1930 to 3.4% of land area in 2015.

To illustrate the extent of these changes, by 2015:

- **31% of arable land present in 1930 had been converted to improved grassland;**
- **64% of neutral grassland had been converted to agriculturally improved grassland;**
- **43% of calcareous grassland had been converted to arable, and 47% to improved grassland;**
- **50% of acid grassland had been converted to improved grassland; and**
- **22% of heathland and 17% of broadleaved woodland had been converted to conifer plantations.**

Hambledon Hill © Roger Holman

Land cover change therefore represents the form of environmental change that has affected the natural capital of Dorset most profoundly. However, other types of change have also been influential. Our research into changes in the composition of plant communities in Dorset over the past 80 years[7] has consistently revealed an influence of nutrient enrichment. Even in vegetation that has not been converted to agricultural use, there have been widespread changes in community composition, with plant species favouring higher nutrient availability becoming more abundant over time. Conversely, species favouring low-nutrient conditions have become increasingly rare. This demonstrates how use of fertilizers on farms has negatively affected ecosystems throughout Dorset.

In some plant communities, climate change has also had an impact, with species tolerating higher temperatures becoming more abundant over time. Other changes in Dorset include increasing urbanisation and human population size, increasing pollution and waste, spread of invasive species, and spread of novel diseases of plants and animals. While we have not investigated these factors explicitly, they are all likely to have affected natural capital over the past 80 years. For example, the spread of myxomatosis in the 1950s devastated rabbit populations, and is likely to have had a major impact on grassland habitats in particular.

What has driven these changes? Trends in agricultural land use are largely attributable to the shifting provision of capital grants and subsidies, reflecting changes in government policy. Since 1945, farming practices have become increasingly intensive, leading to an almost fourfold increase in yield. The productivity and efficiency of farming have increased steadily since 1950, in a linear fashion (**Figure 5**). These increases were partly accompanied by increased mechanisation of farming, as illustrated by the number of tractors in use, which increased rapidly after 1945 to reach a peak in the 1980s. Fertilizer use also increased steadily after 1940 to reach a peak in the 1980s, after which it has declined somewhat. Pesticide use was relatively low in the 1970s, but increased markedly after the late 1980s, and is currently near an all-time high. Over time, at the national scale, farms have tended to increase in size and become more specialised; chemical applications have increased massively; around 50% of hedgerows have been removed; and farm labour has decreased by 77%[8].

[7] Keith, S.A. *et al.* (2011) *Oikos* 120(2), 302-331, Keith, S.A. *et al.* (2009) *Proc. Roy. Soc.* 276, 3539-3544, Staley, J.T. *et al.* (2013) *Biol. Cons.* 167, 97-105, Diaz, A. *et al.* (2013) *Biol. Cons.*167, 325-333, Newton, A.C. *et al.* (2012) *J. Ecol.* 100 (1), 196-209.

[8] Robinson, R.A. and Sutherland, W.J. (2002). *J. Appl. Ecol.*, 39, 157-176.

[9] Robinson, R.A. and Sutherland, W.J. (2002). *J. Appl. Ecol.*, 39, 157-176.

Figure 4. Maps illustrating the change in Dorset's land cover over time. The 1930s map was based on Hooftman & Bullock (2012) Biol. Conserv. 145, 30–38. The 2015 map was based on Rowland et al. (2017). Land Cover Map 2015, NERC EIDC. InVEST was used to model the landscapes for 1950 and 1980.

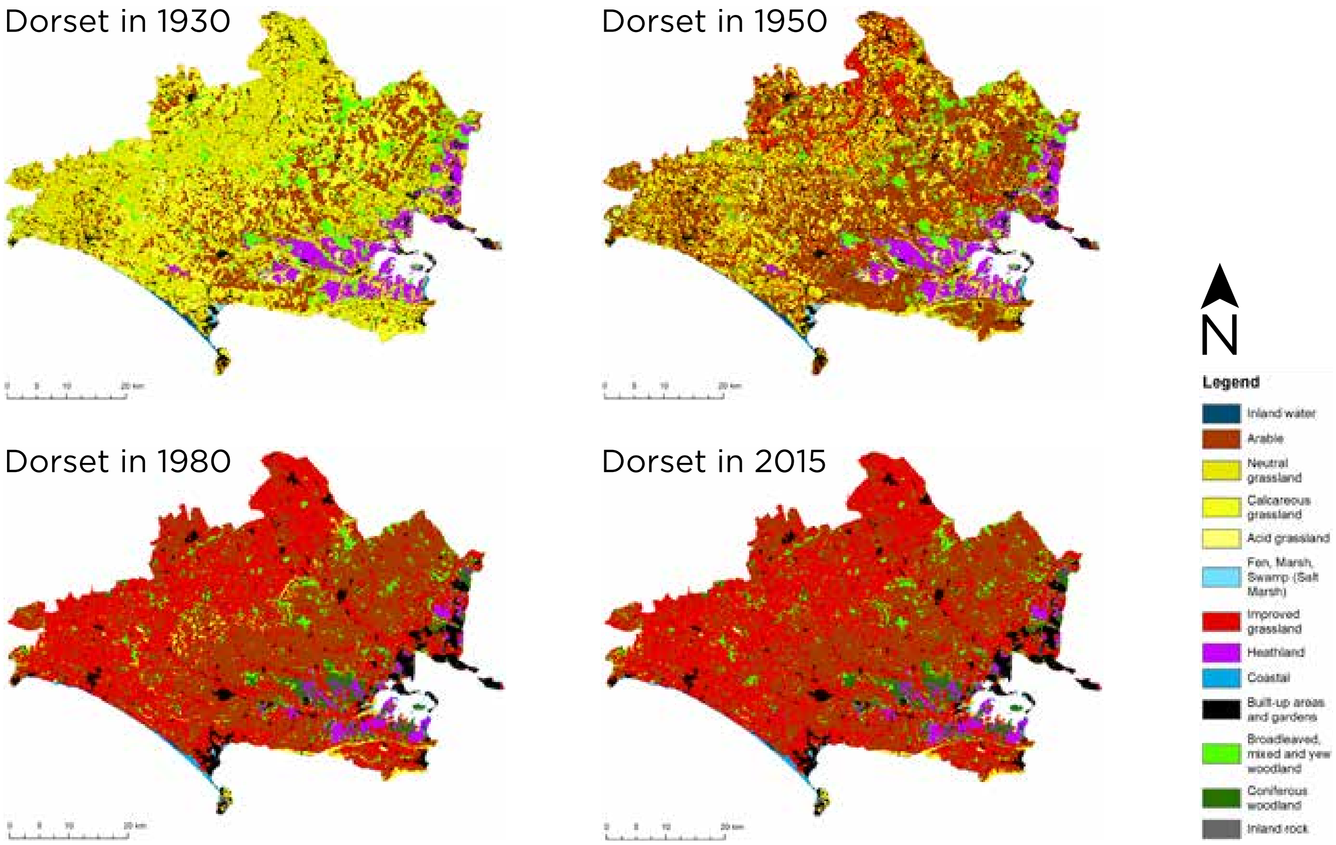
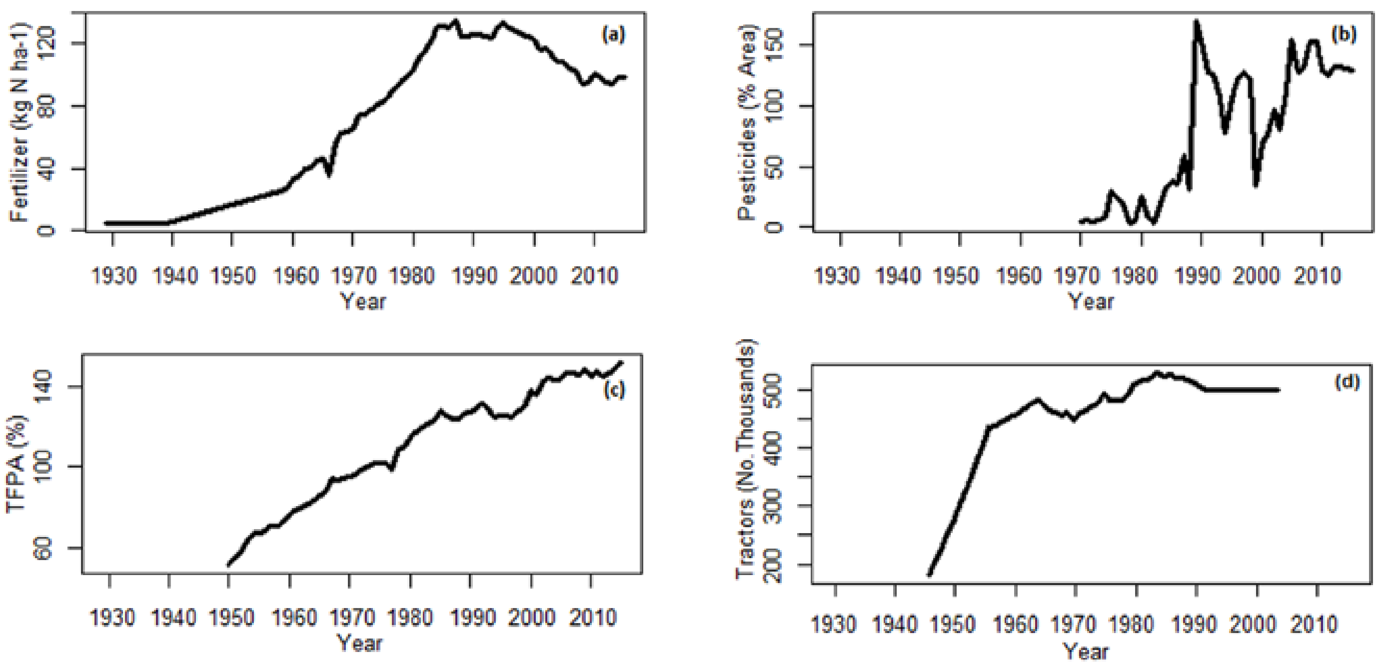


Figure 5. Trends in UK farming metrics over the last 80 years[9]. (a) Total amount of fertilizer applied in Britain, (b) area sprayed with insecticide in the county of Sussex, UK, (c) total factor productivity of UK agriculture (TFPA), (d) numbers of tractors in use in the UK..



Trends in Natural Asset Status: Habitat Area

There are three different aspects of natural capital assets that could potentially vary as a result of environmental change[10]: (i) the *quantity* or area of the asset; (ii) the *quality* or condition of the asset; and (iii) the *spatial configuration* or location and spatial distribution pattern of the asset. Our research examined how each of these three dimensions has changed over time, and how such changes affected flows of ecosystem services to people.

In relation to changes in area, we examined trends in habitats of relatively high biodiversity value. To achieve this, we analysed field survey data in conjunction with the time series of land cover maps. The field data were based on a systematic survey of plant species undertaken in the 1930s by Professor Ronald Good at 7575 sites across Dorset. These "Good sites" were resurveyed in the 1980s by Anne Horsfall, and more recently by the current authors and their colleagues.

Over the last 80 years there has been a considerable loss of semi-natural habitat in Dorset, including calcareous grassland, acid grassland, neutral grassland, wet habitats (fen, marsh swamp), and heathland. Neutral grassland and calcareous grassland have suffered the greatest losses, with declines of 97% and 70% of their initial area, respectively (**Figure 6, 7**). Substantial declines were also recorded in wetland, acid grassland and heathland sites, with losses recorded of 63%, 54% and 57%, respectively. The highest rate of loss of these habitats occurred between the 1950s and 1980s (20% loss), followed by the 1930s to 1950s (14%). Only 1% of semi-natural habitat sites were lost between 1990 and 2015.

Preliminary results from our research show that sites that were protected through designation as a Sites of Special Scientific Interest (SSSI) were more likely to remain as their original habitat, compared to those sites that were not protected (**Figure 8**). These results show that statutory protection has been beneficial in preventing habitat loss, which provides important evidence to policy makers and land managers when undertaking conservation decisions in the future.

[10] Mace, G.M. *et al.* (2015). *J. Appl. Ecol.* 52, 641-653.

Figure 6. The number of sites for each semi-natural habitat (acid grassland, broadleaved woodland, calcareous grassland, heathland, neutral grassland, wet) and land cover type (coniferous woodland, improved grassland, arable, urban) across Dorset in 1930, 1950, 1970, 1990 and 2015.

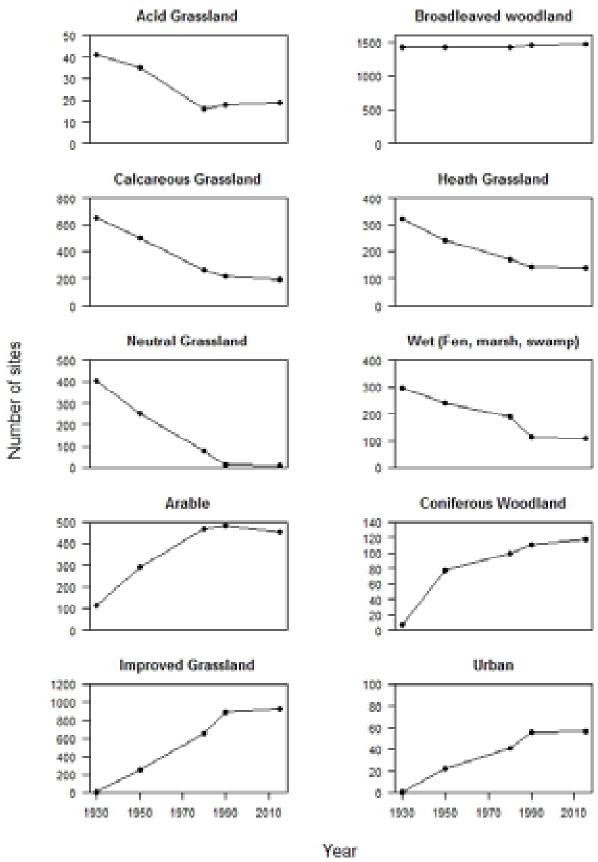


Figure 7. The percentage of neutral grassland, calcareous grassland, wetland habitats, heathland and acid grassland sites that were converted to a more intensively used land cover type (arable, improved grassland, urban, broadleaved, coniferous and other) in Dorset in 1950, 1980, 1990 and 2015.

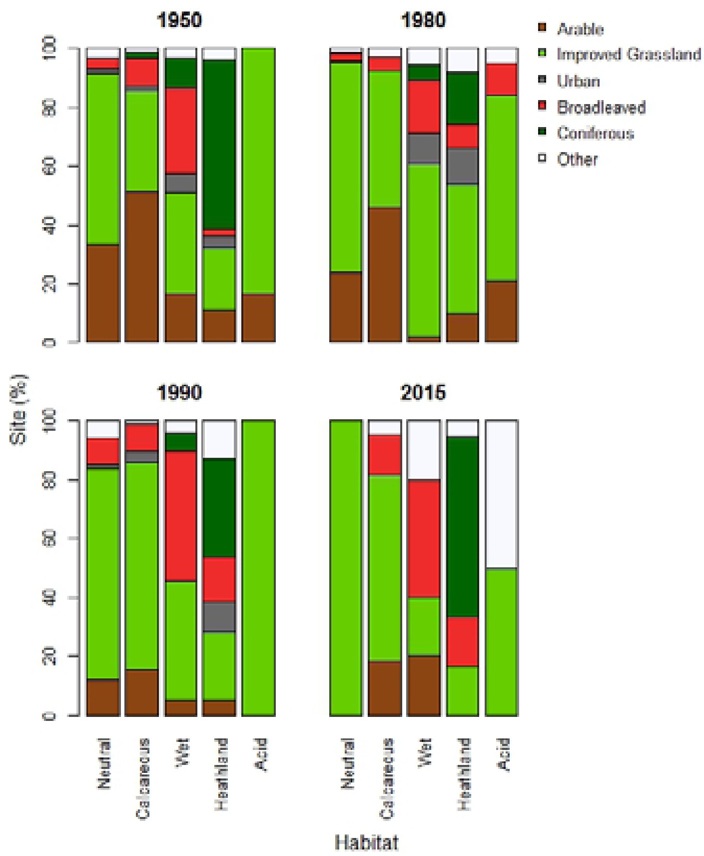
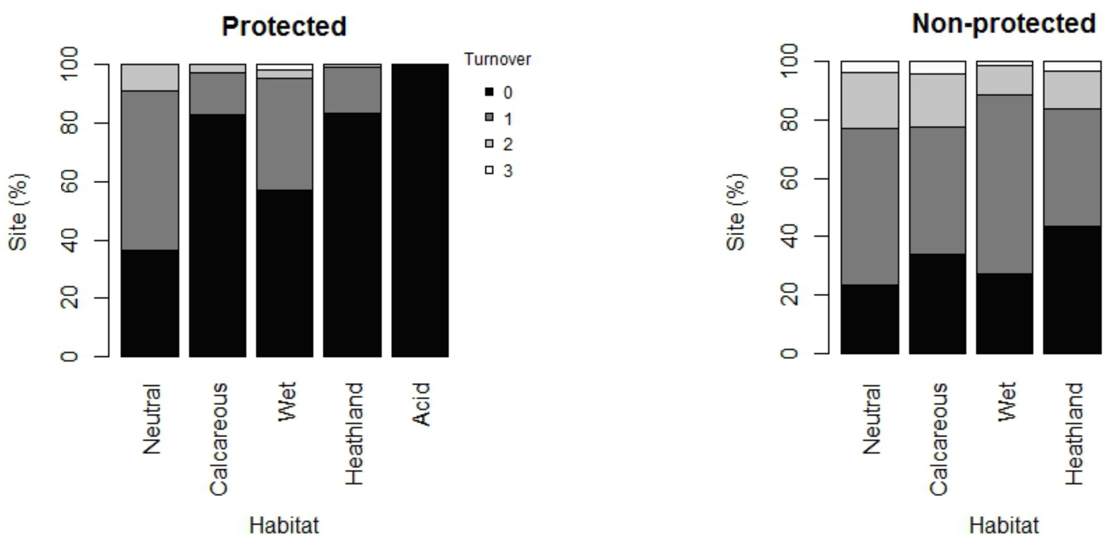


Figure 8. The turnover of protected and non-protected sites across Dorset between 1950 (post protection designations) and 2015 for sites that were neutral grassland, calcareous grassland, wetland habitats, heathland and acid grassland in 1930, where a turnover of 0 indicates that the habitat has not changed and .a turnover of 3 indicates that the habitat changed in each of the time periods assessed post-1930.



Trends in Natural Asset Status: Condition and Fragmentation

In addition to area, our research examined two additional measures of natural asset status: condition and spatial configuration. In this context, condition refers to the functional capacity of a particular ecosystem. Environmental change can affect a variety of ecological processes influencing ecosystem function, including cycling of energy, water, nutrients and other materials. A decline in ecosystem function can reduce the capacity of ecosystems to provide benefits to people.

The relationships between environmental change, ecosystem condition, ecosystem function and benefit flow are not well understood. Here we examined changes in condition by examining two key drivers that have affected ecosystems in Dorset: nitrogen deposition and climate change. To achieve this, we compiled time-series data and associated models.

Nitrogen deposition can have major impacts on the structure and composition of ecosystems; for example, under high nitrogen availability heathlands can be transformed into grasslands. Ecosystem function can also be adversely affected by nitrogen deposition. Results indicated that nitrogen deposition increased steadily since the 1930s, to reach a peak in the 1980s (**Figure 9**). Values of total nitrogen deposition include emissions of oxidised nitrogen from fossil fuel combustion and reduced nitrogen from agricultural sources. Recent trends of declining nitrogen deposition partly reflect declining fertilizer use but are largely attributable to reduced emissions from vehicles and heating sources.

Dorset has also experienced significant climate change over the past 80 years. Mean summer temperatures have increased by about 0.02 °C per year (**Figure 10**). Although total mean annual rainfall has not increased significantly, there have been changes in the pattern of rainfall distribution, with a trend towards wetter winters and drier summers. There has also been an increase in the incidence of drought. While the full impacts of both climate change and nitrogen deposition on the condition of Dorset ecosystems are unknown, there is clear evidence of significant changes in species composition, as revealed by resurveys of vegetation data .

Spatial configuration provides a further measure of natural capital status. Many species are dependent on maintenance of functional links between different patches of habitat, in order to maintain viable populations. Many

[11] Keith, S.A. *et al.* (2011) *Oikos* 120(2), 302-331, Keith, S.A. *et al.* (2009) *Proc. Roy. Soc.* 276, 3539-3544, Staley, J.T. *et al.* (2013) *Biol. Cons.* 167, 97-105, Diaz, A. *et al.* (2013) *Biol. Cons.*167, 325-333, Newton, A.C. *et al.* (2012) *J. Ecol.* 100 (1), 196-209.

[12] McGarigal, K. *et al.* (2012) FRAGSTATS 4. **https://www.umass.edu/landeco/research/fragstats/fragstats.html**

[13] From Cordingley J.E. *et al.* (2015). *PLOS One* 10(6), e0130004.

[14] From Cordingley J.E. *et al.* (2015). *PLOS One* 10(6), e0130004.

[15] Tipping, E. *et al.* (2017). *Sci. Rep.* 7, 1-11.

[16] Martin, P.A. *et al.* (2015). *Forest Ecology and Management* 358, 130-138.

[17] Cordingley, J.E. *et al.* (2015) *Journal of Applied Ecology* 53(1), 96-105.

Summer Landscape Above Bowerchalke © Roger Lane

ecological processes, including the dispersal of organisms and flows of energy and materials, are influenced by the spatial configuration of habitats. The size, density and connectivity of habitat patches are of particular importance in this context. Land cover change can result in increased habitat fragmentation, leading to declining patch size and connectivity. Globally, this has been identified as a major cause of biodiversity loss.

Using the time series of land cover maps of Dorset, we analysed how different habitats have become increasingly fragmented over time. This was achieved using FRAGSTATS, a software program designed to calculate a wide range of landscape pattern metrics . Results showed how key habitats have become progressively more fragmented since 1930, with a decline in mean patch size and an increase in the number of patches observed in many habitats (**Figure 11**, **12**). Patterns of habitat fragmentation in Dorset are illustrated by the example of heathlands, where the mean area of heathland patches has declined by 29% since 1978 (**Figure 13**, T**able 1**). The effects of habitat fragmentation on ecosystem functions and services are not well documented. However in Dorset heathland, we found that decreasing fragment size was found to be associated with a decrease in biodiversity and recreational values, but an increase in relative carbon storage, aesthetic value and timber values. This reflects more rapid ecological succession on smaller heaths.

Table 1. Fragmentation metrics for the Dorset heathlands over four surveys calculated using FRAGSTATS[14].

	Total number of heath fragments	Total number of heath fragments under 10 ha	Mean area (ha)	Maximum area (ha)	Median area (ha)	Mean distance to nearest heath (km)	Median distance to nearest heath (km)
1978	112	31	111	992	30	0.69	0.40
1987	130	45	90	992	22	0.63	0.40
1996	130	47	78	820	18	0.61	0.45
2005	110	35	79	708	20	0.63	0.45

Figure 9. Modelled atmospheric nitrogen deposition totals from all sources (wet, dry, oxidised, reduced) combined, for Dorset (data from CEH, 2019[15]).

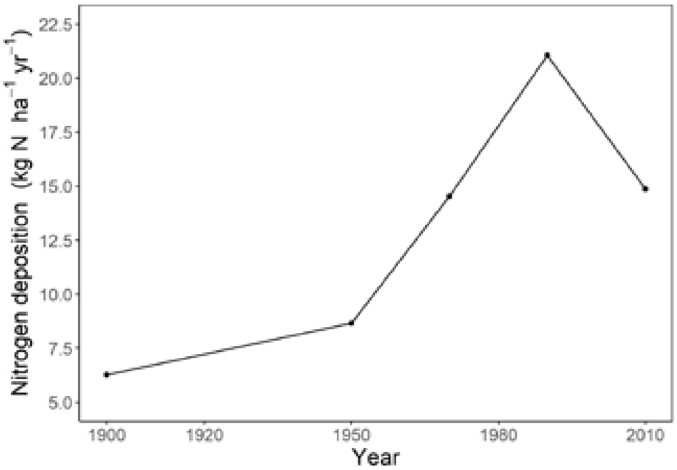


Figure 10. Climate records from 1964 to 2014 showing (a) mean temperature during April–September (b) incidence of drought years. Data taken from the Hurn weather station, Dorset[16].

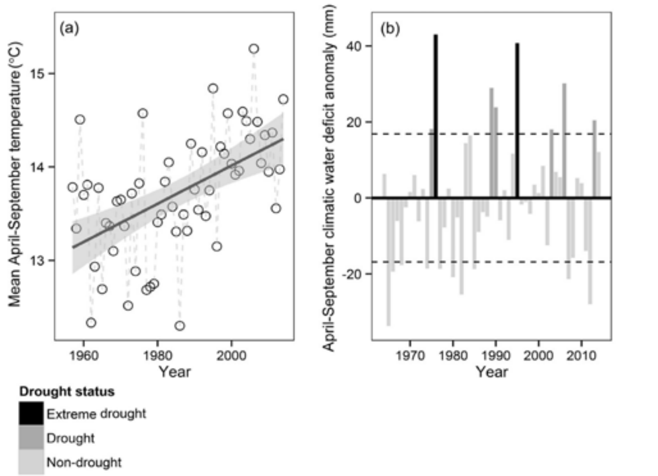
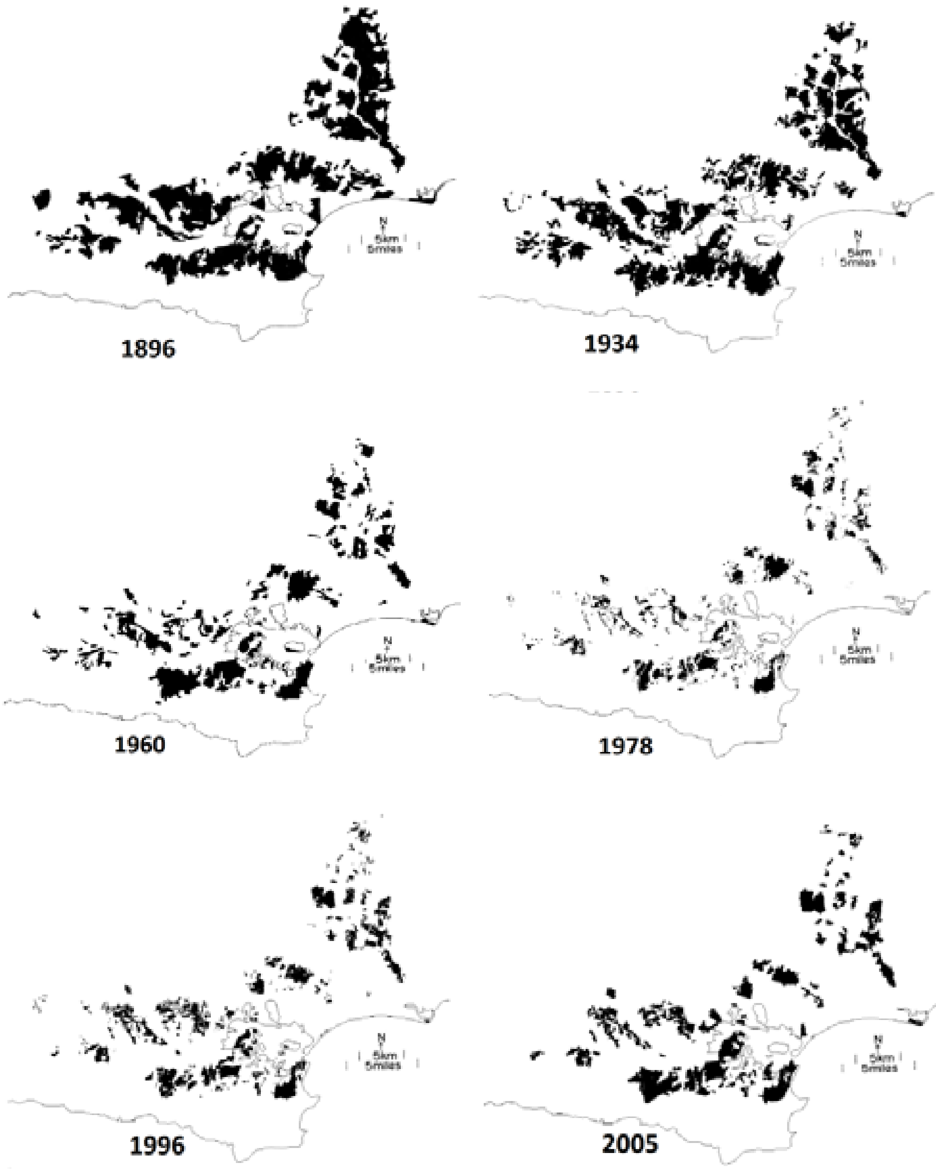


Figure 13. Maps indicating the progressive fragmentation of heathland in Dorset over time[17].



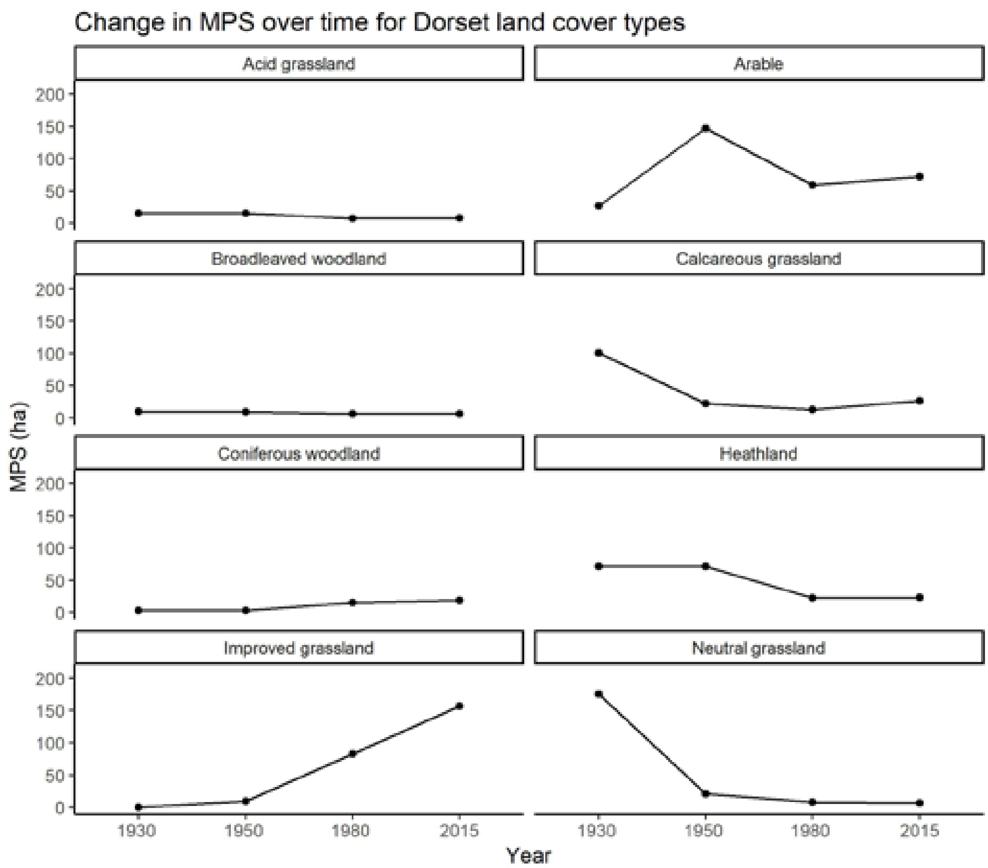


Figure 11. Changes over time in the mean patch size of different land cover types in Dorset, determined using FRAGSTATS.

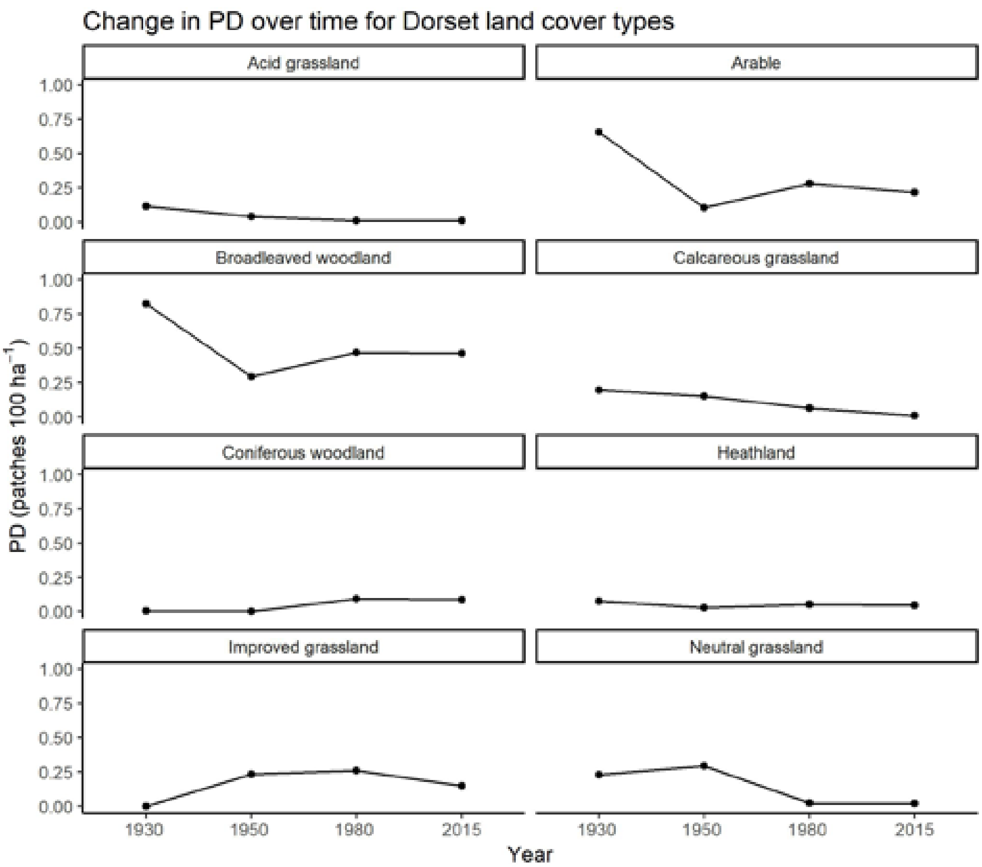


Figure 12. Changes over time in the patch density of different land cover types in Dorset, determined using FRAGSTATS.

Ecosystem Condition and Service Flows

Many human activities can potentially reduce the condition of ecosystems, including pollution, harvesting of plants or animals, and use of livestock or fire. However, the relationships between ecosystem condition and the provision of ecosystem benefits to people are not well understood. Here we examined these relationships by conducting a field survey in Dorset along gradients of ecosystem condition. A range of different variables were measured to provide insights into variation in ecosystem functions and services, including soil carbon and nitrogen content, pollinator abundance, and both aesthetic and recreational value.

Three habitats were selected on the basis of their high ecological value: calcareous grassland, heathland and broadleaved woodland. Only sites that had been identified as these respective habitats by field surveys conducted in the 1930s were selected. Thirteen sites were chosen for each habitat type to provide gradients of decreasing ecosystem condition, representing the common patterns of ecosystem degradation in Dorset. The gradients were as follows:

Calcareous grasslands (SSSI quality) → restoring calcareous grassland → improved grassland

Heathland (SSSI quality) → gorse-covered heathland → coniferous plantation

Ancient woodland (SSSI quality) → broadleaved woodland → coniferous plantation

Measurements were made within 50 x 50 m sample plots located randomly within each site. Analysis of floristic composition enabled each site to be classified according to the National Vegetation Classification (NVC). Ecosystem condition was assessed as the degree of similarity in vegetation composition to that of relatively undisturbed sites, using the NVC classification as a reference.

The majority of ecosystem functions and services displayed linear relationships with ecosystem condition, along the gradients (**Table 2**). Over half of the variables assessed displayed a positive relationship,

[18] **http://www.cldm.ceh.ac.uk/exceedances/maps**

Figure 14. An estimated smoothing curve (solid line) with standard error (blocked grey area) for the model of the carbon content of trees (m^2) across a woodland gradient (a higher NVC fit equates to a better quality site). This is an example of a negative linear relationship (-) in **Table 2.**

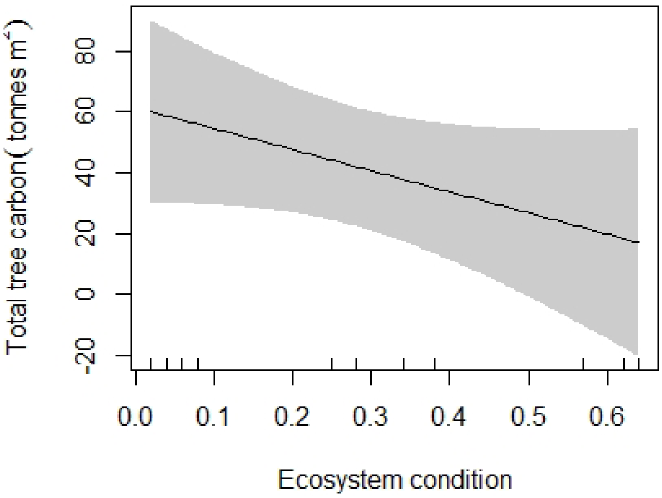
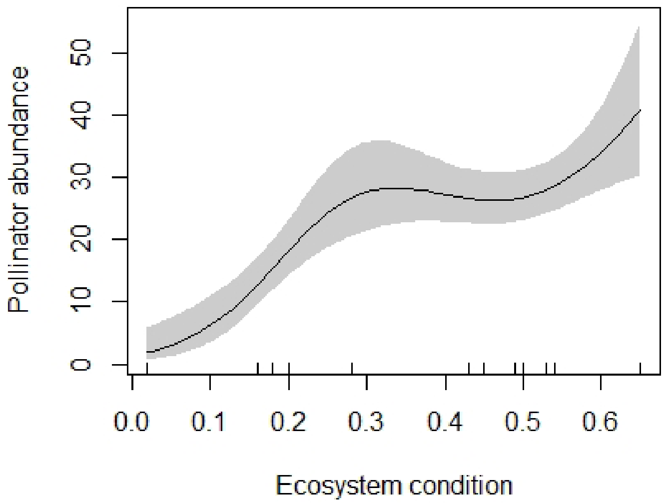


Figure 15. An estimated smoothing curve for the model that contains pollinator (bumblebee, solitary bee and butterfly) abundance with standard error (blocked grey area) across a calcareous grassland gradient. A higher NVC fit equates to a better quality site. This is an example of a non-linear relationship (+/-) in **Table 2**.



increasing with an improvement in site condition, although a fifth of the relationships were negative in trend (**Figure 14**). Some non-linear relationships were also observed (**Figure 15**). Overall, results also showed that ecosystem functions and services may often be less sensitive to environmental change than floristic composition. For example, if an ancient broadleaved woodland were converted into a conifer plantation, species composition might change completely, but the amount of carbon stored in the vegetation might change relatively little.

Another way of considering ecosystem condition in Dorset is to refer to data on critical loads. Internationally agreed critical loads have been defined for the protection of a number of habitats, in relation to different pollutants. Exceedance of these critical loads indicates where there is the potential for harmful effects to occur. Evidence for Dorset indicates that critical loads for nitrogen are currently being exceeded throughout the county, in all habitats, by at least 7 kg N ha^{-1} yr^{-1}.[18] How this is affecting ecosystem service flows is largely unknown.

Table 2. Summary of significant relationships between ecosystem functions and services, and ecosystem condition along gradients. + positive relationship, - negative relationship, +/- non-linear relationship.

	Soil Carbon	Soil Nitrogen	Soil C:N ratio	Vegetation C:N	Pollinator abundance	Aesthetic value	Total tree C
Calcareous Grassland	+/-	+/-	-	+	+	+	n/a
Heathland	+	+	+	+	+/-	+	n/a
Woodland	-	+	-	-	+/-	+	-

Trends in Ecosystem Services

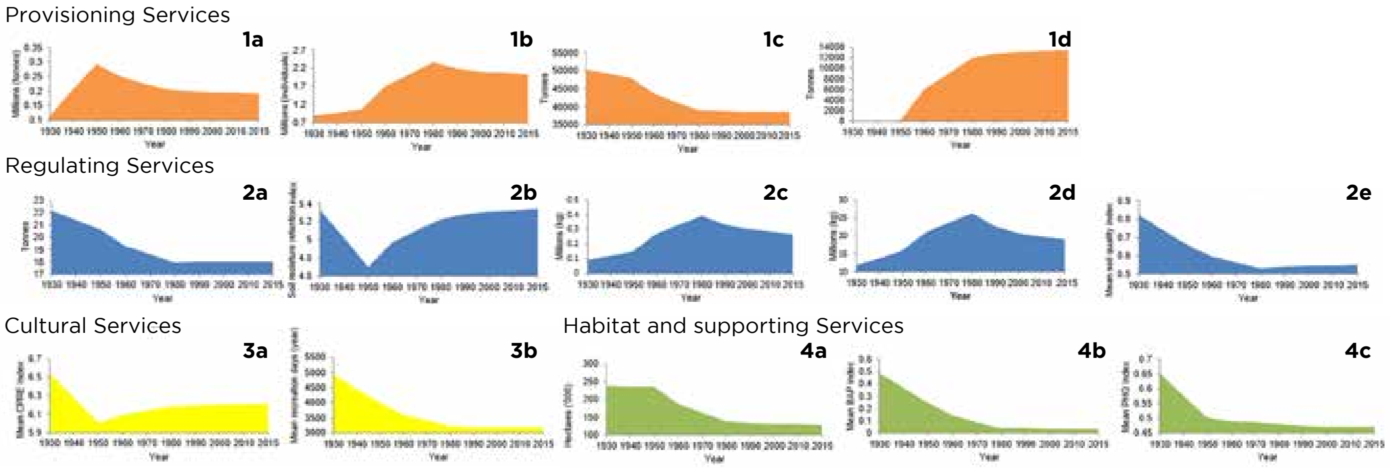
We used the time series of historical land cover maps to estimate how flows of ecosystem services have changed over time. To achieve this, we used the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) software models[19] for the periods 1930, 1950, 1980 and 2015. Using this approach, we mapped the ecosystem service values of Dorset at a 100 m x 100 m resolution for 12 services, including food production (crops and livestock), timber production, carbon sequestration and storage, flood protection, water purification, soil quality, water regulation, aesthetic value, recreation, habitat quality for pollinators and biodiversity value.

Key results were as follows (**Figures 16, 17**):

- **Measures of biodiversity value have undergone a substantial decline since the 1930s. We mapped the quality of habitat for species of conservation concern (i.e. those listed on the UK's Biodiversity Action Plan (BAP)), using records of field observations. This declined rapidly from 1930-1980, and more gradually thereafter. Habitat quality for pollinating insects also declined rapidly from 1930-1950, and subsequently continued to decline at a lower rate.**
- **Production of arable crops increased rapidly from 1930 to reach a peak around 1950, after which values declined. Livestock production increased rapidly after 1950 to reach a peak in the 1980s.**
- **Timber production from conifer plantations increased substantially after the 1950s, whereas that from broadleaved woodlands declined overall, particularly between 1950 and 1980.**
- **Carbon storage, soil quality and regulation of water flow have declined since the 1930s, although the latter has recovered somewhat since reaching a minimum in the 1980s.**
- **The flow of nitrogen into the wider watershed of the catchment (i.e. 'nitrogen export') increased steadily between 1930 and 1980, declining slightly thereafter. This largely reflects patterns of fertilizer application on farmland.**
- **Mitigation of flood risk demonstrated a more complex pattern, declining rapidly between 1930 and 1950, but thereafter recovering, to reach values similar to those observed at the outset. This pattern partly reflects the increase and subsequent decline of arable land, which promotes high run-off of rainwater.**

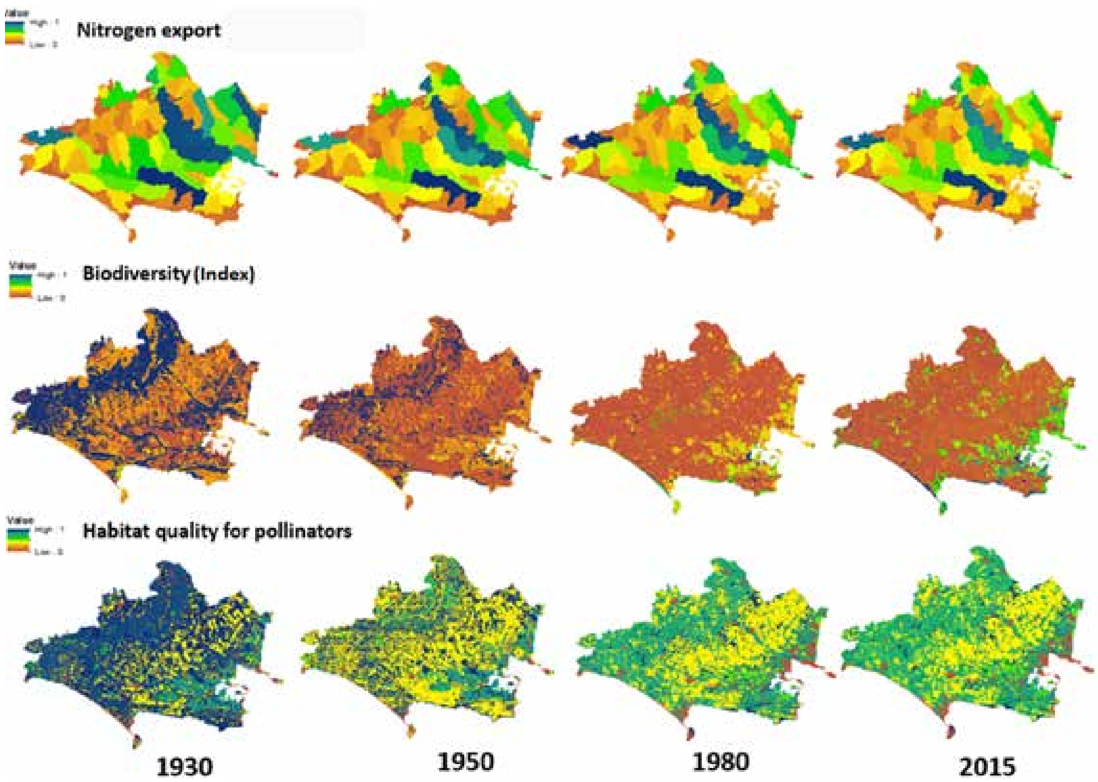
[19] https://naturalcapitalproject.stanford.edu/invest/

Figure 16. Trends in ecosystem service provision in Dorset. Values represent annual output of InVEST models and land-use-based proxies for the 1930-2015 period.



1a Food production (crops) **1b** Food production (livestock) **1c** Timber (broadleaved) **1d** Timber (coniferous) **2a** Carbon sequestration and storage **2b** Flood protection **2c** Nutrient export **2d** Nutrient retention **2e** Soil quality **3a** Aesthetic value **3b** Recreation value **4a** Habitat area (BAP species) **4b** Habitat quality (BAP species) **4c** Habitat quality (for pollinators)

Figure 17. Maps of selected ecosystem services, generated using InVEST models, to show changing distributions of service provision in Dorset over time.



Overall, nine of these measures have declined since the 1930s, primarily as a result of the intensification of agricultural and forestry practices. Contrasting dynamics of different services were attributable to shifting patterns of land use over time, particularly the increase in arable crop cultivation after 1945, and the subsequent transition from arable to livestock farming over large parts of Dorset that occurred after the 1950s, reflecting changes in agricultural subsidies. Nutrient export (a major driver of eutrophication) peaked in the 1980s, when use of artificial fertilizers reached a maximum. While some services (such as mitigation of flood risk) have increased in recent years owing to land use changes, others (such as soil quality, carbon storage and biodiversity) have declined continuously over the survey period, with no sign of recovery.

Economic Trends and Environmental Linkages

Dorset has around 30,000 businesses, about 90% of which are relatively small (i.e. fewer than 10 employees). The most important sectors in terms of their contribution to the overall economy are currently the retail trade, construction, financial and insurance, health, and public administration and defence. In terms of employment, the most important sectors are the retail trade, education, health and construction. Currently, agriculture and forestry account for just over 1% of Dorset's economy, and less than 1% of employment. Employment in agriculture has declined by more than half since 1981.

Analysis of official statistics shows that Dorset's economy has grown continuously over the past 50 years, indicated by a seven-fold increase in GVA (**Figure 18**). Employment has also risen, although at a much lower rate (**Figure 19**). These data illustrate how Dorset's economy has developed, even though the environment has deteriorated over the same period, as documented earlier in this report. This raises a pertinent question: do these opposing trends indicate that economic growth has been fuelled by environmental degradation? Or are the environment and economy simply disconnected?

We examined the links between the environment and economic activity by conducting a questionnaire survey of 200 Dorset businesses, drawn from a range of different sectors. We asked them how dependent their business activities were on the provision of different ecosystem services. Overall, 47% of businesses stated that they were at least somewhat dependent on flows of ecosystem services (**Table 3**). Results also showed that:

[20] Watson, S.C.L. and Newton, A.C. (2018). *Sustainability* 10(5), 1368 **https://doi.org/10.3390/su10051368**.

[21] ONS Office for National Statistics (2015).

[22] ONS Office for National Statistics (2015).

[23] Watson, S.C.L. and Newton, A.C. (2018). *Sustainability* 10(5), 1368

Brewery Square, Dorchester © Nigel Jarvis

- **Sectors that were highly dependent on ecosystem service flows included tourism and travel, manufacturing (food and beverages), education and agriculture (Table 3)**
- **The most important services to businesses were provision of freshwater, waste and water treatment, microclimate regulation, water quality and carbon storage (Figure 20).**
- **More than 50% of businesses reported that the quality of the natural environment was one of the main reasons for conducting business in Dorset.**
- **Many businesses placed high importance on locally produced materials and utilities, with >50% of businesses surveyed suggesting locally produced fuel, energy, water (for human consumption and industrial use) and building materials (including timber) were an important factor for locating their businesses in Dorset.**
- **Many businesses indicated little or no dependence on services such as pollination and soil condition, which may reflect a lack of awareness of dependencies occurring upstream of their value chains**.

Our research also showed that Dorset's economy is geographically structured. Most businesses are located in urban areas, which are concentrated in the south-east corner of the county. Yet most ecosystem services are produced in rural parts of the county. This shows that although the direct contribution of agriculture to the economy is low, its indirect impact on the economy is much higher. Many of Dorset's businesses are at least partly dependent on ecosystem service flows from rural areas, which are profoundly affected by the prevailing patterns of land use. How the land is used therefore has a major impact on economic development and employment, beyond the immediate contribution of agriculture as an economic sector.

Table 3. Dependency of Dorset businesses on provision of ecosystem services, averaged by sector. Values were determined by a questionnaire survey. Values presented indicate the percentage of businesses who indicated that their business operations were highly or entirely dependent on ecosystem service flows.[20]

Business Sector	ES Mean Dependency (High or Entirely dependent)	Business Sector	ES Mean Dependency (High or Entirely dependent)
Agriculture and forestry	76%	Retail	34%
Ecological consultancy	74%	Mining and quarrying	32%
Fishing	65%	Private health	31%
Education	62%	Transportation and storage	27%
Tourism and travel	60%	Public health	26%
Charitable trust	54%	Estate agencies	25%
Manufacturing (Food and beverage)	54%	Business services - scientific and technical	22%
Electricity	49%	Manufacturing (Advanced engineering)	19%
Water & sewage and waste	49%	Gas	17%
Food and beverage	43%	Advertising and promotion	13%
Construction	40%	Business services - professional services	12%
Entertainment	38%	Communication	12%
Public administration	35%	Manufacturing (Other)	9%
Wholesale	35%	Financial services	7%

Figure 18. Trends in the economy and employment estimates for Dorset: total industry Gross Value-Added (GVA) for all economic sectors.[21]

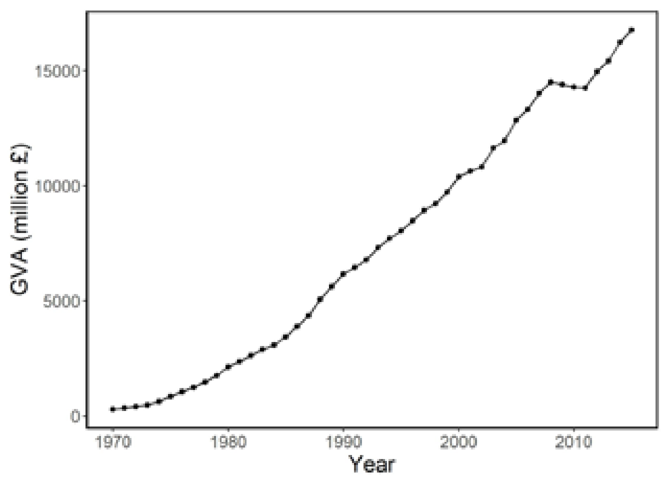


Figure 19. Trends in the economy and employment estimates for Dorset: total employment (FTE).[22]

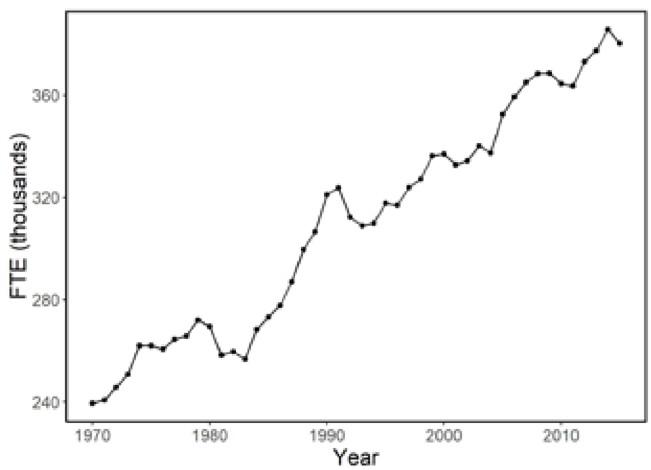
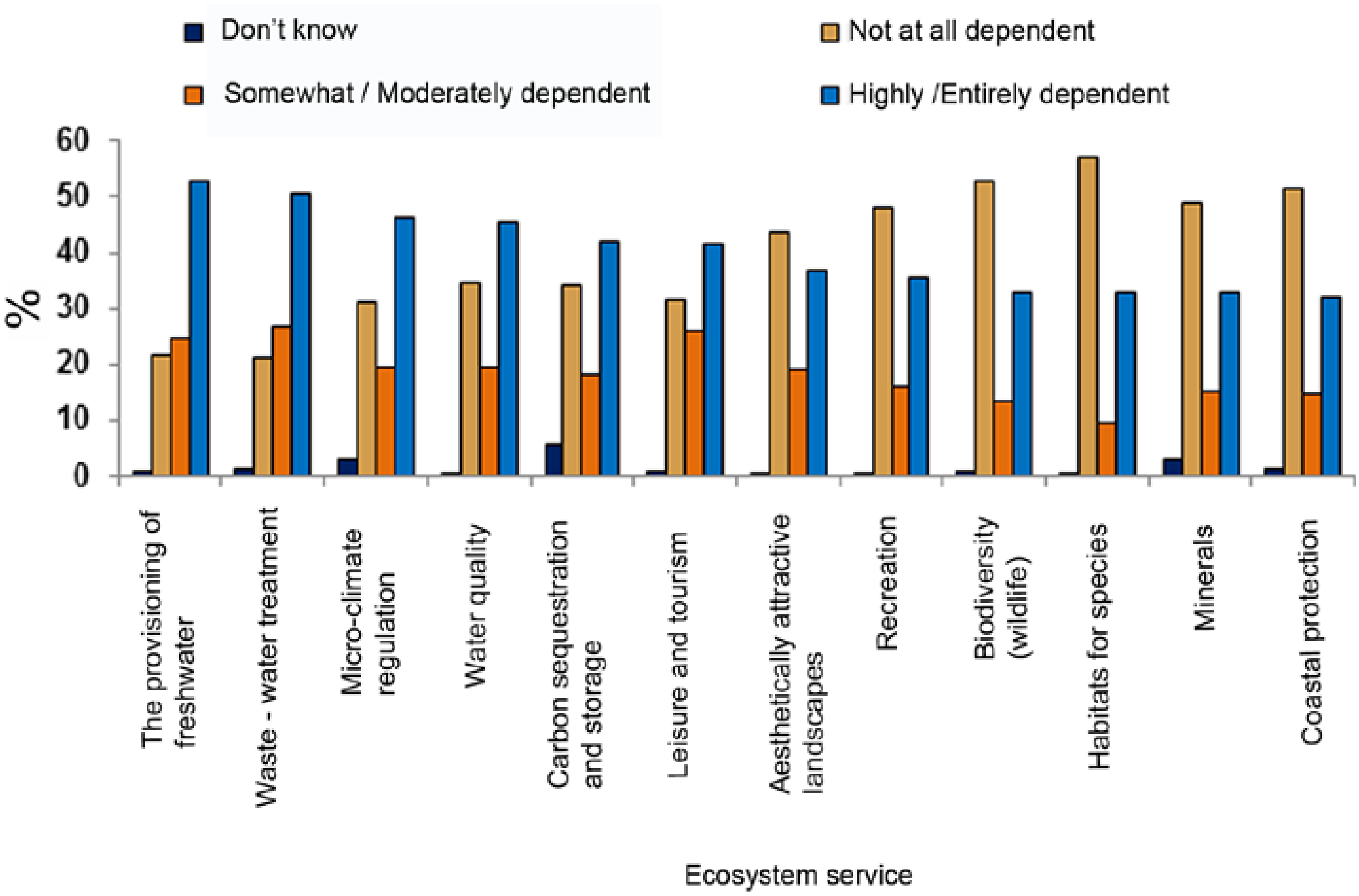


Figure 20. The ecosystem services on which Dorset businesses were most dependent, based on results of a questionnaire survey[23].



Sunseeker assembly facility, Poole Harbour © Sunseeker International

Environmental and Economic Linkages: Poole Harbour as a Case Study

As one of the world's largest natural harbours, Poole Harbour provides an informative example of economic links with the environment. The south side of the harbour is home to extensive areas of semi-natural habitats of high conservation value, including saltmarsh, mudflats, sand dunes and heathland. This contrasts with the high-value residential areas located on the northern side, which neighbour the port and its associated industrial areas. Poole Harbour illustrates some of the many conflicts and challenges that can occur when centres of economic activity are located in places that also have high environmental value.

The environmental value of Poole Harbour is recognised by its designation as a Special Protected Area (SPA) and as a Ramsar site. The area is particularly notable for the large populations of waterbirds that it supports, which feed on the extensive intertidal mud-flats and areas of grazing marsh. One of the main threats affecting the area is increasing nutrient enrichment, which is principally caused by agricultural run-off entering the rivers that flow into the Harbour (**Figure 21**). This contributes to the growth of algal mats, which can restrict the food available for wading birds. In this study we found a direct link between the proliferation of algal mats and decreases in mudflat area, saltmarsh area and populations of overwintering wading birds (**Table 4**).

We also examined dynamics of the Manila clam (*Ruditapes philippinarum*) industry within the Harbour. This fishery developed in the 1980s after the species was first introduced for aquaculture. It then spread and started to reproduce, enabling development of an industry harvesting 'wild' populations, which is currently worth some £1.4 million annually. Analysis of time-series catch data indicated that populations of Manila clam collapsed in 2008, having reached a peak the previous year (**Figure 22**). This decline was partly attributable to illegal fishing pressure, although other factors such as disease also appear to have been influential. Potentially, interactions between climate change, fishing pressure and disease could provide a feedback mechanism leading to a tipping point in the provision of this ecosystem service (**Figure 23**). More recently feral clam stocks of the harbour have recovered, owing to improved management measures taken by the local inshore fisheries and the conservation authority (IFCA). These efforts have recently been recognised by certification by the Marine Stewardship Council (MSC).

[24] Watson, S.C.L. *et al.* (2018). *Estuarine, Coastal and Shelf Science*, 215, 112-123.

[25] Data from the Freshwater Biological Association.

[26] Data from the Southern IFCA.

Table 4. The impact of different pressures (drivers) on the natural capital assets of Poole Harbour. The tick represents a statistically significant negative relationship ($p \leq 0.01$), while the cross represents no effect, as determined by analysis of time-series data[24].

Reported cause (Drivers)	Negative Impact on Natural Capital			
	Manila Clam (*Ruditapes philippinarum*)	Mudflat (Area)	Saltmarsh (Area)	Waders and wildfowl
Macroalgal mats caused by nitrogen inputs	✗	✓	✓	✓
Disease (bacteria)	✓	✗	✗	✗
Illegal fishing	✓	✗	✗	✗
Channel and habitat alterations	✗	✓	✓	✗
Climate change (water temperatures)	✗	✗	✗	✗

Sandbanks ferry in Poole Harbour entrance © Steven Mckell

The five main Islands in Poole Harbour © allou

Figure 21. Normalised time series of nitrogen entering Poole Harbour from the river Frome at East Stoke for the period 1980-2015[25].

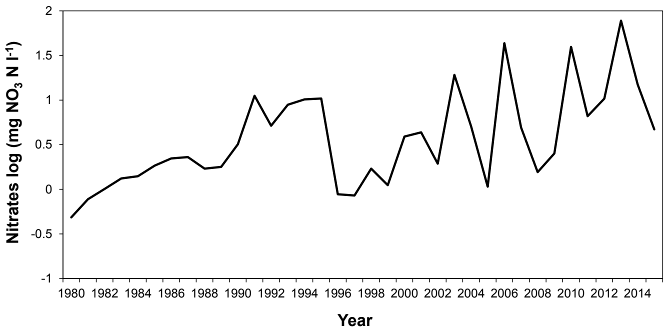
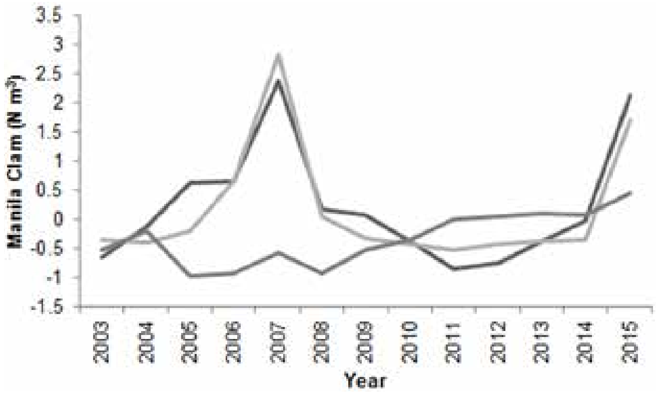


Figure 22. Annual stock surveys for Manila clam obtained for three sites in Poole Harbour: Arne Bay, Seagull Island and Round Island[26].



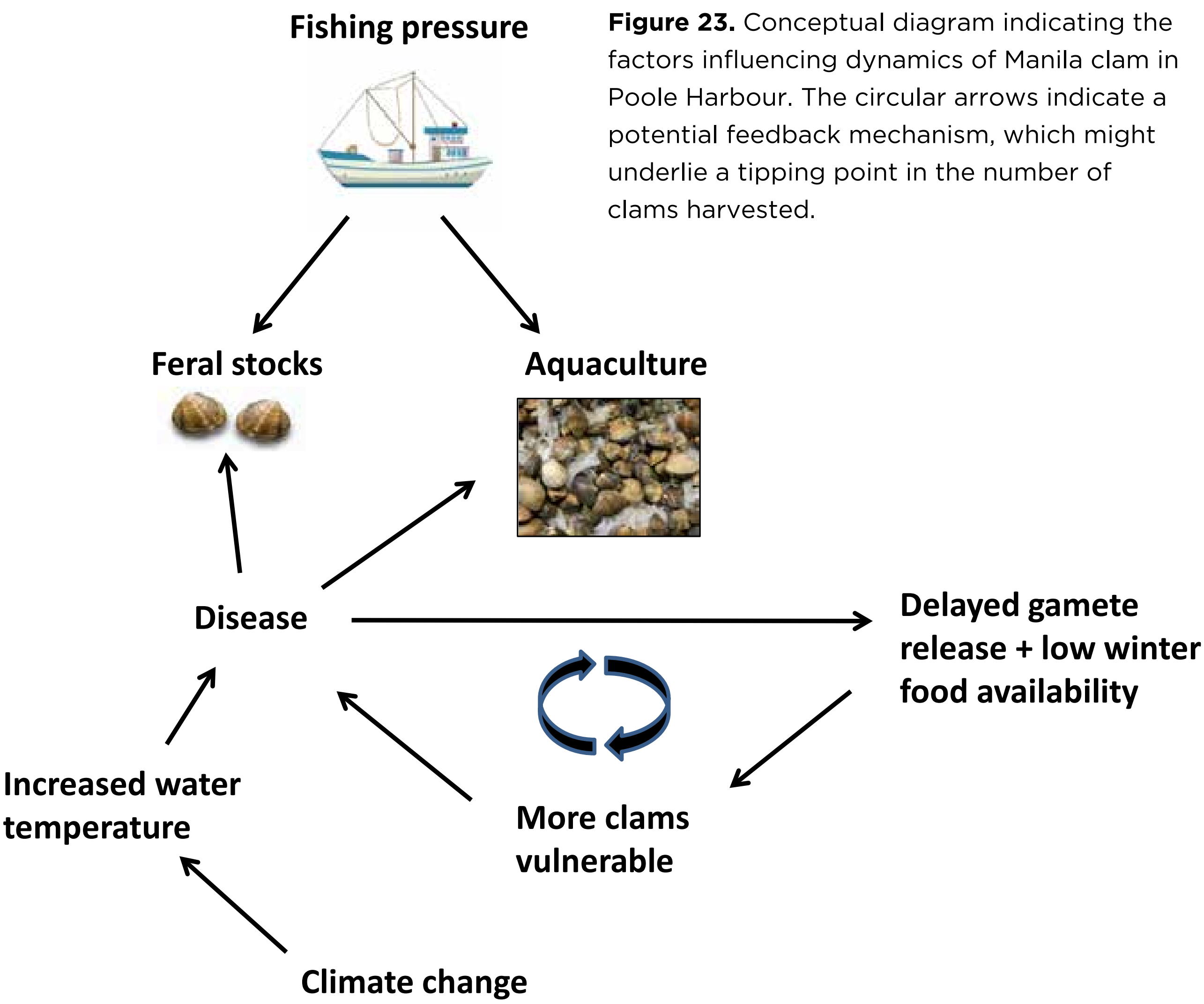


Figure 23. Conceptual diagram indicating the factors influencing dynamics of Manila clam in Poole Harbour. The circular arrows indicate a potential feedback mechanism, which might underlie a tipping point in the number of clams harvested.

Future Trends

How might Dorset's environment and economy change in the future? This is a very pertinent question, given the current political uncertainty surrounding the UK's relationship with the EU. If the UK leaves the EU as planned following the referendum result in 2016, this will have major implications for agriculture. Specifically, Brexit involves departure from the EU's Common Agricultural Policy (CAP) schemes, which are currently an important source of revenue for farmers. While the UK will be able to develop its own agricultural policy to replace the CAP, the details of this have not yet been finalised. It appears that farmers and land managers will likely be able to receive government funds for the provision of environmental services and benefits[27], as well as traditional products such as food and timber. This policy shift might provide economic opportunities for managing the landscapes of Dorset in a profoundly different way.

To explore the potential impacts of possible future trends, we developed scenarios of future land use in collaboration with local stakeholders. Representatives of local businesses, conservation organisations and government agencies were invited to evaluate different land use options at a project workshop. Scenario development was further supported by use of two modelling approaches: (i) an input-output economic model, and (ii) an agent-based model. While input-output models are widely used to support economic planning, they do not explicitly consider links with the environment. For this reason an agent-based model (DONC) was developed that incorporates land cover maps of Dorset, and enables simulation of ecosystem service flows to businesses under different scenarios of environmental change. The two models were used in combination to explore the potential impacts of different scenarios of land cover change.

[27] **https://www.gov.uk/government/publications/the-future-for-food-farming-and-the-environment-policy-statement-2018**

[28] Lawton, J.H. *et al.* (2010). *Making Space for Nature: a review of England's wildlife sites and ecological network.* Report to Defra.

[29] See also the *"Biodiversity 2020"* strategy produced by Defra.

[30] **https://www.gov.uk/government/publications/25-year-environment-plan/25-year-environment-plan-our-targets-at-a-glance**

[31] **http://www.biodiversitysouthwest.org.uk/nmap.html**

Table 5. The extent of land cover change in the different scenarios. BAU: "Business as usual", HIGB "Green Brexit", High Intensity; LIGB "Green Brexit", Low Intensity; HIAB "Agribrexit", High Intensity; LIAB "Agribrexit", Low Intensity.

Land cover type	BAU (%)	HIGB (%)	LIGB (%)	HIAB (%)	LIAB (%)
Inland water	0.28	0.28	0.28	0.28	0.28
Arable	30.04	19.8	24.03	32.34	31.73
Neutral grassland	0.28	3.64	1.74	0	0
Calcareous grassland	0.6	10.41	6.12	0	0
Acid grassland	0.15	0.15	0.15	0	0
Fen, Marsh, Swamp (incl. Saltmarsh)	0.53	2.32	0.85	0.53	0.53
Improved grassland	45.46	24.39	35.84	56.73	50.56
Heathland	2.64	5.18	3.27	0	0
Coastal	1.68	1.68	1.68	1.68	1.68
Built-up areas and gardens	8.14	8.14	8.14	8.14	8.14
Broadleaved, mixed and yew woodland	6.24	20	13.93	0	3.11
Coniferous woodland	3.66	3.66	3.66	0	3.66
Inland rock	0.31	0.37	0.32	0.31	0.31
Agriculture	75.5	44.19	59.87	89.07	82.3

We developed five scenarios for the period 2015-2050, which were designed to cover a wide spectrum of possibilities:

- **"Business as usual" (BAU) – the land cover of Dorset remains unchanged.**
- **"Green Brexit", High Intensity – the area of agricultural land declines by 41.47% over the 35 year interval.**
- **"Green Brexit", Low Intensity – the area of agricultural land declines by 20.7%.**
- **"Agribrexit", Low Intensity – the area of agricultural land increases by 9%.**
- **"Agribrexit", High Intensity – the area of agricultural land increases by 17.9%.**

Here, agricultural land referred to both arable and improved grassland. In the "Green Brexit" scenarios, the area of agricultural land was reduced to enable the large-scale expansion of habitats with high conservation value, such as calcareous grassland and heathland. This is consistent with the ideas presented in the *"Making Space for Nature"* [28] report, which sets out an ambitious vision for creating a resilient ecological network in England through ecological restoration[29]. Similarly, targets for large-scale habitat restoration are included within the UK Government's *25 Year Environment Plan*[30], which aims to restore 500,000 ha of wildlife-rich habitat throughout the UK, and to achieve a 12% increase in woodland cover in England by 2060.

To produce the land cover maps for the "Green Brexit" scenarios, we used the South-West Nature Map[31], which provides an assessment of where habitat restoration might best be undertaken in the region. For the "Agribrexit" scenarios, all of the remaining habitats that are suitable for agriculture were converted to farmland; the type of agriculture in each location was determined by the relative suitability of different soil types. The "low intensity" scenarios implemented half of the land cover change implemented in the "high intensity" scenarios (**Table 5, Figure 24**). Ecosystem services were mapped for each scenario using the InVEST software models.

Results indicated that:

- There is limited scope for further expansion of agricultural land in Dorset; most of the land that is suitable for farming has already been converted to agricultural land use. Even if all land suitable for agriculture were converted, this would only increase the area of farmland by about 18%.

- In addition to increasing their area, the "Green Brexit" scenarios also had a positive impact on the fragmentation of habitats with high conservation value, such as calcareous grassland, broadleaved woodland, heathland and unimproved grassland. This was indicated by increases in mean patch size and patch density (**Figure 25**).

- As expected, the "Green Brexit" scenarios had a positive impact on wildlife, values of the overall biodiversity index and insect pollinator index increasing significantly over 2015 values. However, neither of these indices achieved the values that were present in 1930, indicating that much more extensive habitat restoration measures would be required to return the wildlife value of Dorset to what it was around 80 years ago (**Figure 26**).

- Other ecosystem services that increased under the "Green Brexit" scenarios included carbon storage, soil quality, retention of nitrogen, recreation, aesthetic value and water yield. Only crop yield and livestock production were higher under the "Agribrexit" scenarios.

- Analysis using only the input-output model indicated that the economic impact of the simulated land cover change was very slight, with values of GVA changing by ≤ 0.3% under each scenario. However, when the value of ecosystem service provision was included by using the agent-based model, the overall economic impact was much greater (up to 5%) (**Figure 27**). In addition, the relative impact of the different scenarios was completely reversed: when ecosystem services were considered, the "Green Brexit" scenarios had a positive economic impact, whereas the "Agribrexit" scenarios had a negative economic impact. This demonstrates how rural land use can affect the wider economy by affecting the provision of ecosystem services to other business sectors. This influence of farming on the wider economy is ignored by conventional approaches to economic forecasting.

- Projections of employment mirrored those obtained for economic growth. Changes in employment values obtained with the input-output model were very small, the total number of jobs increasing by 0.25% in the "Agribrexit" High Intensity scenario. Much larger values were obtained using the agent-based model, which incorporated ecosystem service flows. Here, the largest increase (of 8%) was obtained in the "Green Brexit" High Intensity scenario. This demonstrates how investment in natural capital can make a significant contribution to increasing employment.

Figure 24. Land cover maps associated with four scenarios of potential future land use in Dorset. (a) HIGB "Green Brexit", High Intensity; (b) LIGB "Green Brexit", Low Intensity; (c) LIAB "Agribrexit", Low Intensity, (d) HIAB "Agribrexit", High Intensity.

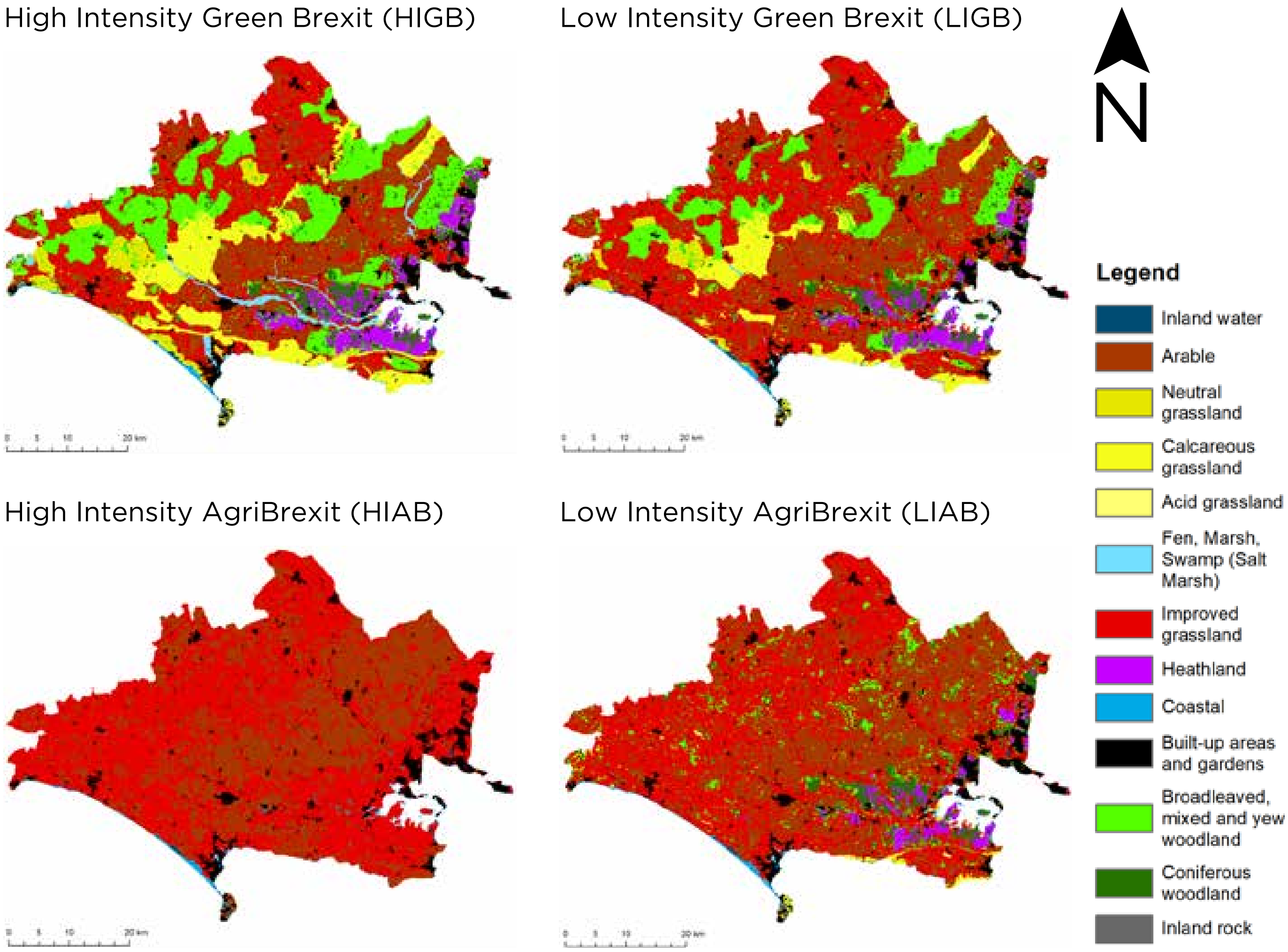


Figure 25. Habitat fragmentation under the four scenarios of future land use in Dorset. (a) mean patch (MPS) size, (b) patch density (PD).

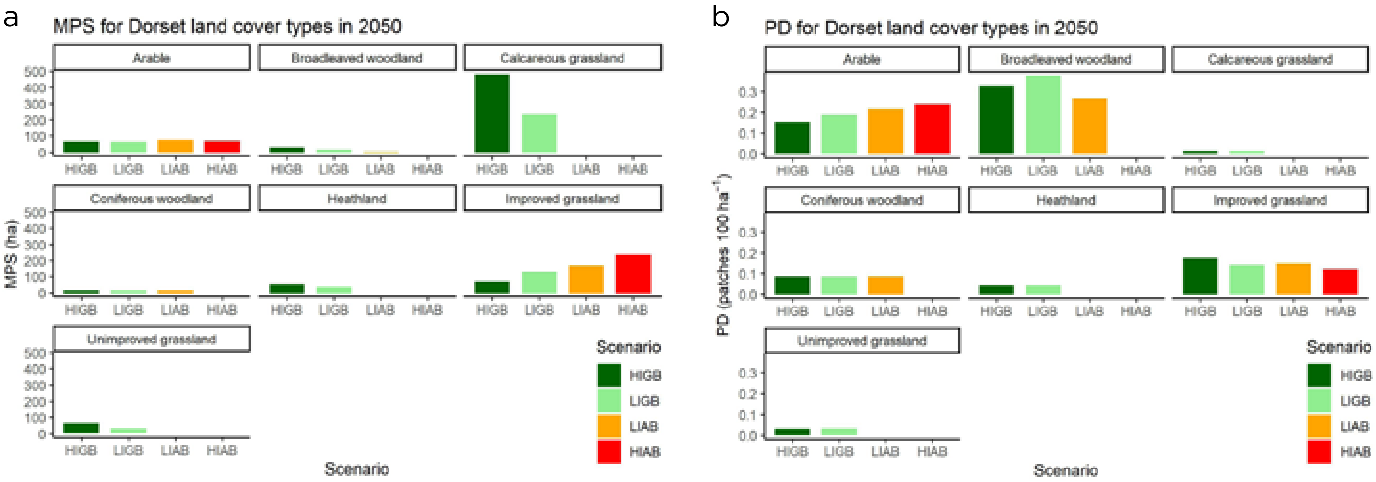


Figure 26. Flows of selected ecosystem services under the scenarios of future land use in Dorset.

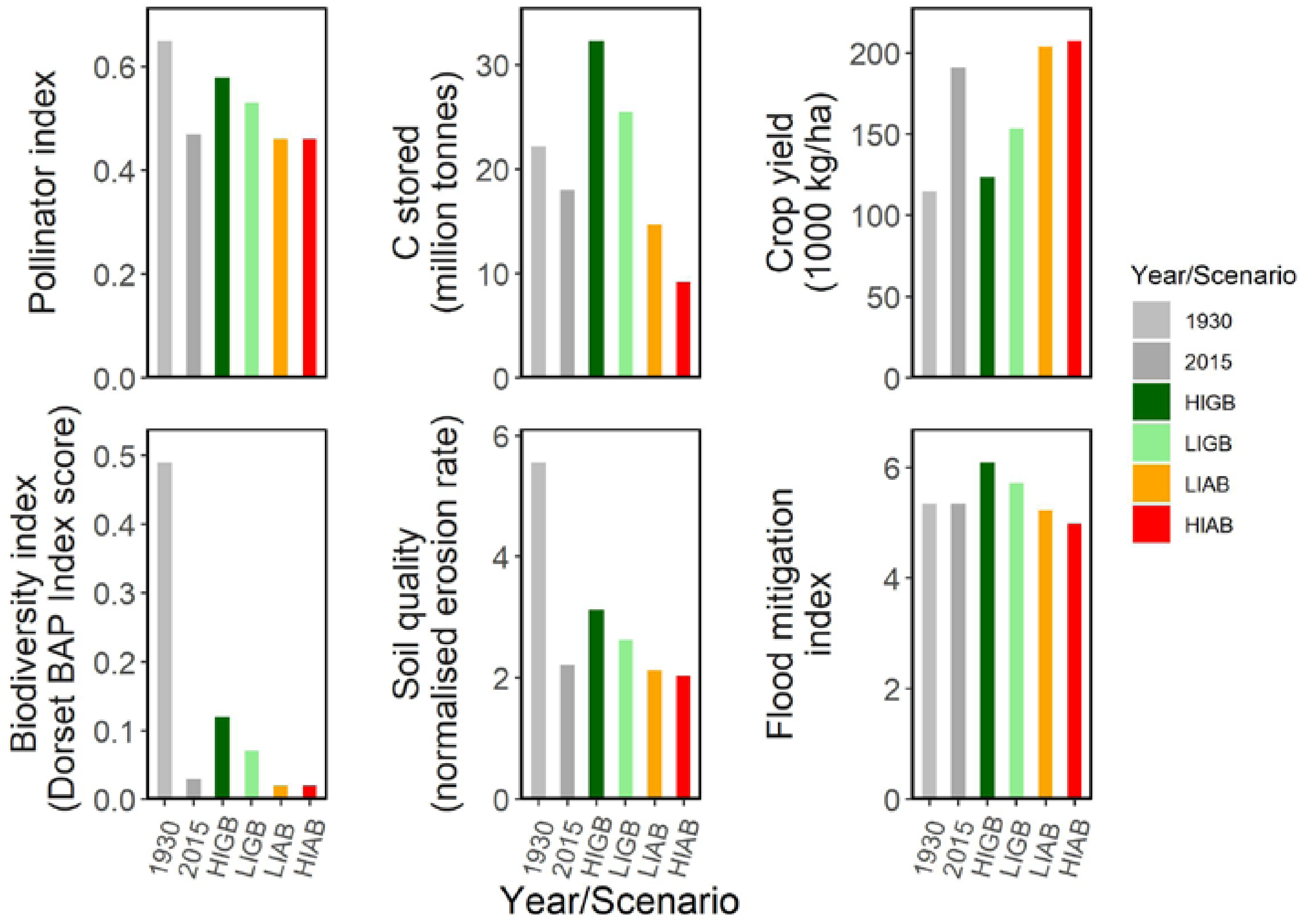
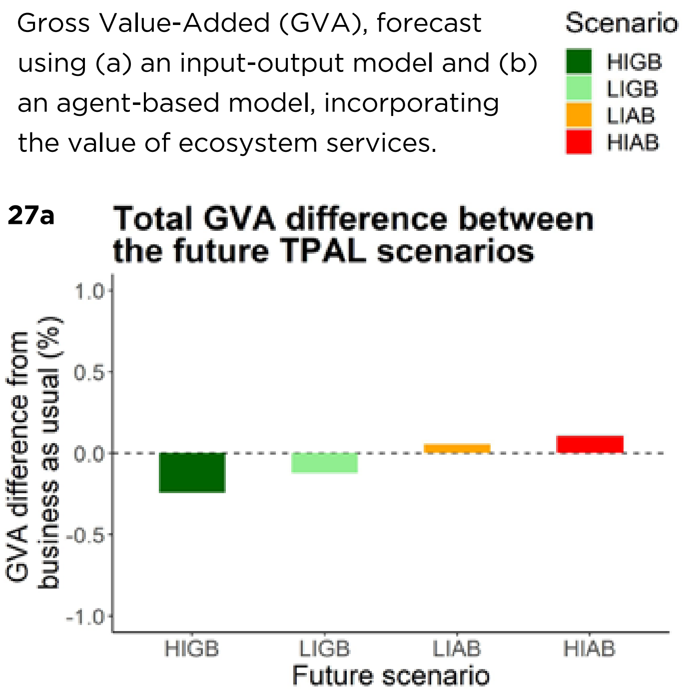
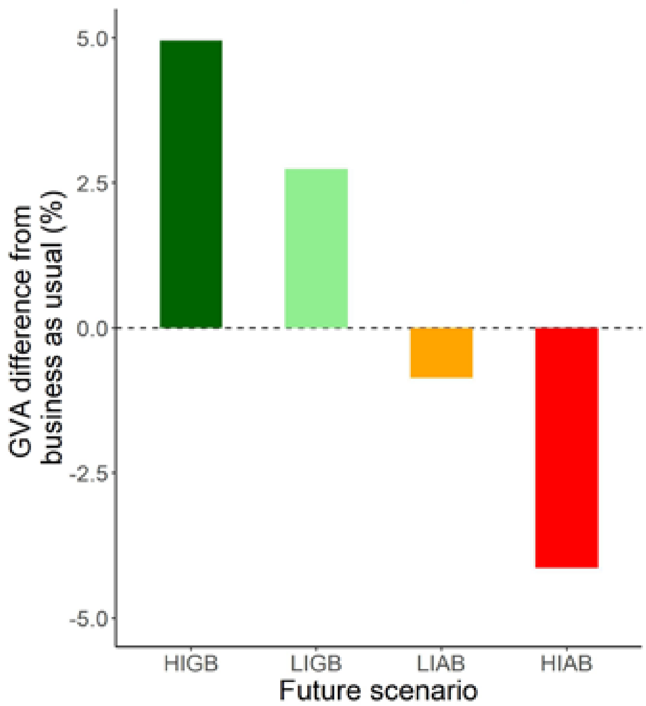


Figure 27. Economic impact of scenarios of future land use in Dorset. Gross Value-Added (GVA), forecast using (a) an input-output model and (b) an agent-based model, incorporating the value of ecosystem services.

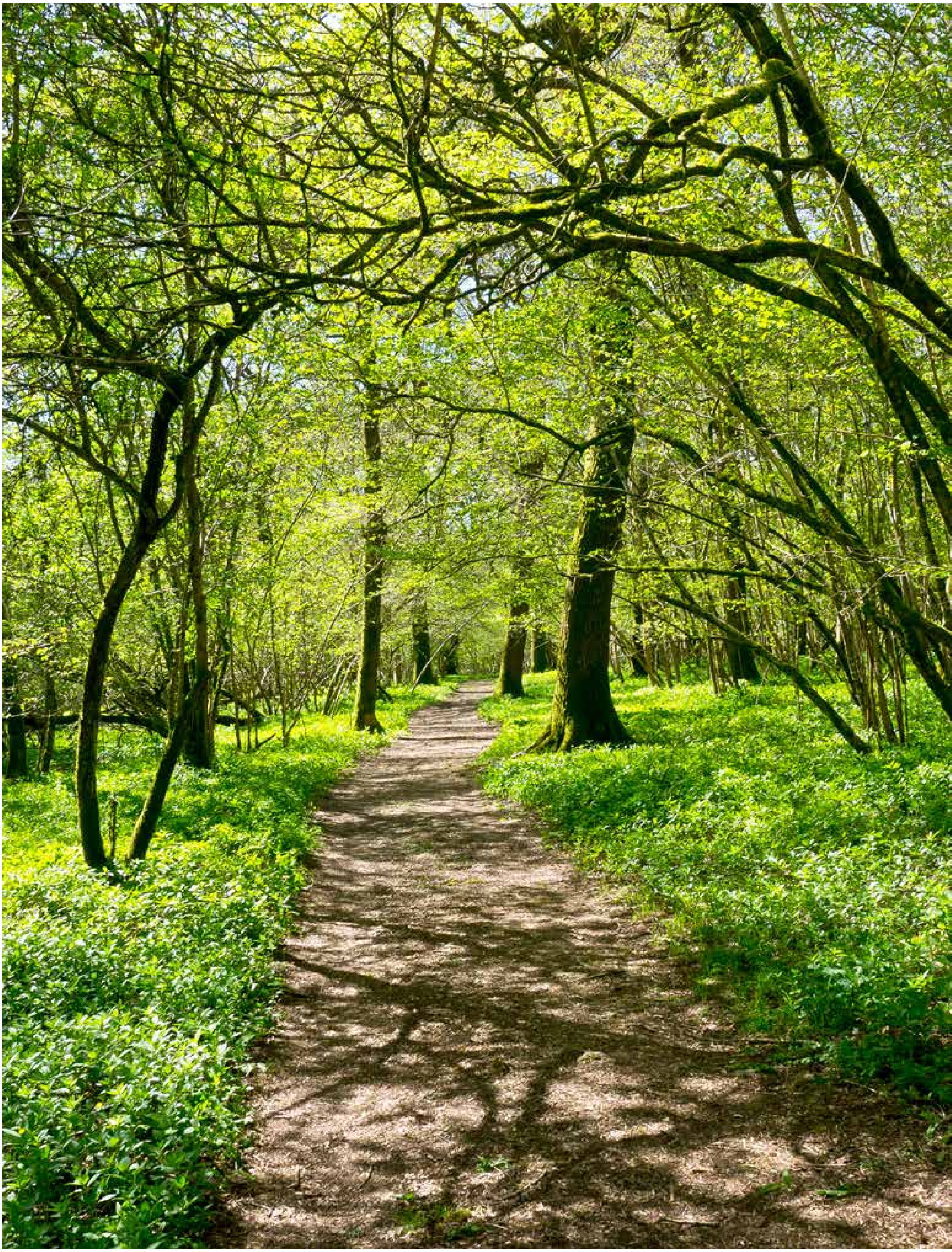
27a



27b



Garston Wood © Roger Lane



Conclusions

How degraded are Dorset's ecosystems?

Dorset remains a very important county for wildlife, with extensive areas of semi-natural habitats, high species richness and important populations of many species of conservation concern. However, it is clear from our analyses that Dorset's wildlife value has undergone a substantial decline in the past 80 years, as indicated by the loss and fragmentation of many important habitats, such as calcareous grassland, neutral grassland and heathland. Many of these habitats have lost more than half of the area that was present in 1930. These losses are largely attributable to intensification of agriculture and changing farming practices. Although the rate of habitat loss has slowed in the past three decades, the productivity and efficiency of agriculture continues to increase. This intensification is associated with ongoing losses of biodiversity. All of Dorset's semi-natural ecosystems are receiving nitrogen deposition in exceedance of critical loads, and this is changing the structure and composition of ecological communities. Such trends are apparent throughout Dorset, showing that farming practices are having a significant impact on surrounding habitats. However, trends in ecosystem services reveal a more complex picture. While some services such as carbon storage and soil quality have declined continuously over the past 80 years, others such as mitigation of flood risk have displayed more complex dynamics.

[32] Woodcock, B. A. *et al.* (2017). *Science*, 356, 6345, 1393-1395.

[33] See *Philosophical Transactions of the Royal Society* special issue (2003), vol. 358, issue 1439.

[34] **https://www.metoffice.gov.uk/research/collaboration/ukcp**

Jurassic Coast west of Kimmeridge © Panaglossian

How will Dorset's ecosystems change in the future?

It is difficult to predict what the future holds for Dorset's ecosystems, but this will depend on future trends in the key drivers of change. Based on current trends, the productivity and efficiency of agriculture are likely to continue to increase, perhaps supported by new technological innovations. Such innovations and associated changes in farming practice can often be damaging to wildlife, as demonstrated for example by the use of neonicotinoid pesticides[32] and genetically modified crops[33]. Further biodiversity loss may therefore result from future intensification of agriculture. Patterns of rural land use are likely to depend critically on developments in agricultural policy. In particular, the proposed shift towards providing payments to farmers for provision of environmental services and benefits could have major implications. Potentially this could provide incentives for restoring extensive areas of semi-natural habitats that are of high value for provision of ecosystem services, such as broadleaved woodland, calcareous grassland and heathland. A further key trend is global warming. While climate change has already affected the distribution and abundance of some species within Dorset, such impacts are likely to become much more intense and widespread in future. By 2070, our summers may be as much as 5.8 °C warmer[34], approximating what parts of the Mediterranean experience today. This may result in radical changes to the structure and composition of ecological communities, as well as the provision of benefits to people.

Might Dorset ecosystems be vulnerable to tipping points?

We detected a number of non-linear relationships in our analyses. For example, many of the ecosystem services varied in a non-linear fashion over time, even though agricultural intensification - the main driver of land cover change - increased linearly. Some measures of land cover change, such as the area of arable land, increased non-linearly. We also detected some non-linear relationships along gradients of ecosystem condition in our field surveys. This indicates that the existence of some ecological thresholds in relation to the status of natural capital assets, which could lead to relatively abrupt change in provision of ecosystem services[35]. However, we found little evidence for true "tipping points", which require an underlying feedback mechanism to be identified. This partly reflects the difficulty of identifying such feedback mechanisms. The recent decline of Manila clam in Poole Harbour might provide an example, with a potential feedback mechanism involving bacterial disease, and possible interactions with fishing pressure, climate change and eutrophication.

Currently, there is a lack of understanding of the feedback mechanisms that might cause rapid shifts in Dorset's ecosystems. It is becoming clear, however, that agricultural use of pesticides can cause a massive decline in insect populations[36], which could potentially cause the collapse of food webs and associated extinction cascades. Such processes may account for the 75% decline in biomass of flying insects recently recorded in protected areas in Germany over a period of 27 years[37]. It is possible that similar trends are occurring in Dorset, although appropriate data are currently lacking. However, our analysis of time-series data suggested that profound shifts in Dorset's ecosystems have already happened, because the process of agricultural intensification is now well advanced. For example, the conversion of 97% of neutral grassland and 70% of calcareous grassland over the past 80 years must have been associated with a major loss of functional capacity of these ecosystems, although evidence for this is lacking. Furthermore, the fact that critical loads for nitrogen deposition are being exceeded throughout Dorset implies that an important ecological threshold has been crossed, which may have implications for future provision of ecosystem benefits to people. Climate change and its interaction with other drivers such as nitrogen deposition increase the risk of abrupt changes in ecosystem service provision occurring in the future.

[35] Mace, G.M. *et al.* (2015). *J. Appl. Ecol.* 52, 641-653.

[36] Sánchez-Bayo, F. and Wyckhuys, K.A.G. (2019). *Biological Conservation*, 232, 8–27.

[37] Hallmann, C.A. *et al.* (2017). *PLoS ONE* 12(10), e0185809.

What are the relationships between Dorset's environment and its economy?

One of the most striking results that we obtained was the contrast between environmental and economic trends. Whereas biodiversity and the provision of many ecosystem services has declined over the past 80 years, the economy has grown and employment has risen. This implies that economic development has been achieved through the liquidation of natural assets. However, another feature of these results is the fact that agriculture comprises a very small part of Dorset's economy. This indicates that most economic development has not been driven by direct exploitation of Dorset's natural resources. Conversely, our research has also showed that rural land use has a significant influence on the overall economy in a way that is not captured by traditional approaches to economic analysis. Patterns of rural land use profoundly influence the provision of multiple ecosystem services on which many businesses depend, to varying degrees. Our research also showed that this contribution of rural land use to the economy may be of significantly greater economic value than crop and livestock production. Does this imply that the entire economy of Dorset is vulnerable to environmental degradation? Model simulations suggested that if provision of ecosystem services were to be significantly reduced by future environmental degradation, overall economic activity (as measured by GVA) could decline by more than a third. If employment were also to decline significantly, the economic impacts could be substantially larger. Future environmental trends such as climate change and ongoing agricultural intensification may therefore have significant economic consequences for Dorset, and other comparable areas.

Rewilding at Knepp Estate in West Sussex. © Charlie Burrell

How might future investment in natural capital affect the economy?

Our results suggest that any investment in increasing agricultural productivity or efficiency is unlikely to have a significant impact on the local economy, despite its potential value for improving food sovereignty. However, the scenarios we developed demonstrate how investment in natural capital could potentially strengthen Dorset's economy, by improving provision of ecosystem services on which many businesses depend. For example, according to our simulations, implementation of ecological restoration at the scale described under the "Green Brexit – High Intensity" scenario could potentially deliver an £0.8 billion increase in GVA and create more than 25,000 jobs. How might investment in natural capital be achieved in practice? Many different options have been proposed[38], including development of ecological networks, woodland planting, development of green infrastructure, and creation of wetlands or semi-natural grasslands. Each of these options was rated 'highly' or 'very highly' by more than half of the stakeholders consulted at our project workshop, where different natural capital investment options were explored. Any approach that improves the condition or extent of semi-natural habitats could potentially strengthen the provision of ecosystem services, including wildlife-friendly farming approaches such as organic approaches to pest control and soil improvement, ecological restoration, habitat enhancement schemes and maintenance of habitat diversity.

We examined one particular approach in detail: rewilding. The term "rewilding" refers to a form of ecological restoration that seeks to support the recovery of ecosystems primarily through the action of natural ecological processes. The term has been applied to a wide variety of different conservation practices including species reintroductions (particularly of large vertebrates), taxon substitution, flood pattern restoration and the abandonment of agricultural land. While rewilding is increasingly being explored in many different parts of the world, including the UK, its relevance to lowland agricultural landscapes such as Dorset has been little explored. We therefore examined the potential application of a number of different rewilding approaches[39], involving the consultation of local stakeholders. Survey results showed strong support for rewilding among stakeholders, with the reintroduction of beavers and pine martens being especially popular. Naturalistic grazing and farmland abandonment were also identified as rewilding approaches that have widespread potential across Dorset (**Figure 28**). On the basis of previous research conducted into other rewilding sites in the UK, implementation of such approaches is likely to significantly increase provision of ecosystem services[40]. An example of how rewilding can be successfully implemented in lowland agricultural landscapes is provided by the Knepp Estate in West Sussex (see photo page 40).

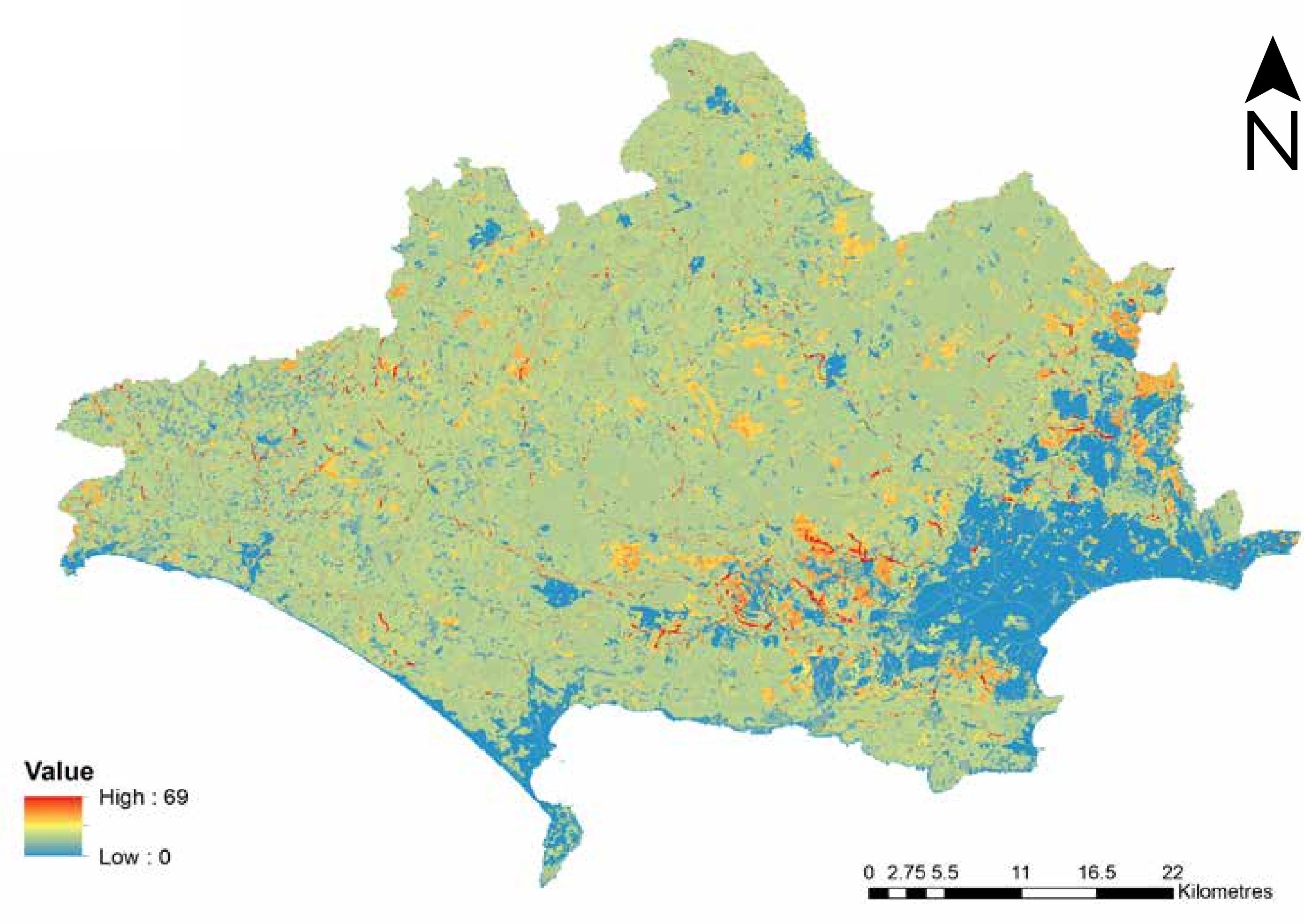
[38] For example, see the reports of the Natural Capital Committee to the UK Government; **https://www.gov.uk/government/groups/natural-capital-committee**

[39] Loth, A.F., and Newton, A.C. (2018). *Journal for Nature Conservation*, 46, 110-120.

[40] Hodder, K.H. et al. (2014). *International Journal of Biodiversity Science, Ecosystem Services and Management.* 10(1). 71-83.

[41] Loth, A.F., and Newton, A.C. (2018). *Journal for Nature Conservation,* 46, 110-120.

Figure 28. Map illustrating the relative suitability of different parts of Dorset for rewilding[41]. This combined map was produced incorporating a range of different rewilding options, including farmland abandonment, naturalistic grazing, beaver or pine marten reintroduction, passive management and river restoration. These analyses were based on results of a stakeholder consultation.



Eurasian beaver © Podolnaya Elena

Recommendations

- Invest in natural capital, by enhancing ecosystem condition and by increasing the area of semi-natural habitats of high conservation value. Such investment would provide direct benefits to businesses, support economic growth and increase employment, while also providing wider benefits to society and to the environment.

- Develop policies aimed at providing incentives for farmers to produce environmental goods and services. Evidence indicates that this would provide greater benefits to the economy than increased production of traditional agricultural products.

- Incorporate the value of ecosystem services provided by rural land use in economic analysis and forecasting approaches. The value of these services to the broader economy can potentially exceed the economic value of the agricultural sector itself.

- Use land use approaches that improve the condition and extent of semi-natural habitats to strengthen the provision of ecosystem services, including wildlife-friendly farming approaches, organic approaches to pest control and soil improvement, ecological restoration, habitat enhancement schemes and maintenance of habitat diversity.

- Reduce nitrogen deposition. There is an urgent need to improve the condition of semi-natural ecosystems in agricultural landscapes such as Dorset. Initiatives designed to help farmers reduce nitrogen applications, such as the ***Code of Good Agricultural Practice for Reducing Ammonia Emissions***[42], should be strongly supported.

- Develop and implement plans for large-scale habitat creation and restoration. Environmental degradation can lead to abrupt changes in the provision of ecosystem services, which could negatively affect the economy and wider society. The risks of such abrupt changes occurring are likely to intensify with increasing climate change. Approaches aiming to increase the extent and condition of semi-natural habitats, such as ecological restoration, rewilding and development of ecological networks, would help mitigate these risks.

[42] https://www.gov.uk/government/publications/code-of-good-agricultural-practice-for-reducing-ammonia-emissions

Further information

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Durdle Door at sunrise © Shaun Jacobs

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