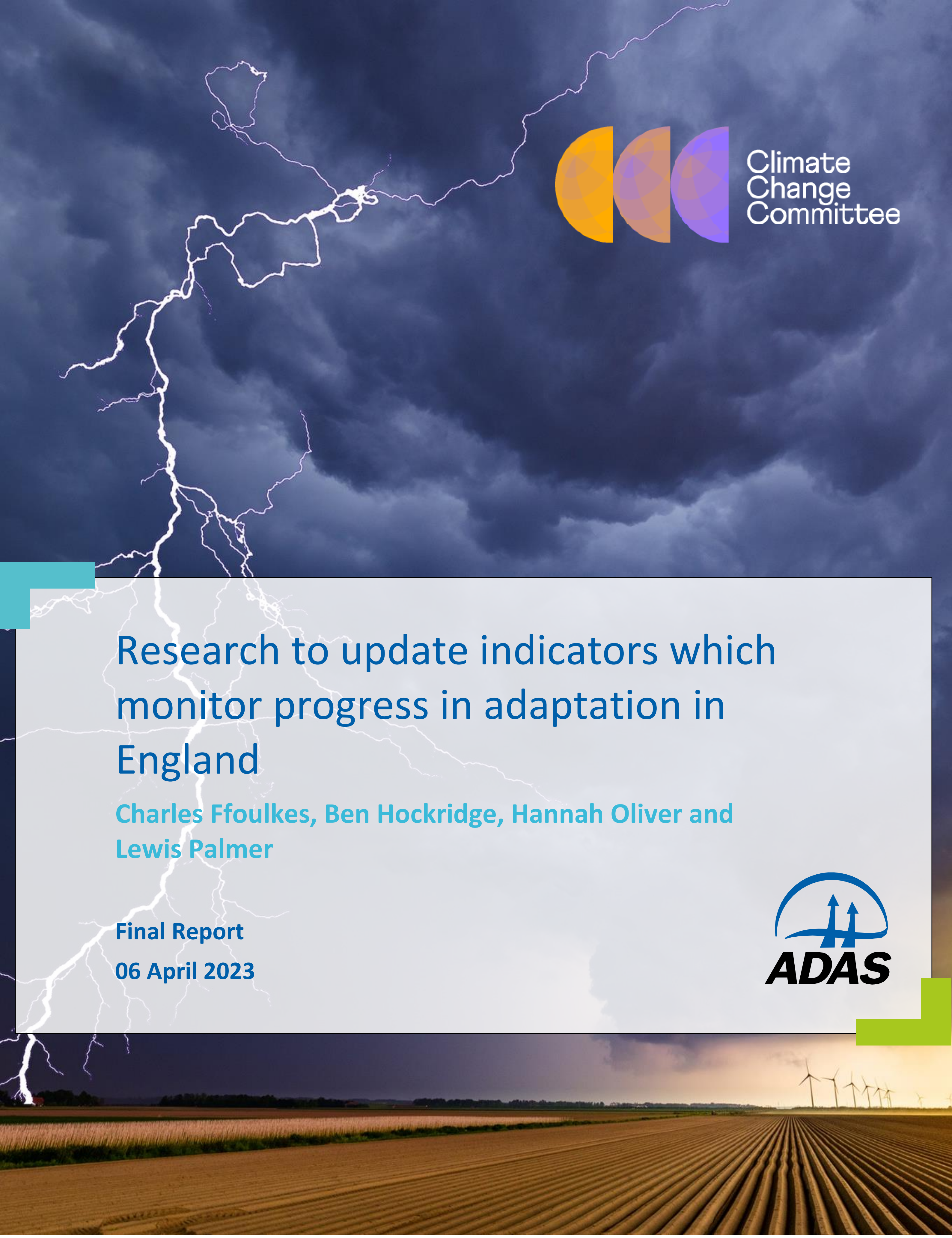

Climate Change Committee

Research to update indicators which monitor progress in adaptation in England

Charles Ffoulkes, Ben Hockridge, Hannah Oliver and Lewis Palmer

ADAS

Final Report

06 April 2023

ADAS GENERAL NOTES

Project No.:	1030409
Title:	Research to update indicators which monitor progress in adaptation in England
Client:	Climate Change Committee
Date:	06 April 2023
Office:	ADAS Oxford, 11D Park House, Milton Park, Abingdon, Oxford, OX14 4RS
Contact:	charles.ffoulkes@adas.co.uk
Status:	Final Report
Citation:	Ffoulkes, C., Hockridge, B., Oliver, H., and Palmer, L. (2023) Research to update indicators which monitor progress in adaptation in England. ADAS report for the Climate Change Committee.

This document has been approved by:

Project Manager and Technical Reviewer:	Charles Ffoulkes
Position:	Director – Climate Adaptation and Resilience ADAS Climate and Sustainability, RSK ADAS Limited
Date:	06 April 2023
Technical Reviewer:	Ben Hockridge
Position:	Principal GIS and Remote Sensing Consultant ADAS Modelling and Informatics, RSK ADAS Limited
Date:	06 April 2023

ACKNOWLEDGEMENTS

The ADAS Project Team

Charles Ffoulkes, Director – Climate Adaptation and Resilience

Ben Hockridge, Principal Consultant (GIS and Remote Sensing)

Hannah Oliver, Climate and Sustainability Consultant

Lewis Palmer, Environmental Consultant

The Committee on Climate Change

Brendan Freeman (Adaptation Committee)

Olivia Shears (Adaptation Committee)

Miriam Kennedy (Adaptation Committee)

Data and information providers

We would like to thank the organisations that directly or indirectly contributed data, information or support for the analysis provided in this study:

Adaptation Committee; Centre for Ecology & Hydrology; English Wine; Environment Agency; Forestry Commission; HR Wallingford; Joint Research Committee; Met Office; Ordnance Survey; Rural Payments Agency; and Wines of Great Britain.

CONTENTS

ACRONYMS AND ABBREVIATIONS

ADAS	Not an acronym, but the name of the organisation
CCC	Climate Change Committee
EFFIS	European Forest Fire Information System
FC	Forestry Commission
Ha	Hectares
JRC	Joint Research Centre
MCM	Multi-coloured manual
ONS	Office for National Statistics
OS	Ordnance Survey
RoFRS	Risk of Flooding from Rivers and Sea
RoFSW	Risk of Flooding from Surface Water
RPA	Rural Payments Agency
UK	United Kingdom

1 INTRODUCTION

1.1 Background

The Adaptation Committee of the Committee on Climate Change (CCC) are mandated under the Climate Change Act (2008)[1] to report to Parliament every two years on progress in adapting to climate change in England. To support this assessment, the Adaptation Committee use a set of metrics and indicators to assess and track changes in climate change risks and adaptation, whereby observed changes are monitored through time (using key data and information) across three core components of adaptation: indicators of risk, indicators of adaptation action, and indicators of climate impact.

To inform the Adaptation Committee's 2023 Progress Report to Parliament, several metrics and indicators that form the basis of this assessment required updating.

1.2 Research purpose

This research reviews a subset of the Adaptation Committee's full indicator set. The subset of indicators updated in this study were identified by the Adaptation Committee as part of the procurement process for this project. ADAS were not involved with the selection of indicators chosen to be updated. It is recognised that there may be alternative indicators that could also be suitable to demonstrate progress in adaptation, however these were not considered within the scope of this project.

The subset of indicators assessed by ADAS in this project provides supporting evidence to inform current understanding of adaptation progress being made in England. It is expected that these indicators will be used by the Adaptation Committee, alongside other indicators within the full indicator set, to inform the Adaptation Committee's 2023 Progress Report.

The purpose of this research is not to provide a comprehensive or representative overview of adaptation progress in England, rather it is intended to provide updated metrics and indicators (within the context of climate resilience) to inform the Adaptation Committee of the current evidence base.

1.3 Approach

Eight indicators of climate-related risk and action were evaluated. These indicators cover a range of sectors, including the built environment, the natural environment (including agriculture, forestry, and fisheries), people and health, and business. The data and information obtained came through a range of sources through consultation with stakeholders and industry representatives, as well as web-based searches.

For each indicator, a high-level description is provided and reference to the type of indicator it is categorised as under the Adaptation Committee's assessment.

Where robust datasets were available, with suitable metrics to demonstrate change over time, indicators were updated or developed to provide trends. Trends were then used to indicate progress in adapting to climate change. For each indicator, we provide detail on the data sources and methods used, outline the trends and implications for climate resilience, and assess the robustness of the indicator as a measure of assessing climate-related risks and actions.

[1] Climate Change Act (2008). Available at: https://www.legislation.gov.uk/ukpga/2008/27/contents [Accessed 17 Feb. 2023]

Where datasets or suitable metrics were not available, the evidence base was updated instead. For this, we provide detail on the available information, which may include industry insight, ad hoc data, grey literature, maps etc.

1.4 Scope and interpretation of climate

The project scope was for England only. However, for some indicators and evidence bases, disaggregated data was not available. In these instances, the data represented will include England, but not be completely attributable at a regional level, such as where data is for England and Wales, or the United Kingdom (UK).

In this study we provide analysis of the available data and information. It is noted that these indicators are not purely climate driven or may have limited sensitivity to climate change. Subsequently, indicators are proxies and should be interpreted with caution and not used in isolation or out of context.

2 INDICATORS UPDATED

The indicators in this section of the report are part of the Adaptation Committee's current indicator set and were updated with new data and analysis as part of this study.

2.1 Rate of development of properties in areas at risk of flooding

Description: *Rate of development of residential and non-residential properties in areas at risk of flooding*

Type: *Exposure*

Time series: *2018 to 2022*

Region: *England*

2.1.1 Introduction

This indicator was last updated by ADAS (2021). The indicator provides an assessment of the development of residential and non-residential properties within areas of flood risk to understand changes and trends in exposure and vulnerability of property to flooding. This update provides new data for 2022.

2.1.2 Data source and method

This indicator examines the impact of two different sources of flooding on properties, following on from work originally conducted by HR Wallingford (2015), and subsequently updated by ADAS (2019; 2021). The data sources are 'Risk of Flooding from Rivers and Sea' (RoFRS) and 'Risk of Flooding from Surface Water' (RoFSW), produced by the Environment Agency.

This analysis follows the same method used by ADAS (2021) and uses the latest AddressBase Plus dataset. It is noted that the analysis of this indicator by ADAS (2019) used a slightly different dataset (AddressBase Premium) and therefore results are not directly comparable to ADAS (2019) but are comparable with ADAS (2021).

AddressBase Plus provides information on all current addresses validated from Local Custodians and non-postal addresses (e.g. electricity sub-stations) whereas AddressBase Premium is the most detailed view of an address provided by Ordnance Survey and includes sites classified as Objects Without a Postal Address (e.g. places of worship, community centres and utilities) (Ordnance Survey, 2021). AddressBase Premium has over 40 million addresses and 100 million cross references as well as providing all the information relating to an address or property from creation to retirement (Ordnance Survey, 2023), creating a lot of additional datapoints that need to be extracted, processed and/or sorted through.

Property data was provided by the latest OS AddressBase layer. This layer provides a classification code for each property, which provides information on the property type. Previous studies of properties at risk have classified properties into multi-coloured manual (MCM) codes: dwelling, retail, offices, warehouses, leisure, public buildings, industry and miscellaneous. Therefore, to maintain consistency with previous studies, the AddressBase codes were matched to an MCM code:

- **Dwelling** (MCM_0): residential, caravans, sheltered accommodation, care homes etc.
- **Retail** (MCM_2): retail, banks, post offices, markets, petrol stations, bars and restaurants, shops, takeaways etc.

- **Offices** (MCM_3): offices, work studios, central and local government, and broadcasting (TV / Radio) etc.
- **Warehouses** (MCM_4): warehouses, depots, factories, manufacturing, food processing, chemical/cement/steel/printing works, shipyards, mining etc.
- **Leisure** (MCM_5): hotels, hostels, campsites, museums, leisure centres, sport facilities, cinemas, zoos, theme parks, arenas/stadiums etc.
- **Public Buildings** (MCM_6): schools, prisons, universities, health centres, hospitals, emergency services, air force, cemetery etc.
- **Industry** (MCM_8): farms, fisheries, water infrastructure and treatment, power stations, waste management etc.
- **Miscellaneous** (MCM_9): animal sanctuaries, airports, car parks, marinas, railway stations, bus depots etc.

Spatial analysis was then carried out to identify which (if any) flood risk area each property was within, and the local authority it was within, enabling summaries by local authority, MCM code and flood risk.

2.1.3 Trends and implications for climate resilience

Risk of flooding from rivers and sea

Changes in the number of properties at RoFRS is likely to be a combination of changes to the flood risk extents, changes in flood risk protection and mitigation (e.g. the presence of defences), changes in property numbers resulting from new development, and also how developments are recorded in the underlying datasets used.

The percentages of the total numbers of properties per local authority that are in high (each year, there is a chance of flooding of greater than 1 in 30), medium (each year, there is a chance of flooding of between 1 in 30 and 1 in 100), low (each year, there is a chance of flooding of between 1 in 100 and 1 in 1,000) and very low (each year, there is a chance of flooding of less than 1 in 1000) flood risk areas are outlined in

Table 1 and illustrated in Figure 1.

All property types (except retail and leisure) recorded a decrease in the number of properties with a high likelihood of flooding from rivers and seas. There was no change in the number of retail properties at high risk of flooding. The number of leisure buildings (recreational sites and enterprises such as leisure centres) with a high likelihood of flooding in 2022 increased by 8% to 9,535 compared with 8,867 in 2020. The total number of leisure buildings increased by 5% in 2022 and this was the only property type to record an increased vulnerability across all flood risk areas.

Across all property types (except for public buildings which saw no change), there has been an increase in the number of properties at a very low likelihood of flooding from rivers and seas, with warehouses and industrial buildings seeing the greatest increases of 10% and 9% respectively. In contrast, the number of public buildings at a high, medium, and low risk of flooding has decreased. The total number of public buildings has decreased by 6% from 20,565 in 2020 to 19,333 in 2022.

Table 1. Number of properties at risk of flooding from rivers and sea, for England, by property type, in 2022, for four risk levels; high (each year, there is a chance of flooding of greater than 1 in 30), medium (each year, there is a chance of flooding of between 1 in 30 and 1 in 100), low (each year, there is a chance of flooding of between 1 in 100 and 1 in 1,000) and very low (each year, there is a chance of flooding of less than 1 in 1000). Source: ADAS for the CCC.

		Likelihood of flooding				
Property type	**Data**	**High**	**Medium**	**Low**	**Very low**	**Total**
Dwelling	2022	126,678	461,003	859,367	611,796	**2,058,844**
	% Change*	-4%	-3%	+2%	+5%	**+1%**
Retail	2022	8,480	21,171	33,361	18,414	**81,426**
	% Change*	0%	-6%	0%	+4%	**-1%**
Offices	2022	5,504	14,151	21,180	18,609	**59,444**
	% Change*	-3%	-4%	+2%	+5%	**+1%**
Warehouses	2022	9,897	22,874	31,752	12,543	**77,066**
	% Change*	-1%	-3%	+5%	+10%	**+2%**
Leisure	2022	9,535	7,958	14,497	5,155	**37,145**
	% Change*	+8%	+4%	+5%	+3%	**5%**
Public Buildings	2022	2,083	5,214	7,849	4,187	**19,333**
	% Change*	-9%	-9%	-7%	0%	**-6%**
Industry	2022	2,951	6,333	5,600	2,425	**17,309**
	% Change*	-3%	-1%	+2%	+9%	**+1%**
Miscellaneous	2022	12,765	16,743	26,522	17,668	**73,698**
	% Change*	-1%	-4%	0%	+3%	**0%**
Total	**2022**	**177,893**	**555,447**	**1,000,128**	**690,797**	**2,424,265**
	% Change*	**-3%**	**-3%**	**+2%**	**+5%**	**+1%**

**Percentage change compared with results for 2020 (ADAS, 2021).*

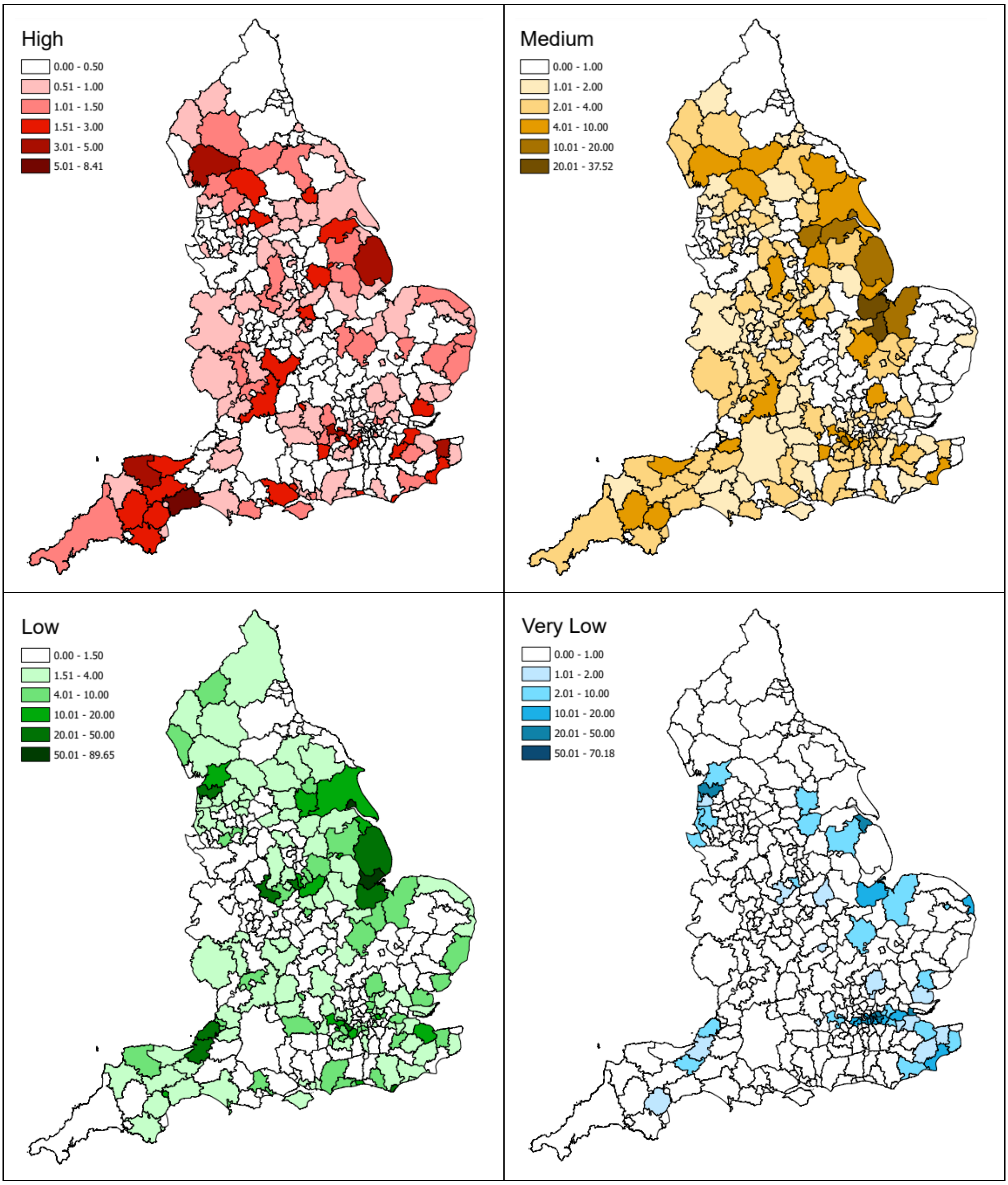

Figure 1. Percentage of all types of properties in each Local Authority at high, medium, low, and very low risk of flooding from rivers and sea in England in 2022. Source: ADAS for the CCC.

Risk of flooding from surface water

Table 2 outlines, and Figure 2 illustrates, the number of properties at RoFSW. The RoFSW assesses flooding scenarios as a result of rainfall with the following chance of occurring in any given year: 3.3% (1 in 30), 1% (1 in 100), and 0.1% (1 in 1000)[2].

Table 2. Number of properties at risk of flooding from surface water, for England, by property type, in 2022, for three levels of flood risk; high (3.3% probability), medium (1% probability) and low (0.1% probability). Source: ADAS for the CCC.

		Probability of flooding			
Property type	**Data**	**High**	**Medium**	**Low**	**Total**
Dwelling	2022	129,344	281,642	1,000,605	**1,411,591**
	% Change*	+11%	+8%	+7%	**+7%**
Retail	2022	4,375	9,908	37,276	**51,559**
	% Change*	+5%	+1%	-2%	**-1%**
Offices	2022	2,109	4,707	19,248	**26,064**
	% Change*	0%	-16%	-6%	**-7%**
Warehouses	2022	2,937	6,386	24,279	**33,602**
	% Change*	+17%	+14%	+7%	**+9%**
Leisure	2022	1,533	2,963	10,032	**14,528**
	% Change*	+6%	+6%	+5%	**+6%**
Public Buildings	2022	1,927	4,257	14,075	**20,259**
	% Change*	-9%	-13%	-14%	**-13%**
Industry	2022	2,489	4,775	12,957	**20,221**
	% Change*	+7%	+5%	+3%	**+4%**
Miscellaneous	2022	12,201	23,676	65,466	**101,343**
	% Change*	+3%	0%	-1%	**0%**
Total	**2022**	**156,915**	**338,314**	**1,183,938**	**1,679,167**
	% Change*	**+9%**	**+7%**	**+5%**	**+6%**

**Percentage change compared with results for 2020 (ADAS, 2021).*

All property types (except for offices and public buildings) show an increased number of properties that are categorised as having a high risk of surface water flooding. The largest of which is the number of warehouses at high risk of surface water flooding, which has increased by 17% from 2,518 in 2020 to 2,937 in 2022. This corresponds with a 9% increase in the total number of warehouses.

The total number of dwellings increased by 7% and the number of dwellings at high risk of surface water flooding increased by 11% from 116,860 in 2020 to 129,344 in 2022. The number of dwellings at a medium and low risk of flooding also increased by 8% and 7% respectively.

[2] The Risk of Flooding from Surface Water dataset assesses flooding scenarios as a result of rainfall with a 3.3%, 1% or 0.1% chance of occurring in any given year. The RoFSW overlays rainfall modelling on a two meter model grid of land features including detailed ground level information upon which a wide range of storm scenarios were modelled using three flood probabilities (1:30, 1:100 and 1:1000) (Environment Agency, 2019).

There was no change in the number of offices at high risk of flooding and a respective decrease of 16% and 6% in the number of offices at a medium and low flood risk. As with the flood risk from rivers and sea, the number of public buildings at risk from surface water flooding has decreased across all risk levels, corresponding to a 13% decrease in the total number of public buildings.

Across all the risk levels, the south-east consistently has a high percentage of properties at risk of surface water flooding (Figure 2).

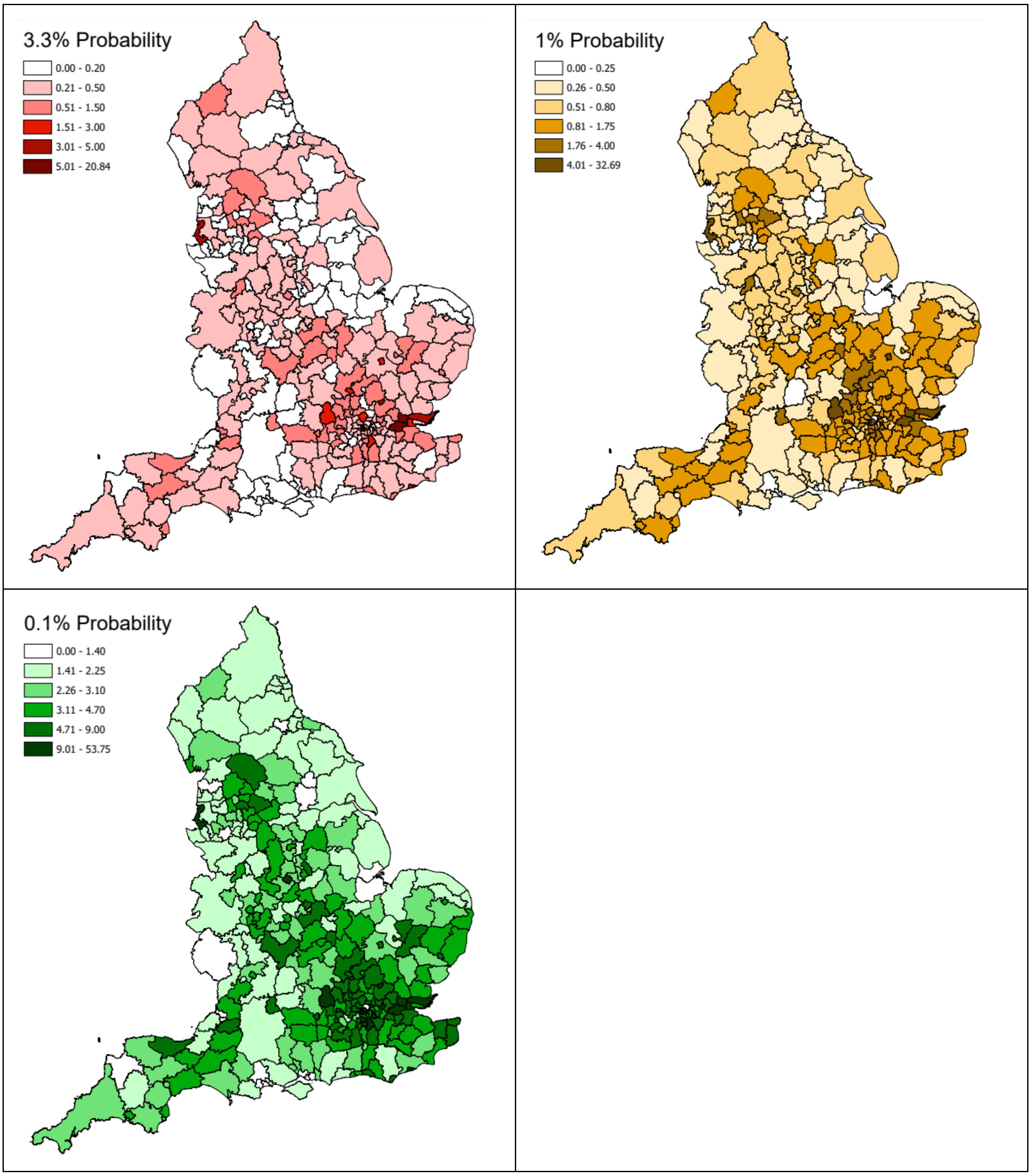

Figure 2. Percentage of properties in each Local Authority with a 3.3%, 1% and 0.1% probability of flooding from surface water in England in 2022. Source: ADAS for the CCC.

2.1.4 Robustness of indicator

In this analysis, AddressBase classification codes had to be converted to MCM codes; used in the original analysis by HR Wallingford (2015). This amalgamation into MCM categories may result in some differences to the allocation of property types in HR Wallingford (2015). In addition, it was recognised that some property types are not currently included in the results, such as mosques, temples, and other such buildings. Whilst these are available in AddressBase, they were not included in previous analysis as they didn't naturally fall into the MCM codes. For future updates of this indicator, it is recommended that these are also included for completeness.

Furthermore, the use of different AddressBase data (Plus rather than Premium) will lead to some differences in property numbers and the types of properties included in the analysis, if comparing with previous years (e.g., ADAS, 2019) as AddressBase Plus excludes addresses classified as Objects Without a Postal Address and so contains fewer address records than Premium (Ordnance Survey, 2021).

2.2 Area of impermeable surfacing in urban areas

Description: *Area of impermeable surfacing in urban areas*

Type: *Vulnerability*

Time Series: *2001 to 2022*

Region: *England*

2.2.1 Introduction

This indicator was last updated by ADAS (2021). The indicator provides the relative proportions of manmade and semi-natural surfaces in the urban environment, in England, between 2001 and 2022. This update provides new data and analysis for 2022.

2.2.2 Data source and method

The 'Topography' layer of Ordnance Survey's MasterMap product records the 'make' (i.e. surface material) of each land parcel as natural, manmade, multiple, unclassified or unknown, which is noted as a useful attribute in applications where the porosity of land cover is important, such as in calculating surface run-off from rainfall (Ordnance Survey, 2010). These are defined as:

- Natural (features that are not man-made but possibly man altered, for example, cliffs, areas of water and uncultivated/cultivated vegetation).
- Manmade (features that have been constructed, for example, areas of tarmac or concrete).
- Multiple (features that are a mixture of makes but are not depicted separately within the data, for example, the area around a dwelling may be a mixture of made and unmade surfaces).
- Unclassified (features that have not had a make allocated).
- Unknown (features the make of which is not known).

The area categorised as "Manmade" is assumed to be impermeable. The "Multiple" category uses properties as a proxy for number of domestic gardens, which is assumed to be a mixture of permeable and impermeable surfaces.

A methodology was developed by HR Wallingford (2012) to estimate the impermeable fraction of this category based on urban creep research under the assumption that estimated urban creep rates could be applied to these areas to determine the potential likely increase in intra-urban impermeable areas. The same method has been used for this indicator update.

Data was sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data, and ADAS (2021) for 2016, 2018 and 2020 data. 2022 data was new analysis as part of this report.

To define the urban (built-up) area, up-to-date Ordnance Survey (OS) AddressBase Plus data was used to calculate the property density per 1km grid cell. Two methods were used to define the urban area:

- Method 1: Uses the method first developed by HR Wallingford (2012) that uses a property density of >500 properties per 1km cell to identify the urban area. This method is comparable to previous impermeable calculations dating back to 2001.
- Method 2: An improved method to include larger areas of greenspace within cities and towns, which are not captured in method 1. This improved approach takes account of the values of the neighbouring cells by taking an average of the central cell and its surrounding eight cells. This smooths the values, better defines the edge of urban areas and accounts for city centre greenspace. The original mask using > 500 properties per 1km cell was added to the revised mask to ensure inclusion of smaller settlements that would be missed by the revised method.

The methods are comparable to previous impermeable calculations carried out in 2016 (ADAS, 2017), 2018 (ADAS, 2019), and 2020 (ADAS, 2021). See ADAS (2021) for the full method.

2.2.3 Trends and implications for climate resilience

The area of built-up areas covered by impermeable surfaces is outlined for both methods of urban area calculation.

Method 1

The area of impermeable surfaces in urban areas is shown in Table 3 and Figure 3 for the current analysis (2022), alongside previous updates of this indicator in 2001, 2008 and 2011 (HR Wallingford, 2012), 2016 (ADAS, 2017),2018 (ADAS, 2019) and 2020 (ADAS, 2021).

The total impermeable area (manmade and multiple (impermeable)) has increased by 168,000 hectares (ha), from 477,000 ha in 2001 to 645,000 ha in 2022. The impermeable fraction of the total urban area has increased from 37% in 2001 to 46% in 2022.

The manmade area has increased by 7,000 ha since 2020, whilst the multiple (impermeable) area has increased by 17,000 ha since 2020. The impermeable fraction of the total urban area (1,396,000 ha in 2022) has increased by 1% to 46% since 2020.

Table 3. Area of built-up urban areas covered by impermeable surfaces as estimated using OS MasterMap and using assumptions of urban creep (method 1). The multiple category represents domestic gardens, separated into multiple (permeable) and multiple (impermeable). Data sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data, and ADAS (2021) for 2016, 2018 and 2020 data. 2022 data is new analysis as part of this project. Source: ADAS for the CCC.

Thousand ha	2001	2008	2011	2016	2018	2020	2022
Manmade	384	398	401	429	451	461	468
Multiple (impermeable)	94	142	163	160	170	160	177
Total impermeable area	**477**	**540**	**565**	**589**	**621**	**621**	**645**
Total urban area	1,298	1,297	1,296	1,332	1,383	1,383	1,396
Impermeable fraction	0.37	0.42	0.44	0.44	0.45	0.45	0.46

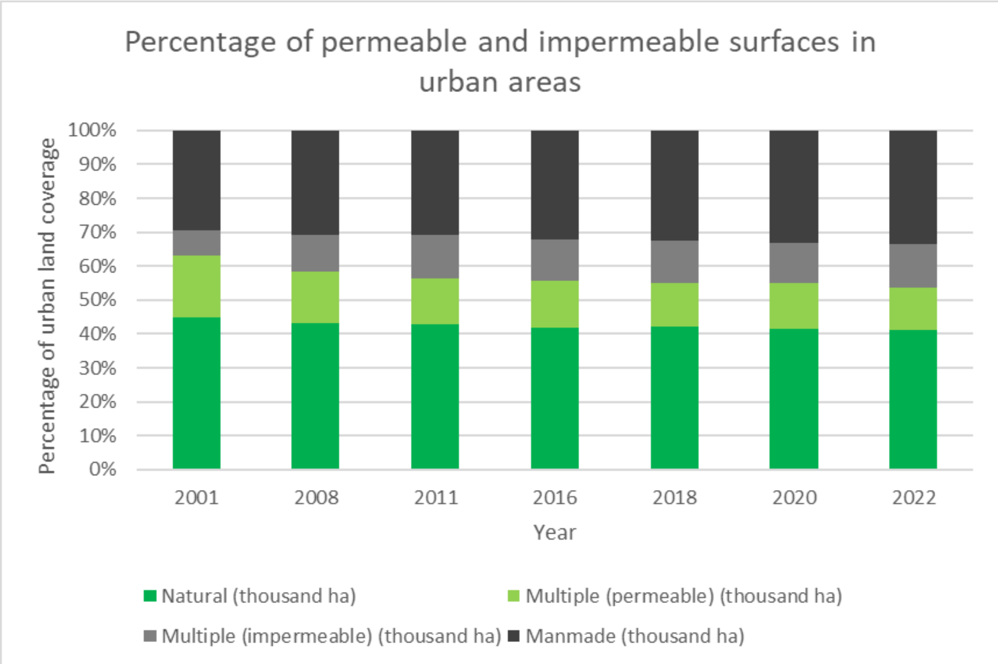

Figure 3. Changes in the proportion of permeable and impermeable surfaces in built-up urban areas in 2001, 2008, 2011, 2016, 2018, 2020, 2022 (urban areas defined using method 1). The multiple category represents domestic gardens, separated into multiple (permeable) and multiple (impermeable). Data sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data, and ADAS (2021) for 2016, 2018 and 2020 data. 2022 data was new analysis as part of this project. Source: ADAS for the CCC.

Method 2

Area of impermeable surfaces is shown for the current analysis (2022) and previous analyses of this indicator in 2016 (ADAS, 2017), 2018 (ADAS, 2019), and 2020 (ADAS, 2021) – updated using Method 2, which includes estimation of urban creep. Results are shown in Table 4 and Figure 4, outlining the area covered by each land surface type (ha).

Table 4. Area of built-up urban areas covered by impermeable surfaces as estimated using OS MasterMap and using assumptions of urban creep (method 2). Data sourced from ADAS (2021) for 2016, 2018 and 2020 data. 2022 data is new analysis as part of this project. Source: ADAS for the CCC.

Thousand ha	2016	2018	2020	2022
Manmade	498	509	520	532
Multiple (impermeable)	184	180	170	188
Total impermeable area	**682**	**689**	**690**	**720**
Total urban area	1,772	1,730	1,720	1,778
Impermeable fraction	0.38	0.40	0.40	0.41

As with the first method, the overall impermeable fraction of the total urban area has continued to increase, from 38% in 2016 to 41% in 2022. The impermeable fraction is lower in all years compared to Method 1 due to the inclusion of more urban greenspace (i.e. additional grid cells) that mean it is slightly more sensitive to the types of green space expansion that might be found in urban areas.

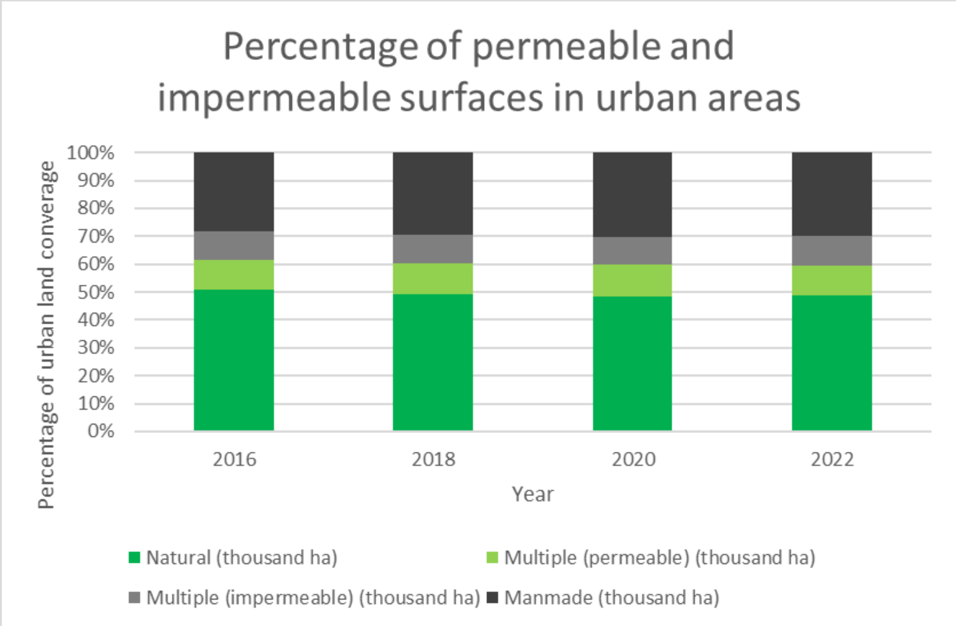

Figure 4. Changes in the proportion of permeable and impermeable surfaces in built-up urban areas in 2016, 2018, 2020 and 2022 (urban areas defined using method 2). Data sourced from ADAS (2021) for 2016, 2018 and 2020 data. 2022 data is new analysis as part of this project. Source: ADAS for the CCC.

2.2.4 Robustness of indicator

Ordnance Survey MasterMap is recognised as the definitive source for detailed geographic data of Great Britain. This indicator is therefore robust in terms of the mapping used to represent impermeable surfaces; however, an estimate had to be made of the impermeable fraction of the 'Multiple' surface type based on research into urban creep. This may lead to under- or over-estimation of impermeable area but should be consistent across years. The indicator is designed to act as proxy record to indicate the use of permeable surfaces to enable more sustainable drainage in urban areas.

Different products in different years have been used to estimate the number of properties. The Address point data used prior to 2016 was superseded by OS AddressBase. Furthermore, OS AddressBase Premium was used in 2018 while OS AddressBase Plus was used in 2020 and in this analysis. The property data is used to identify housing densities which is used to identify urban areas and density classes. Therefore, changes in the product used can impact on these calculations as AddressBase Premium provides the most detailed view of addresses provided by OS and contains approximately 42 million records whereas AddressBase Plus contains approximately 36.5 million records (OS, 2021).

2.3 Area of urban greenspace

Description: *Area of urban greenspace*

Type: *Vulnerability*

Time Series: *2001 to 2022*

Region: *England*

2.3.1 Introduction

This indicator was last updated by ADAS (2021). The indicator provides the relative proportions of semi-natural areas (greenspace) within towns and cities in England between 2001 and 2022. This update provides new data and analysis for 2022.

2.3.2 Data source and method

The method used was equivalent to that used for 'the area of impermeable surfacing in urban areas' (see section 2.2), except that the area of greenspace in urban areas was estimated from the area of the "Natural" material plus the permeable fraction of "Multiple".

The 'Topography' layer of Ordnance Survey's MasterMap product records the surface material of each land parcel as "Natural", "Manmade" or "Multiple". The area categorised as "Natural" is assumed to be Greenspace which is expected to represent semi-natural areas and defined in MasterMap as features that are not man-made but possibly man altered, for example, cliffs, areas of water and uncultivated/cultivated vegetation. The "Multiple" category represents domestic gardens, which is assumed to be a mixture of permeable and impermeable surfaces. A methodology was developed by HR Wallingford (2012) to estimate the impermeable fraction of this category based on urban creep research under the assumption that estimated urban creep rates could be applied to these areas to determine the potential likely increase in intra-urban impermeable areas. The same method has been used for this indicator update. See section 2.2 and ADAS (2021) for the full method applied in this analysis.

Data was sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data, and ADAS (2021) for 2016, 2018 and 2020 data. 2022 data is new analysis as part of this project.

2.3.3 Trends and implications for climate resilience

The area of built-up urban areas covered by permeable surfaces (greenspace) is shown for both methods of urban area calculation.

Method 1

The area of permeable surfaces (greenspace) in urban areas is shown in Table 5 for the current analysis (2022), alongside previous updates of this indicator in 2001, 2008 and 2011 (HR Wallingford, 2012), 2016 (ADAS, 2017), 2018 (ADAS, 2019) and 2020 (ADAS, 2021).

The total permeable area (natural and multiple (permeable)) has decreased by 70,000 ha, from 821,000 ha in 2001 to 751,000 ha in 2022. The permeable fraction of the total urban area has decreased from 63% in 2001 to 54% in 2022.

The permeable fraction of the total urban area has decreased by 1% since 2020, to 1,396,000 ha in 2022. This is a result of a decrease in the multiple (permeable) area from 189,000 ha in 2020 to 175,000 ha in 2022. This decrease was slightly offset by an increase in the natural portion, which increased by 2,000 ha since 2020 to 576,000 ha.

Table 5. Area of built-up areas covered by permeable surfaces (greenspace) as estimated using OS MasterMap and using assumptions of urban creep (Method 1). Data sourced from HR Wallingford (2012) for 2001, 2008 and 2011 data and ADAS (2021) for 2016, 2018 and 2020 data. 2022 data is new analysis as part of this project. Source: ADAS for the CCC.

Thousand ha	2001	2008	2011	2016	2018	2020	2022
Natural	581	559	554	558	583	574	576
Multiple (permeable)	240	198	178	185	179	189	175
Total permeable area	**821**	**757**	**732**	**743**	**762**	**763**	**751**
Total urban area	1,298	1,297	1,296	1,332	1,383	1,383	1,396
Permeable fraction	0.63	0.58	0.56	0.56	0.55	0.55	0.54

See Figure 3 for a graph showing the percentage split between permeable and impermeable surfaces in the built-up urban area using Method 1.

Method 2

The area of permeable surfaces (greenspace) is shown for the current analysis (2022) and previous analyses of this indicator in 2016 (ADAS, 2017), 2018 (ADAS, 2019) and 2020 (ADAS, 2021). Results are shown in Table 6.

Like Method 1, the overall permeable area fraction has decreased by 1% since 2020, to 59% of the total urban area in 2022. The permeable fraction is higher in all years compared to Method 1 due to the inclusion of more urban greenspace within the approach taken. Equally, the total urban area is higher in all years by ~500ha compared to Method 1, due to greater granularity in defining the edge of urban areas in Method 2.

Table 6. Area of built-up areas covered by permeable surfaces (greenspace) as estimated using OS MasterMap and using assumptions of urban creep (Method 2). Data sourced from ADAS (2021) for 2016, 2018 and 2020 data. 2022 data is new analysis as part of this project. Source: ADAS for the CCC.

Thousand ha	2016	2018	2020	2022
Natural	899	849	828	870
Multiple (permeable)	191	192	202	187
Total permeable area	**1,090**	**1,041**	**1,030**	**1,058**
Total urban area	1,772	1,730	1,720	1,778
Permeable fraction	0.62	0.60	0.60	0.59

See Figure 4 for a graph showing the percentage split between permeable and impermeable surfaces in the built-up urban area using Method 2.

2.3.4 Robustness of indicator

Ordnance Survey MasterMap is recognised as the definitive source for detailed geographic data of Great Britain. This indicator is therefore robust in terms of the mapping used to represent permeable surfaces; however, an estimate had to be made of the permeable fraction of the 'Multiple' surface type based on research into urban creep. This may lead to under- or over-estimation of the permeable area but is consistent across years when analysed using the same method.

Different products in different years have been used to estimate the number of properties. The Address point data used prior to 2016 was superseded by OS AddressBase. Furthermore, OS

AddressBase Premium was used in 2018 while OS AddressBase Plus was used in 2020 and in this analysis. The property data is used to identify housing densities which is used to identify urban areas and density classes. Therefore, changes in the product used can impact on these calculations.

2.4 Wildfire incidents and area burnt

Description: *Number of wildfire incidents and total area burnt*

Type: *Realised impact*

Time Series: *2009-10 to 2020-21; and 2015 to 2021*

Region: *England, and the UK*

2.4.1 Introduction

The indicator provides an assessment of the number of wildfire incidents and the total area burnt by land cover class from two different datasets:

- The Forestry Commission dataset covering wildfires in England, between 2009-10 and 2020-21. This update provides new data for 2017-18 to 2020-21. This part of the indicator was last updated by ADAS (2019).
- The European Forest Fire Information System (EFFIS) dataset covering wildfires in the UK. This update provides new data for 2015 to 2021. This part of the indicator was last updated by ADAS (2021).

2.4.2 Data source and method

Forestry Commission dataset

The Forestry Commission (FC) (2019) published a report 'Wildfire Statistics for England 2009-10 to 2016-17' in 2019, which formed the basis of this indicator (ADAS, 2019). This dataset was updated in their latest report 'Wildfire Statistics for England 2009-10 to 2020-21' in February 2023 (Forestry Commission, 2023). This analysis used the definition of wildfires presented in the FC report: *"Any uncontrolled vegetation fire which requires a decision, or action, regarding suppression."* The 2023 report provides an update to the previous FC report used for this indicator, including revised data following improvements to the methodology and updates to the database.

Statistics for two sub-categories of wildfires are presented in the FC report: woodland fires as classified by the National Forest Inventory (NFI) and non-woodland fires (i.e., wildfires on other land cover classes), derived from the Centre for Ecology and Hydrology's (CEH) Land Cover Map 2020. Using the NFI definition of woodlands allows for comparison to other nations' reports on forest fires. As part of the revisions in the 2023 report the FC have included additional categories of woodland land cover: coppice with standards, failed woodland, and windblow woodland. To reflect these updates in this analysis the additional categories have been added to the combined land cover categories presented in ADAS (2019). The data is recorded in financial years (months not specified but estimated to reflect April to March).

The FC database also provides information on wildfire incidents in 'Built-Up Areas & Gardens' and incidents of 'No Classification'. These categories were not included within this analysis. Whilst it is noted that in many locations the natural environment sits within the built environment (e.g. gardens and parks), the focus of this indicator was wildfires in the non-urban environment. The exclusion of these two categories may result in some wildfire incidents being omitted, such as wildfires on the rural/urban interface, however the overall impact of omission is deemed to be relatively minor. The total area burnt in all built-up areas and gardens, within the time series, equates to 16% of the total area burnt, despite accounting for 54% of all wildfire incidents reported.

The updated eight key combined categories used in this analysis are listed below. Verification status in the Ordance Survey MasterMap® (OSMM) refers to analysis undertaken by the FC on land that did not meet the NFI definition for woodland but was classified as woodland in the CEH Land Cover Map 2020, achieved by comparing with the OSMM topographic layer.

Woodland Fires - NFI

- **Broadleaved Woodland** (Broadleaved Woodland; and Mixed Woodland - Predominantly Broadleaved)
- **Conifer Woodland** (Conifer Woodland; and Mixed Woodland – Predominantly Conifer)
- **Other Woodland** (Coppice; Coppice with Standards; Young Trees; Low Density; Assumed Woodland; Ground Prepared for Planting; Shrub land; Felled; Failed; Windblow, Uncertain and Woodland – verified in OSMM)

Non-woodland fires – CEH LCM

- **Arable**
- **Improved Grassland**
- **Semi-Natural Grassland**
- **Mountain, Heath & Bog**
- **Other** (Other - freshwater, saltwater and coastal, and Non-Woodland - not verified in OSMM)

The Joint Research Centre

The EFFIS consists of a modular web geographic information system that provides near real-time and historical information on forest fires and forest fire regimes in the European, Middle Eastern and North African regions. Data was sourced from the annual reports produced by the Joint Research Centre (JRC) based on EFFIS information and supplemented by qualitative information submitted by representatives from the four devolved UK countries, for the years 2015 (San-Miguel-Ayanz et al., 2016), 2016 (San-Miguel-Ayanz et al., 2017), 2017 (San-Miguel-Ayanz et al., 2018), 2018 (San-Miguel-Ayanz et al., 2019), 2019 (San-Miguel-Ayanz et al., 2020), 2020 (San-Miguel-Ayanz et al., 2021) and 2021 (San-Miguel-Ayanz et al., 2022).

The ‘rapid damage assessment module’ of EFFIS provides reliable and harmonized estimates of the areas affected by forest fires during the fire season. EFFIS rapid damage assessment is based on the analysis of the Moderate Resolution Imaging Spectroradiometer satellite imagery. The methodology and the spatial resolution of the satellite sensor data used for this purpose allows the mapping of all fires of about 30 ha or larger.

Statistics on the burnt area by land cover type use data from the European CORINE Land Cover 2016 database, which is overlaid with the mapped burnt areas (San-Miguel-Ayanz et al., 2022). In 2021 more detailed land cover categories were used to classify the vegetation types; ‘forestry/other wooded land’ was separated into ‘broadleafed forest’, ‘coniferous forest’, ‘mixed forest’ and ‘transitional’. For the purposes of comparison these categories were combined to create a ‘forestry/other wooded land’ category for the 2021 results shown here.

Data for this analysis was extracted on the number of wildfires greater than 30 ha and 500 ha, and the area burnt (ha), from the annual reports. The data extracted for 2021 (San-Miguel-Ayanz et al., 2022) is based on the definition of the National Fire Chief Council and National Operations Guidance, where wildfires must meet the criteria of one or more of the following: ≥ 1 ha (10,000 m²), ≥ 4 Appliances or vehicles, ≥6 hours duration, flame Length of ≥1.5 m, and serious risk to life, environment, infrastructure, property.

2.4.3 Trends and implications for climate resilience

Statistics for England (Forestry Commission)

For the period of 2009-10 to 2020-21 the Fire and Rescue Service in England attended 165,222 wildfire incidents in the natural environment, with a total area burnt of 66,661 ha. This analysis excludes incidents which were classified as occurring in "built-up areas and gardens" and incidents with "no classification".

Figure 5 shows that during this time period the majority of wildfire incidents that occurred in England were associated with improved grassland (32%), broadleaved woodland (24%) and arable (17%); averaged for the whole period.

The number of wildfire incidents were notably lower between 2012-13 to 2017-18, compared with the three years before and after this period (2009-10 to 2011-12 and 2018-18 to 2020-21).

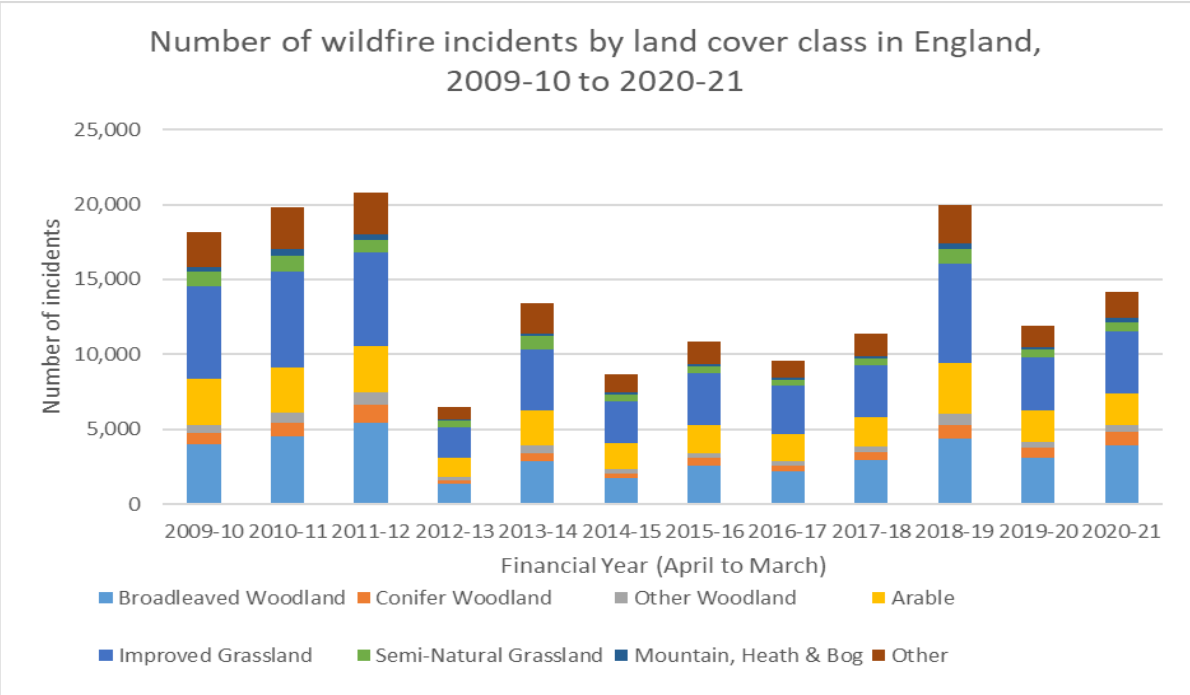

Figure 5. Total number of wildfire incidents recorded each year by the Fire and Rescue Services, split by land cover class. Data sourced from the Forestry Commission (2023) report on wildfire statistics. Source: ADAS for the CCC.

In total there were 52,440 wildfire incidents recorded in woodlands in England between 2009-10 and 2020-21, as shown in Figure 6. Wildfires in broadleaved woodlands constituted 74% of all woodland wildfires, as an average across the timeseries. In conifer woodlands 15% of all incidents occurred and in land classified as other woodland 11% of wildfire incidents were recorded.

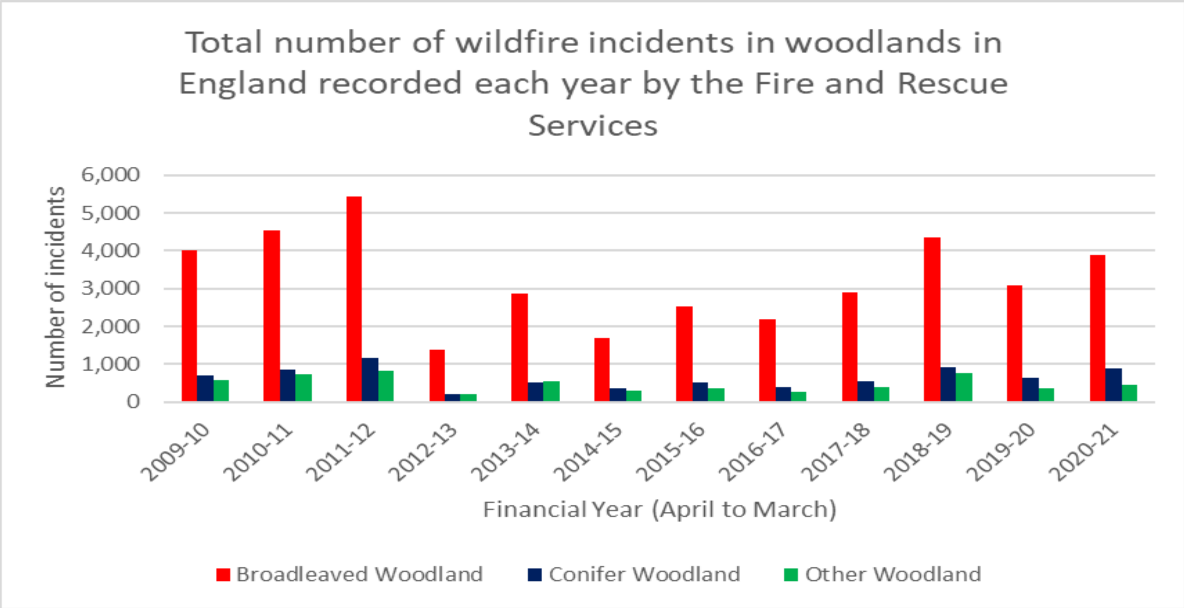

Figure 6. Total number of wildfire incidents in woodlands in England each year. Data sourced from the Forestry Commission (2023) report on wildfire statistics. Source: ADAS for the CCC.

Between 2009-10 and 2020-21 in England there were 88,077 wildfire incidents recorded on agricultural land. Figure 7 shows that averaged across this timeseries 59% of all incidents occurred in improved grassland, 32% in arable and 9% in semi-natural grassland.

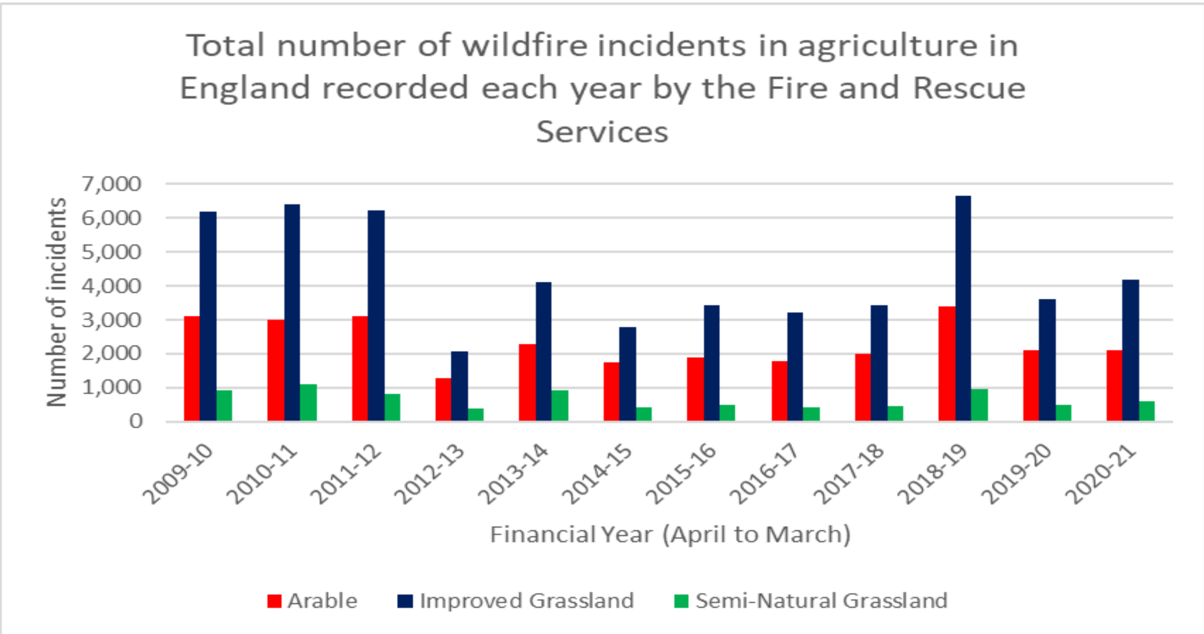

Figure 7. Total number of wildfire incidents in agriculture in England each year. Data sourced from the Forestry Commission (2023) report on wildfire statistics. Source: ADAS for the CCC.

In terms of the area burnt (ha) by land cover class between 2009-10 and 2020-21 (averaged across the whole period), the largest area lost was associated with mountain heath and bog (43%), improved grassland (20%), semi-natural grassland (12%) and other non-woodland (11%), shown in 8. However, it is noted that there is considerable variation year-to-year. For example, the area burnt of mountain heath and bog ranged from 5% of the total area in 2009-10 to 80% in 2011-12.

The largest total area burnt of the timeseries was in 2018-19 with 20,656 ha of land burnt, of which 37% was improved grassland and 33% was mountain, heath, and bog.

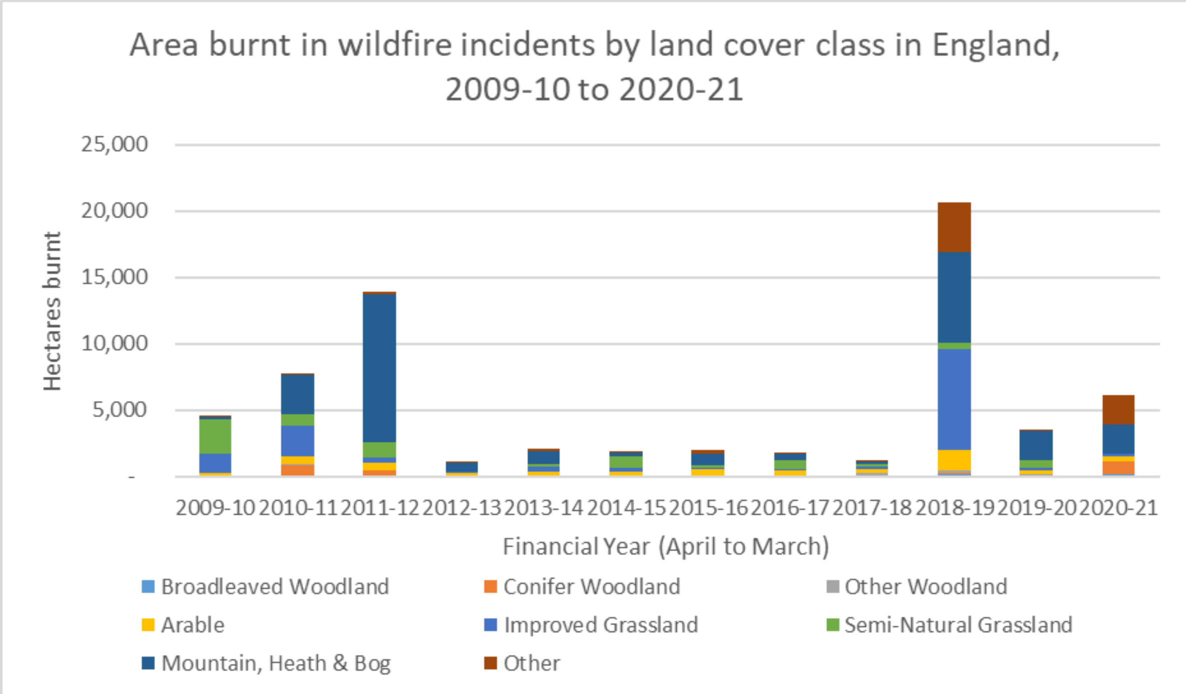

Figure 8. Area burnt in wildfire incidents, recorded each year by the Fire and Rescue Services, split by land cover class. Data sourced from the Forestry Commission (2023) report on wildfire statistics. Source: ADAS for the CCC.

The total area burnt in woodlands between 2009-10 and 2020-21 was 3,940 ha. Of this 60% was conifer woodland, 25% broadleaved woodland and 14% other woodland, averaged across the time series and shown in Figure 9. The peak seen in 2020-21 is likely to be partially attributed to the Wareham Forest wildfire in May 2020, where 223 hectares of mixed coniferous plantation, heath and bog burnt (Belcher et al., 2021).

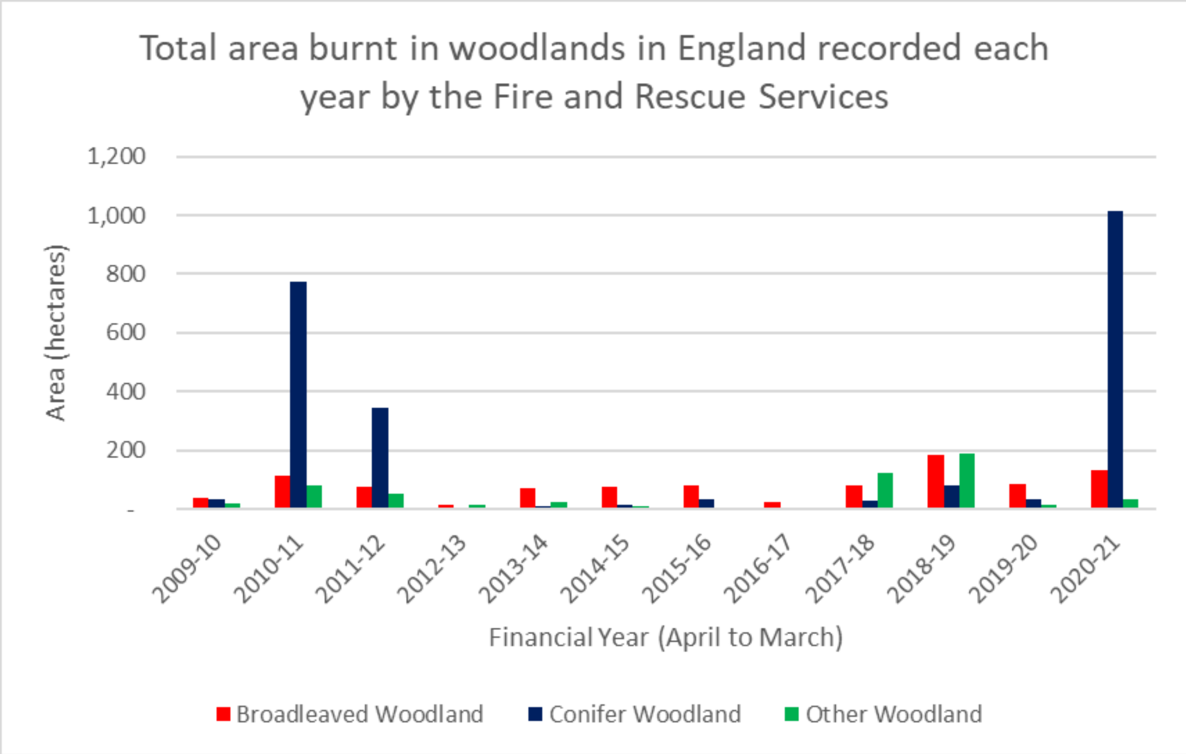

Figure 9. Total area burnt in woodlands in England each year. Data sourced from the Forestry Commission (2023) report on wildfire statistics. Source: ADAS for the CCC.

Figure 10 shows that the total area burnt in agriculture between 2009-10 and 2020-21 in England was 26,566 ha. The greatest burnt area was recorded on improved grassland, contributing 50% of the total area burnt, whilst 30% was semi-natural grassland and 20% arable land.

Improved grassland was the land type with the greatest area burnt associated with agricultural wildfires, with a large spike in 2018-19. This was likely to be a result of the exceptionally hot and dry conditions of summer 2018, which caused a peak in wildfire incidents (Home Office, 2019). This included London's biggest ever grassland wildfire at Wanstead Flats in East London in July 2018, which burnt 100 hectares of grassland (The Guardian, 2018).

Other notable wildfires during the 2018-19 season included Saddleworth Moor in Greater Manchester in June 2018 that burnt 1,800 hectares (BBC News, 2018a), and Winter Hill Lancashire in June/July 2018 that also burnt around 1,800 hectares (BBC News, 2018b), although it is unclear if these were classified as grassland or moorland fires under the Forestry Commission (2023) dataset.

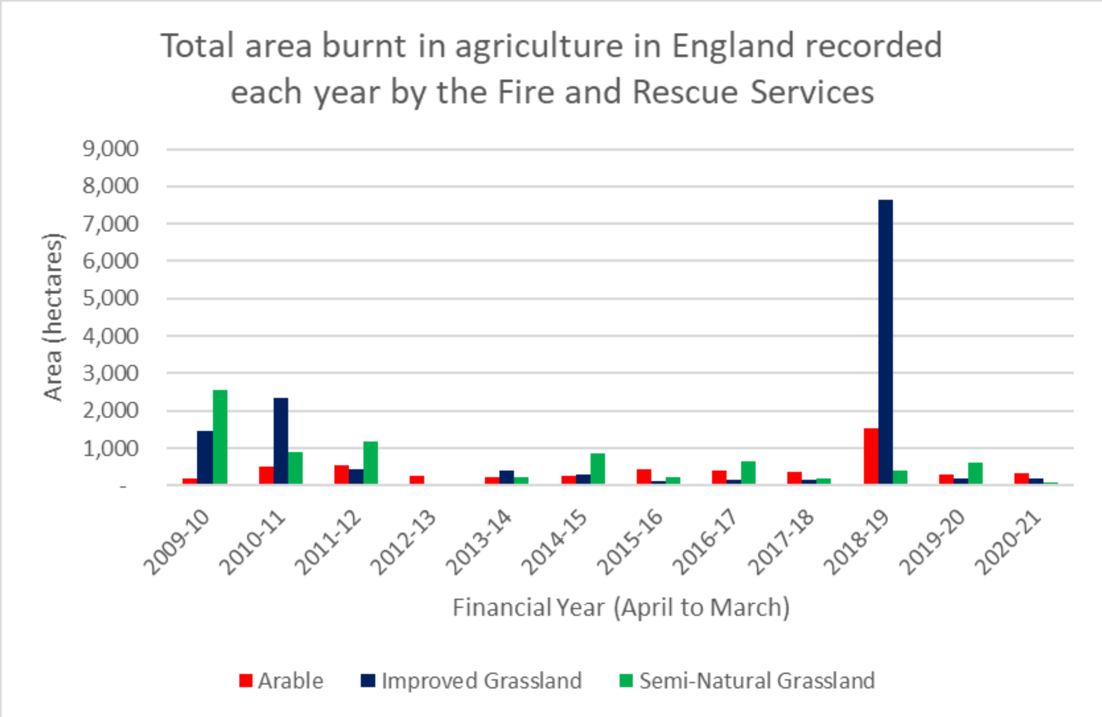

Figure 10. Total area burnt in agriculture in England each year. Data sourced from the Forestry Commission (2023) report on wildfire statistics. Source: ADAS for the CCC.

Statistics for the UK (JRC EFFIS)

Statistics from the JRC show that 2021 had the highest number of wildfires in recent years, with 234 wildfires in total increasing from 75 wildfires in 2020 and 137 in 2019, as shown in Figure 11. None of the wildfire incidents observed in 2021 in the UK exceeded 500 ha, for the first time since 2016. This could be a result of controlled tactical burning during a wildfire to reduce the severity of the wildfire, or better land management or containment, but no direct correlation is possible (Belcher et al., 2021). Wildfire incidents and area burnt was the lowest in four years but above the 10-year average (San-Miguel-Ayanz et al., 2022).

The relatively low number of wildfire incidents observed in the UK in 2018 and 2019 differs with the results of analyses of Forestry Commission data for England during the same period, which show a significant increase in wildfire incidents in the period 2018-19. When comparing the two datasets it is important to note that the JRC data is calculated by calendar year whereas the Forestry Commission data is presented by financial year. In addition, they use different methodologies.

In terms of the area burnt by wildfires, this has decreased since 2019, from 29,000 ha in 2019 to around 13,000 ha in 2020 and 8,000 ha in 2021, shown in Figure 12. The large burnt area observed in the UK between 2018 and 2019 concurs with analysis of Forestry Commission data for England in the same period (see Figure 8).

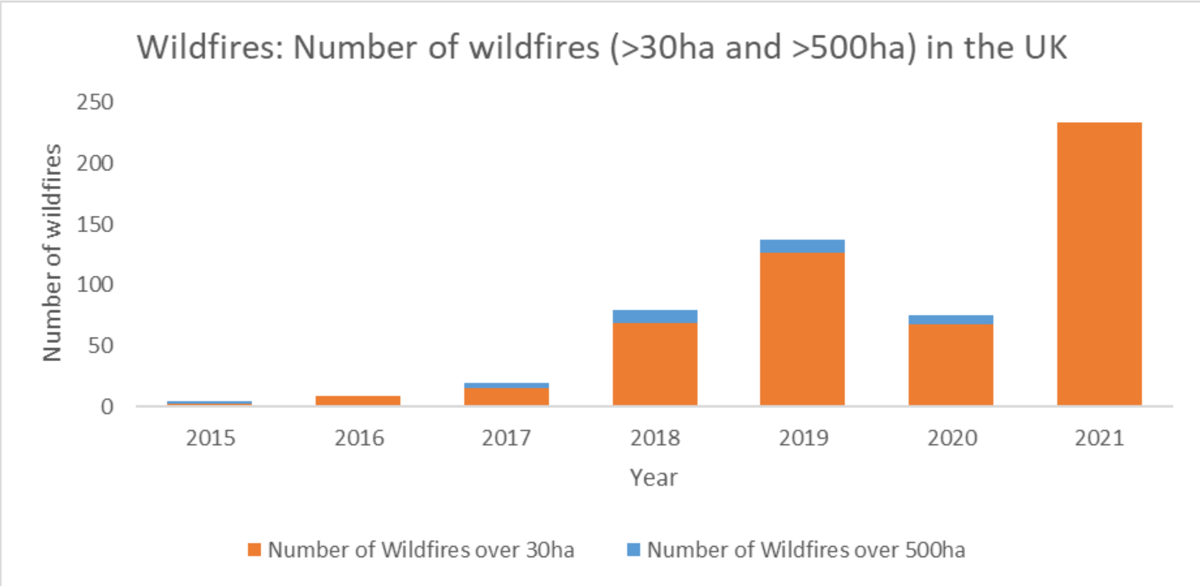

Figure 11. The number of wildfires larger than 30 ha and larger than 500 ha in size in the UK between 2015 and 2021. Data sourced from the Joint Research Centre (San-Miguel-Ayanz et al., 2016; 2017; 2018; 2019; 2020; 2021; 2022). Source: ADAS for the CCC.

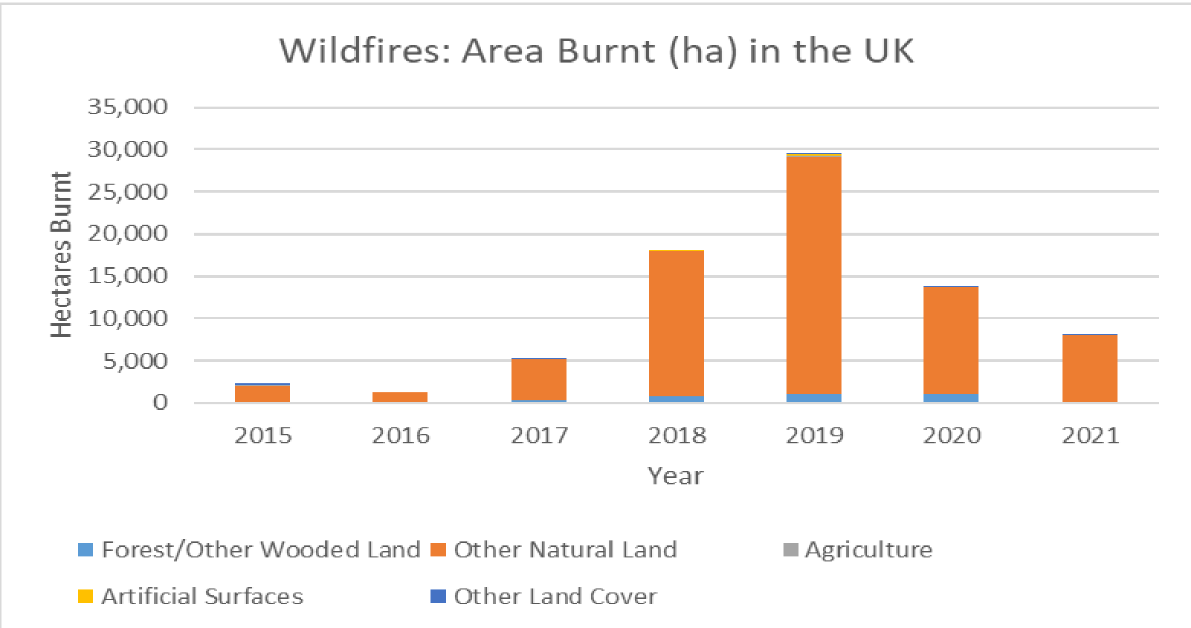

Figure 12. The area burnt by wildfires larger than 30 ha and 500 ha in size in the UK between 2015 and 2021. Data sourced from the Joint Research Centre (San-Miguel-Ayanz et al., 2016; 2017; 2018; 2019; 2020; 2021; 2022). Source: ADAS for the CCC.

The majority of the area burnt each year was classified as 'other natural land', with this land cover type accounting for between 91% and 97% of the total burnt area in each of the seven years. The land cover categories are based on CORINE Land Cover 3.2, which is very broad and includes different land cover types for different countries. In the UK, the other natural land category largely includes fires on natural grassland, and moors and heathland, defined as:

- **Natural grassland**; grasslands under no or moderate human influence. Low productivity grasslands. Often situated in areas of rough, uneven ground, steep slopes; frequently including rocky areas or patches of other (semi-) natural vegetation.
- **Moors and heathland**; vegetation with low and closed cover, dominated by bushes, shrubs, dwarf shrubs and herbaceous plants, forming a climax stage of development. Including for example, wet heath distributed on humid or semi-peaty soils (peat depth < 30 cm); and dwarf-shrub covered areas with <30 cm peat and without visible sign of morphological features typical of bogs (e.g., pools, peat hags, peatland gullying).

Most large wildfires in the UK have occurred on land associated with these land cover types. The second most prevalent land cover type was 'forest/other wooded land'. Whilst it is noted that the dataset only covers wildfires greater than 30 ha, it suggests that most large wildfires (>30 ha) consistently occur in natural habitats, rather than agriculture, artificial surfaces or other land cover types. There is also indication of a change in the fire management techniques used to contain and manage large wildfires, for example controlled tactical burning was used in the 2020 major wildfire incident in Wareham Forest (Belcher et al., 2021).

2.4.4 Robustness of indicator

Forestry Commission dataset

The data used within the Forestry Commission report was sourced from the Home Office's online Incident Recording System, which records all incidents attended by Fire and Rescue Services in England. This includes a wildfire element of the Incident Recording System that provides a record of the nature of incidents requiring a response by the Fire and Rescue Services, in line with the UK Vegetation Fire Standard. The Forestry Commission report is deemed to be robust with a consistent, recently improved methodology (using an updated database to calculate the number of wildfire incidents, and area burned, each financial year), providing a continuous 12-year time series. It is not known when the Forestry Commission will publish its next report on wildfires. In future updates it may be beneficial to create a separate indicator for the incidence of wildfires in built-up areas and gardens to support the increased focus on urban habitats.

Joint Research Centre dataset

The Joint Research Centre note that, due to the significant processing periods for fire statistics, it is not possible to gain access to Incident Recording System data for Great Britain, gathered from Fire and Rescue Services. The data is therefore based on qualitative information submitted by representatives from the four developed UK Countries (San-Miguel-Ayanz et al., 2021). However, data for 2021 suggests it was from data recorded on the UK National Resilience Reporting Tool (San-Miguel-Ayanz et al., 2022). There are some differences observed between the EFFIS online dashboard and the published reports. For this analysis, we have used the published reports as the default.

The Joint Research Centre analysis, based on EFFIS data and qualitative information, is considered to be less robust than the analysis conducted by the Forestry Commission (2023), which did have access to and used data sourced from the Home Office's online Incident Recording System. However, the Joint Research Centre analysis does provide an alternative metric to monitor wildfires over time, which appears to be a comparable indication (between years) of the number of large wildfires (i.e. >30 ha) and area burnt in the UK each fire season (i.e., calendar year).

2.5 Vineyards, area under vine, and volume of wine produced

Description: *Number of vineyards, area of vines planted, and volume of wine produced in England and Wales*

Type: *Realising Opportunity*

Time Series: *1989 to 2022*

Region: *England and Wales*

2.5.1 Introduction

This indicator was last updated by ADAS (2021). The indicator provides an assessment of the area of vines planted and volume of wine produced, in England and Wales, between 1989 and 2021, based on annual production data from the Wine Standards Branch of the Food Standards Agency. This update provides data for 2020 (replacing the estimates used in the previous update) and 2021, and estimated data for 2022 based on provisional indications from industry. In addition, the number of active vineyards and wineries are included, covering the period 2011 to 2021.

2.5.2 Data source and method

Number of vineyards

Data on the number of vineyards was extracted from the English Wine website. The time series data used for this analysis was 2011 to 2021, providing information on the number of active vineyards and wineries in England and Wales. Under European Union regulations, all vineyards of 0.10-ha or more (0.25-acres) have to be registered with the Wine Standards Branch of the Food Standards Agency who issue a Vineyard Register (English Wine, 2023).

Area under vine and volume of wine produced

Data on the area under vine and volume of wine produced for this analysis was sourced from English Wine, for the period 1994 to 2022. These datasets are predominantly based on values supplied by the Wine Standards Branch of the Food Standards Agency. The Wine Standards Branch produce the official record of vintage production for DEFRA, based on annual harvest and production declarations provided to the Food Standards Agency from commercial vineyards. Data for 1989-93 has not been included in this analysis due to the Wine Standards Branch figures including data from hobby vineyards and abandoned vineyards. Wine Standards Branch data for 1994 onwards includes the commercial area only and therefore provides a more consistent and representative time series. The commercial area is split between the area (ha) in production, and not in production.

The data for 2020 provides updated figures to those estimated in ADAS (2021). Data for 2022 is estimated and subject to change.

2.5.3 Trends and implications for climate resilience

Number of vineyards

The number of active wine producing vineyards have been steadily increasing in England and Wales, rising to an estimated 879 vineyards in 2021 from 800 in 2020, shown in Figure 13. In addition, the number of wineries has also increased from 190 in 2020 to 195 in 2021. The number of wineries has increased year on year at a slower but consistent rate since 2011.

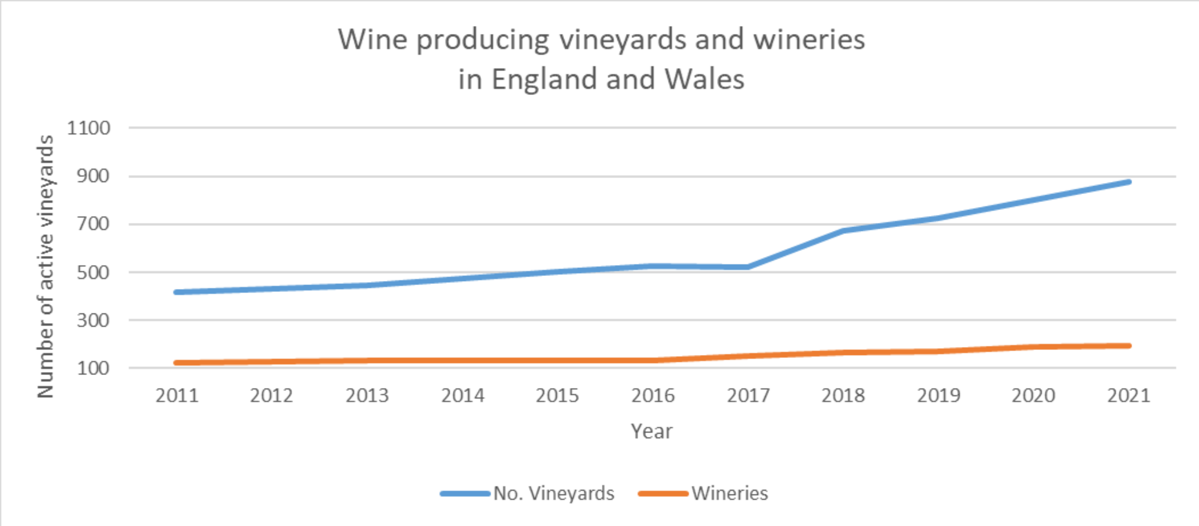

Figure 13. Number of wine producing vineyards and wineries in England and Wales from 2011 to 2021. Based on data from the Wine Standards Branch of the Food Standards Agency data, sourced from English Wine: ADAS for the CCC.

Area under vine

The total commercial area under vine in England and Wales has more than doubled in the last decade from 1,384 ha in 2011, to 3,661 ha in 2021, shown in Figure 14. These values are for commercial vineyards only and exclude 'hobby vineyards' and 'abandoned vineyards', which in 2021 accounted for an estimated additional 120 ha collectively.

Approximately 78% (2,841 ha) of the total commercial area under vine in 2021 was in active production. Of the 22% of the planted area not in production, the majority is attributed to newly planted crops that have not yet been fully established, and thus not growing high quality fruit in the quantities required for active harvesting.

There is no indication in the datasets as to whether this increase in area is being driven by improving climatic conditions for the vines, or whether there are other economic reasons for the increase in area. However, it anticipated that the climate is becoming more suitable for vine production and thus allowing the opportunity to be capitalised upon by growers interested in wine production.

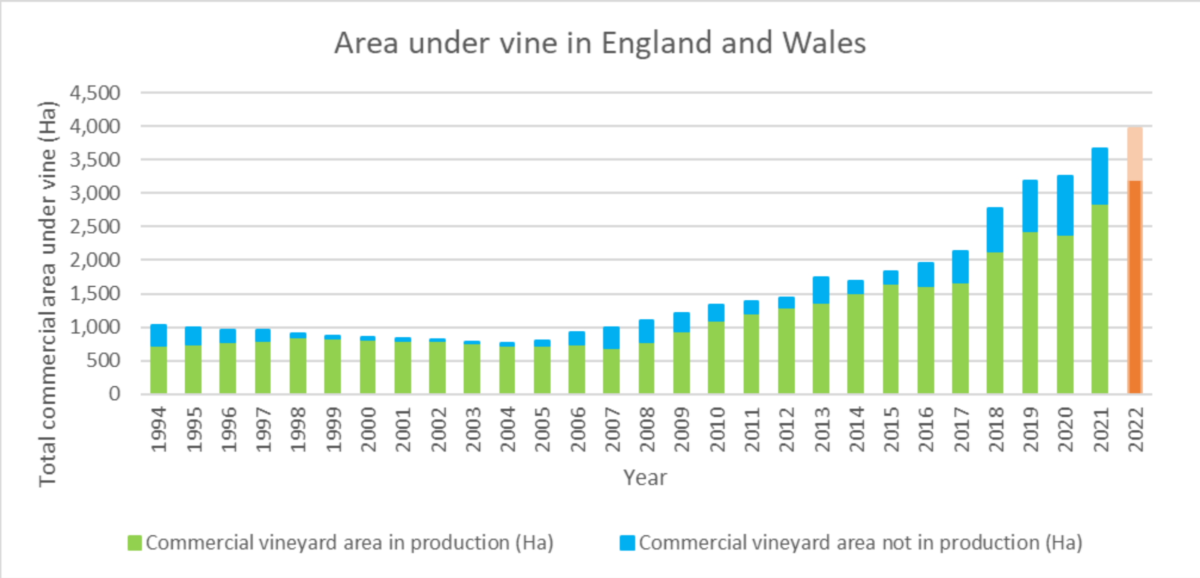

Figure 14. Total commercial area (ha) under vine each year, excluding 'hobby vineyards' or 'abandoned vineyards', split between area in production (green), and not in production (blue), for England and Wales from 1994 to 2022. Data sourced from English Wine, based on data supplied by the Wine Standards Branch of the Food Standards Agency for the period 1994-2021. Data for 2022 is estimated and subject to change. Source: ADAS for the CCC.

Volume of wine produced

The total volume of wine produced each year (i.e., number of 75cl bottles produced) is highly variable depending on the weather conditions experienced during the growing season. Figure 15 shows how the volume of wine produced has changed year on year.

It is evident that, despite the area in active production typically increasing year on year since 2004 (Figure 14), the volume of wine produced has been much more variable, with large peaks and troughs.

Years with relatively poor production volumes (taking into account increases in the total commercial area) include 2012 and 2016. The 2012 growing season was considered to be particularly poor with extremely unfavourable growing conditions that included the wettest June since 1988, the coldest summer since 1988, and the dullest summer since 1987 with just 403 hours of sunshine across the UK (Met Office, 2012). The 2016 growing season also exhibited poor conditions, due to a combination of cool conditions during the summer, followed by a lack of moisture in the later part of the growing season; to swell the grapes (Skelton, 2016).

Other years with relatively low yields include 2020, which exhibited lower production volumes partially attributed to the late frosts of 2019 and above average spring temperatures, resulting in smaller berries and lower bunch weights (WineGB, 2021), whilst a warmer than average August brought ripening quickly, resulting in an early harvest (Skelton, 2020).

Climate projections show that the UK will experience hotter, drier summers in the future (Met Office, 2022). As a result, the irrigation of some crops during periods of low precipitation may become an increasingly significant adaptation practice. However, water scarcity and competing demand for water resources will limit the extent to which this is possible. The UK’s third Climate Change Risk Assessment (CCC, 2021) recognises that water restrictions will have potential consequences for agricultural businesses, particularly those specialising in crops that are (or become) dependent on supplementary irrigation (CCC, 2021).

The 2018 growing season was exceptional with high quality grapes and favourable weather conditions, associated with a prolonged spell of hot weather, followed by a period with very little rain, enabling the grapes to fully ripen on the vine (Skelton, 2019). Production in 2019 was of high quality and yield the second highest rate of production recorded, after 2018.

Provisional data for 2022 indicates that volumes may have surpassed that of 2018, however, there is much uncertainty around this data to draw any firm conclusions at this stage.

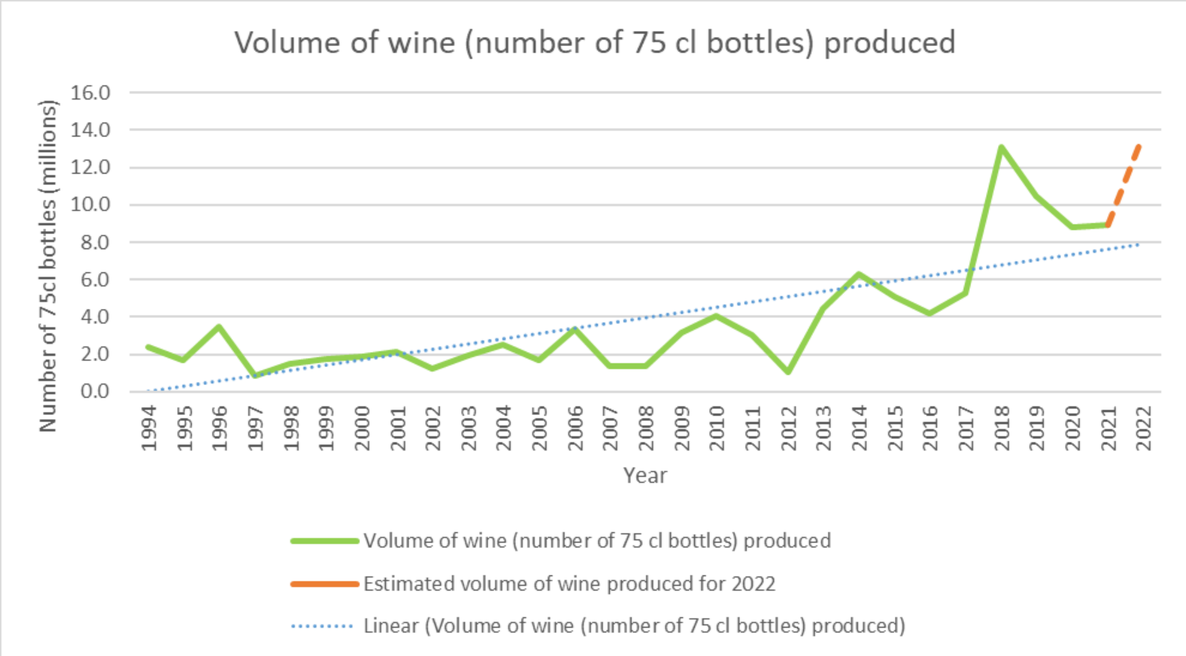

Figure 15. Wine production (millions of 75cl bottles produced) in the UK from 1994 to 2021. Data sourced from English Wine, based on data supplied by the Wine Standards Branch of the Food Standards Agency. Data for 2022 is estimated and subject to change. Source: ADAS for the CCC.

2.5.4 Robustness of indicator

Number of vineyards

The vineyard register provides an indication of the number vineyards that are active. Unfortunately, owing to various factors, parts of the vineyard register are incomplete or estimated and cannot be relied upon to be 100% accurate (English Wine, 2023). However, the number of vineyards and direction of trend appears to be consistent with other industry reports, such as the Wines of Great Britain industry reports (WineGB, 2022).

Area under vine and volume of wine produced

The data sourced from English Wine, originally supplied by the Wine Standards Branch of the Food Standards Agency is considered to be fairly robust and consistent over the time series, providing a good indicator for the total area of commercial vineyards (both in and out of production), as well as robust estimations of the volume of wine produced. WineGB also hold a dataset, based on Wine Standards Branch data. Whilst there are some minor inconsistencies between the English Wine dataset and WineGB dataset, the majority of values match and any differences are considered to be materially insignificant to the larger trends shown. The official figures for the area under vine in 2020 replace industry estimates used in the previous update of this indicator, providing more robust values for vineyard production for this period. Estimates for 2022 are provisional.

The original source of the Wine Standards Branch data comes from annual declarations on a survey, completed by commercial vineyard growers. It is anticipated that the Wine Standards Branch and/or English Wine or WineGB will continue to collect this data year-on-year, allowing for future updates of the indicator.

3 EXPLORATION OF NEW INDICATORS

The indicators in this section explore the evidence base for potential metrics that could inform the basis of new or updated indicators to be included in the Adaptation Committee's indicator set.

3.1 Change in total hedgerow length

Description: *Length of hedgerows in England*

Type: *Exposure*

Time Series: *1984 to 2007*

Region: *GB and England*

3.1.1 Introduction

This indicator was developed by ADAS (2021) and provided an assessment of the change in hedgerow length in England and Great Britain, between 1984 and 2007, based on data from the Countryside Survey (2007). No further comparable data has been provided since this release.

3.1.2 Data source and method

There are a couple of datasets that have been identified to provide information on hedgerow length in England. However, none were available or accessible to inform this report. The key datasets are:

Countryside Survey

Data for the years 1984, 1990, 1998 and 2007 were available in the Countryside Survey (2007), which was used in analysis by ADAS (2021). Unfortunately, this data has not been collected since 2007 within this data collection programme and therefore the indicator could not be updated.

Whilst not confirmed at this stage, there is the possibility of new data becoming available in the next year or so. An organisation has plans, subject to funding, to repeat the Countryside Survey squares hedgerow survey in 2023 (with a small proportion of squares already surveyed in 2022). Should this materialise, it would mean that all the Countryside Survey squares in England will have been revisited by the end of 2023. This would enable a comparable update, with new figures, which show what has been happening with hedges in the last 15 years in England since the 2007 Countryside Survey results. It is not expected that these figures would become available until at least Spring 2024.

Rural Payments Agency

The Rural Payments Agency (RPA) collect information on registered land parcels, which includes the presence of hedgerows. This data is available via OS. However, it was not possible to access the data in time for this report due to licencing restrictions, but we understand that accessibility to the data would be likely in the future; there are plans for the RPA hedge data to become part of the Public Sector Geospatial Agreement when it will form part of the new OS Field Boundaries dataset. In the absence of this data, a request for information was raised to the RPA and dealt with under the Environmental Information Regulations 2004.

3.1.3 Trends and implications for climate resilience

Estimates for hedgerow length

Countryside Survey: The total hedgerow length in Great Britain in 2007 was estimated to be 477,000 km, of which 402,000 km were in England, 54,000 km in Wales and 21,000 km in Scotland.

Rural Payments Agency: The RPA confirmed that there are 477485329.0986m (~477,000 km) of hedgerows currently mapped against registered land parcels. This was live (current) data for the length of hedgerows in England only and was correct as of 30 January 2023. The figure provided is based on the total length of hedges in England's registered agricultural area.

The RPA data suggests that the total length of hedges in England has increased since 2007, although this cannot be confirmed as the Countryside Survey and RPA datasets do not use a comparable methodology.

Expected changes in hedgerow length in the future

It is expected that hedgerow length will show an increasing trend over the coming years. The Environmental Improvement Plan 2023, which builds on the 25 Year Environment Plan vision, has a commitment to support the creation and/or restoration of 30,000 miles of hedgerows by 2037 and 45,000 miles of hedgerows by 2050, returning hedgerow lengths in England to 10% above the 1984 peak of 360,000 miles / ~580,000 km (Defra, 2023).

3.1.4 Robustness of indicator

The robustness of the Countryside Stewardship (2007) dataset was outlined in ADAS (2021).

The robustness of the RPA data is not known at this stage but is assumed to only include the total length of hedges in England's registered agricultural area, therefore excluding all hedges within areas that are not registered with the RPA. It is therefore likely that the figure provided is an underestimation of the total length of hedges in England.

3.2 Current crop production by area in the UK

Description: *Current crop production by area in the UK – to assess levels of production in climatically unsuitable areas under 2/4C warming.*

Type: *Realising opportunity*

Time series: *1984 to 2021 (arable crops) and 2010-2021 (horticulture crops)*

Region: *United Kingdom*

3.2.1 Introduction

Crop production in the UK is diverse and varies geographically. Broadly, arable farming is the most extensive system in the UK, with production most intensive in the east and south-east of England, while pasture-based livestock systems are situated in the west and north of England, as well as Wales, Scotland, and Northern Ireland (Wheeler and Lobley, 2021). Horticulture is the sector of the agricultural industry that is responsible for the production of fruit, vegetables, and ornamental plants, with production largely concentrated in the east and south eastern parts of the UK (Knox et al., 2009).

It is expected that changes in the climate will impact the distribution of areas suitable for the production of certain crops in the UK, presenting both risks and opportunities to crop production (Berry and Brown, 2021). Projections indicate that impacts of climate change on UK agriculture will vary geographically and may present as gradual long-term shifts or through rapid events relating to extreme weather.

Opportunities presented by increasing temperatures include an increased viability of different crop types (e.g., grapes, hemp, chickpeas) that were only marginally viable under previous climatic conditions (Morison and Matthews, 2016). Longer growing seasons may also provide an opportunity for increased productivity for grassland and crops, although may also risk modifying plant phenology

(Berry and Brown, 2021). However, weather extremes such as droughts and prolonged wet winters threaten crop productivity. For example, the hot, dry summer of 2018 produced wheat and spring barley yields 6% and 10% lower than the five-year average, respectively (National Farmers Union, 2019).

Changes in the regional climate are likely to alter the suitability of different crop types, prompting shifts in the distribution of crops across the UK. This indicator currently calculates the area in production of the main arable and horticultural crops in the UK, from 1984 to 2021, with a future ambition to assess how this may change under 2°C and 4°C of warming, in order to map the possible changes and opportunities for crop production. Understanding the potential scale of change will help to inform decisions on agricultural adaptation to climate change.

3.2.2 Data source and method

Defra Agriculture Statistics 2021

This indicator uses data from the report 'Agriculture in the United Kingdom 2021' (Defra, 2022) which is updated by Defra with annual statistics about agriculture in the UK, including information on crop production. Data was sourced from the dataset provided by Defra for the area in production of key crops (arable, fresh fruit, fresh vegetables and flowers and plants) for the timeseries of 1984 to 2021 in calendar years. The dataset provides provisional figures for 2021. The data has been separated to show the change in area in production of the main arable crops and of the main horticultural crops. The crops included within these two categories are listed below.

- **Arable**: wheat, barley, oats, oilseed, linseed, sugar beet, field peas and field beans.
- **Horticulture**: fresh vegetables (protected), fresh vegetables (grown in the open), fresh fruit (orchard), fresh fruit (soft fruit), potatoes, and plants and flowers.

The data used for all crops represents the crop area under production, except for potatoes where information on the area sown is presented.

Assessing climatically unsuitable areas under 2/4C warming

For this report, it was not possible to assess and map levels of production in climatically unsuitable areas under 2/4C warming due to data access issues and time constraints. However, this approach would ideally use the Met Office derived projections (Met Office, 2019) and consider three-time horizons (a baseline, 2050s and 2080s). Then, using temperature and precipitation variables to produce agroclimatic zones (zones where there is an increasing requirement for water), baseline maps would be produced for different agroclimatic zones, a summary of crop areas (using regional statistics) under each zone would be mapped, and changes in the agroclimatic zone areas under future scenarios would be assessed. For example, see illustrative example in Figure 16 (Environment Agency, 2009).

The CCRA2 provided some projections on the agricultural suitability of land in England under low and high emission scenarios (Brown et al., 2016). Drought is projected to cause a reduction in land quality, with the best and most versatile agricultural land area decreasing and the area categorised as poor-quality agricultural land increasing. Potato cropping was identified as a land use vulnerable to climatic changes due to the high level of water use. The projections indicate that a geographic shift in potato cropping to less water-stressed areas in the north and west of England may be required to reduce irrigation needs and keep production viable. Similarly, the south and west of England is projected to become unsuited to the production of carrots under both low and high emission scenarios.

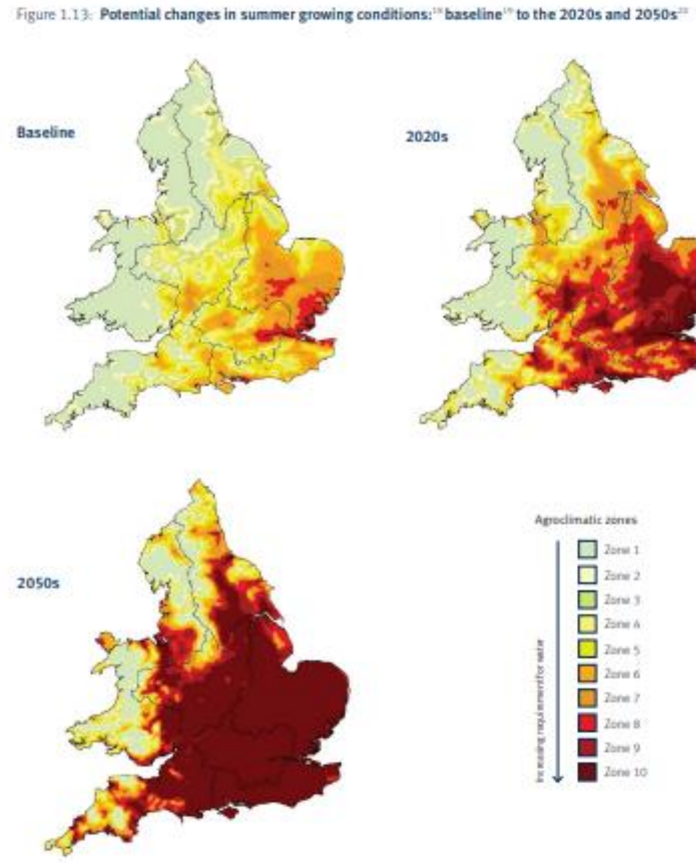

Figure 16. Illustrative map to show the sort of outputs that might be produced if the analysis was undertaken. Source: Adapted from Figure 1.13 (potential changes in summer growing conditions: baseline to the 2020s and 2050s) based on UKCIP02 data and produced by JW Knox and JA Rodriguez-Diaz, Cranfield University, 2007. Source: Environment Agency, 2009.

3.2.3 Trends and implications for climate resilience

The change in crop area under production of the main arable crops between 1984 and 2021 is shown in Figure 17. The area in production of key cereals wheat and barley has declined since 1984 (when records began) and both show considerable fluctuation across the timeseries. 2020 saw a drop of 24% in the area under wheat production but a 19% increase in barley production.

There has been a slight increase in production area for oilseed, increasing from 269,000 ha in 1984 to 307,000 ha in 2021, less than half the area in production a peak of 756,000 ha in 2012. Sugar beet has also seen a decrease of 54% in the area under production, from 199,000 ha in 1980 to 91,000 ha in 2021.

The area in production of the main horticultural crops in the UK has not shown much change in the timeseries of which data for all crops is available, as shown in Figure 18. There has been a 7% reduction in the area under production of fresh vegetables grown in the open between 2010 and 2021, and a 6% decrease in the area sown for potatoes between 2011 and 2021. The area in production of plants and flowers has remained between 12,000 ha and 13,000 ha from 2010 to 2021. There has been no change in the area under production of soft fruit (10,000 ha) and the area of orchard fruit production has decreased by 1,000 ha to 23,000 ha in 2021.

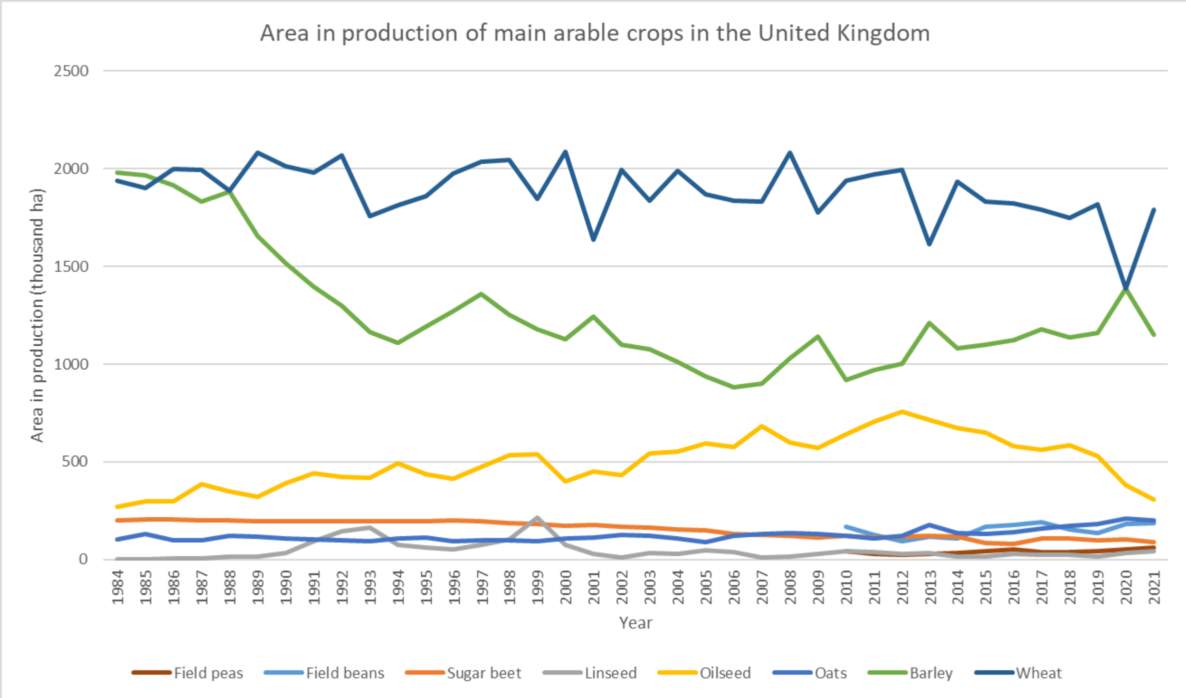

Figure 17. Area in production of main arable crops in the United Kingdom between 1980 and 2021. Data for 2021 is provisional. Data sourced from the Agriculture in the UK 2021 report (Defra, 2022). Source: ADAS for the CCC.

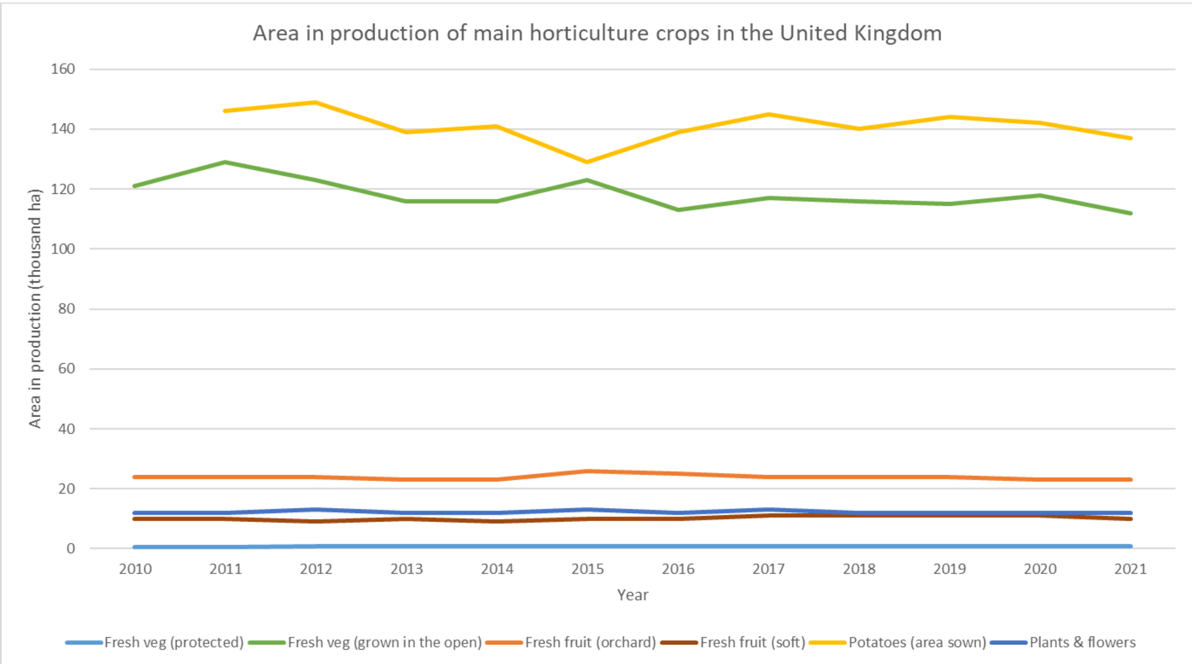

Figure 18. Area in production of main horticulture crops in the United Kingdom between 2010 and 2021. Data for 2021 is provisional. Data sourced from the Agriculture in the UK 2021 report (Defra, 2022). Source: ADAS for the CCC.

3.2.4 Robustness of indicator

It is noted that fluctuations in the date are likely due to several drivers such as crop rotations, market prices, pest and disease pressures, and weather conditions at drilling etc., rather than changes in production due to the suitability of the climate. However, over a long enough timeseries, trends with some underlying attribution to climate suitability may become apparent.

The data used within the Agriculture in the United Kingdom 2021 report was sourced by Defra based on the latest available data using a standardised methodology. The timeseries covered by the dataset varies for the different crops but in all cases the data provided covers all crops from 2011 to 2021. For 2021 the data is provisional. The report holds National Statistics status therefore is deemed to meet the highest standards of trustworthiness, quality and public value and complies with the Code of Practice for Statistics. The statistics are updated annually, with the next update for the 2022 calendar year expected to be published by Defra in summer 2023. It was not possible to source data at a regional (i.e. England) level for this report, but disaggregated data by UK nations is recommended for future reports where this is available.

An assessment of the levels of production in climatically unsuitable areas under 2/4C warming were not undertaken in this analysis. But could be conducted in the future with access to the right datasets and resources.

3.3 Exposure of vulnerable groups to flooding

Description: *Exposure of vulnerable groups (e.g., deprived communities) to flooding (e.g., properties and communities in areas with a high flood risk)*

Type: *Exposure*

Time series: *2022*

Region: *England*

3.3.1 Introduction

Exposure to flooding is influenced by environmental, political, and commercial actions as well as geographic proximity and socio-demographic factors. Certain demographic groups are more likely to be vulnerable to flooding due to pre-existing social vulnerabilities (Lowe et al., 2013). Age, employment status, income deprivation and tenancy status can be used as an index of multiple deprivation to indicate an individual’s vulnerability to the impacts of flooding because these factors can influence the extent to which building occupants can prepare for flooding events. The elderly may be less able to prepare for and cope during flood events, for example through manually putting out barriers (Fielding et al., 2007).; Similarly, individuals who are unemployed or on low incomes may be financially restricted in their access to coping mechanisms that can support flood resilience and recovery (Tapsell et al., 2002). People who are renting have reduced opportunities to ensure homes are prepared for and adapted to flooding, thus tenancy status can also be a useful indicator of flood vulnerability.

Within the UK, the impacts of exposure to floods have been shown to be unequally distributed among the population with deprived communities most vulnerable to flood impacts (Walker & Burningham, 2011). The UK is projected to experience an increased occurrence and intensity of heavy rainfall events which are likely to lead a greater risk of surface water flooding and urban flash flood events (Slingo, 2021). Understanding how the spatial distribution of vulnerable groups compares with flood risk will provide useful information to aid targeted actions to reduce the exposure of vulnerable groups to flooding.

This indicator maps flood risk against an index of vulnerability to assess how flood risk correlates with vulnerability at the local authority level in England.

3.3.2 Data source and method

Data on flood risk was available for England using the Environment Agency data sources 'Risk of Flooding from Rivers and Sea' (RoFRS) and 'Risk of Flooding from Surface Water' (RoFSW). Property data was provided by the latest OS AddressBase layer. This was combined with Office for National Statistics (ONS, 2021) data on household deprivation and mapped against local authority boundaries in England to give flood risk and deprivation scores by local authority area.

To identify the top twenty percent of local authorities with the greatest deprivation scores, the number of properties in local authorities deprived in one dimension, two dimensions, three dimensions, and four dimensions was divided by the total properties in local authorities[3]. The dimensions that an area is deprived in will vary spatially. For example, two different areas could both be deprived in two dimensions, with one of the areas representing deprivation in education and employment, whilst the other could be deprived in health and housing, for example.

This analysis identified the 61 local authorities (out of a total of 306) with the highest deprivation score. These steps were repeated to find the top twenty percent of local authorities with the highest flood risk, by calculating the number of properties in local authorities with a medium and high flood risk, divided by the total properties in local authorities. Risk was calculated separately for RoFRS and RoFSW. Again, the 61 local authorities with the highest flood risk scores were identified. The results of these two steps were overlaid to find where the selected local authorities overlapped, indicating which local authority areas were in the top 20th percentile for both deprivation and risk of flooding from rivers and sea and surface water flooding.

In future analysis this dataset could be expanded to consider tenancy status and risk of flooding, as an additional indicator of vulnerability.

[3] The dimensions of deprivation used to classify households are based on four selected household characteristics (ONS, 2021):

- Education – a household is classified as educationally deprived if no one has at least level 2 education and no one aged 16 to 18 years is a full-time student.
- Employment – a household is classified as deprived in the employment dimension if any member, not a full-time student, is either unemployed or economically inactive due to long-term sickness or disability.
- Health – a household is classified as deprived in the health dimension if any member has general health that is bad or very bad or is identified as disabled.
- Housing – a household is classified as deprived in the housing dimension if the household's accommodation is either overcrowded, in a shared dwelling, or has no central heating.

3.3.3 Trends and implications for climate resilience

Areas with greatest deprivation and risk of flooding from rivers and sea

There are six local authority areas within England in the top twenty percent for properties with the greatest deprivation and at a medium-high flood risk from rivers and sea, all located in the east of England. Two of these local authorities, Kingston Upon Hull, and North East Lincolnshire, are coastal, whilst the others, Doncaster, Leicester, Fenland and Slough, are located in inland.

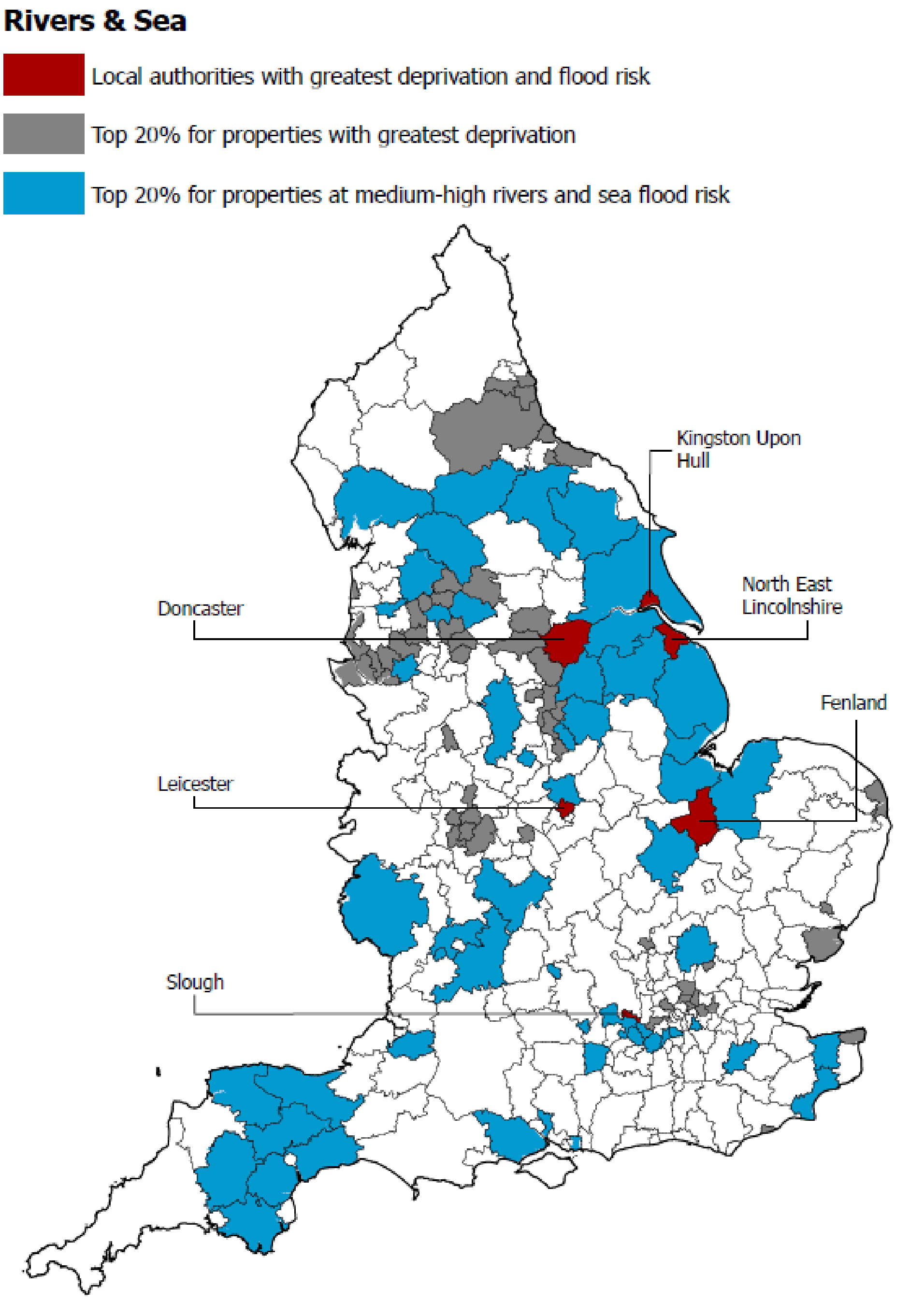

Figure 19. Local authority areas in the top 20% for properties with the greatest deprivation (grey) and at medium-high risk of flooding from rivers and sea (blue). Areas with a combination of high deprivation and flood risk are shown in red. Source: ADAS for the CCC.

Areas with greatest deprivation and risk of surface water flooding

In total, 11 local authority areas in England are in the top 20% for properties with the greatest deprivation and at a medium-high risk from surface water flooding. The majority (nine) are located in the south east of England, of which three are within Greater London (Brent, Hackney, Barking and Dagenham) with a fourth (Slough) on the border of Greater London.

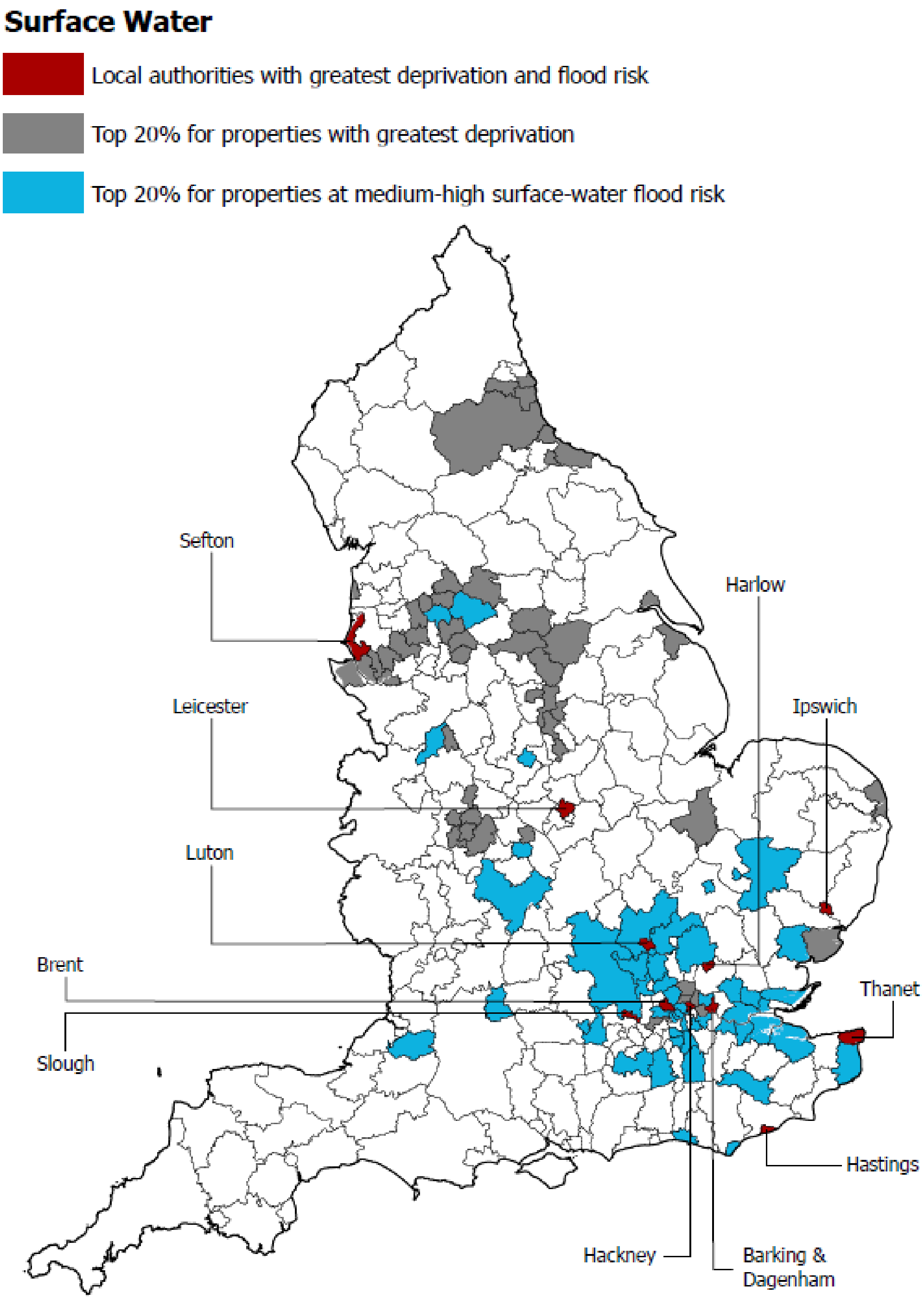

Figure 20. Local authority areas in the top 20% for properties with the greatest deprivation (grey) and at medium-high risk of surface water flooding (blue). Areas with a combination of high deprivation and flood risk are shown in red. Source: ADAS for the CCC.

3.3.4 Robustness of indicator

The data on household deprivation is sourced from the ONS, which is considered to provide highly robust information produced using standardised methodologies. Environment Agency data sources ‘Risk of Flooding from Rivers and Sea’ (RoFRS) and ‘Risk of Flooding from Surface Water’ (RoFSW) provide the best modelled estimate of flood extents for England. Property data was provided by the latest OS AddressBase Plus data. Each address point was assessed for its flood risk; this data was then summarised to Local Authority extent for mapping and matching with ONS data. Property totals did not always match between ONS and AddressBase data due to differences in property classifications (e.g., university accommodation blocks represent multiple address points in AddressBase but may be classed as just one property in ONS data). However, the majority of values did match well, and the few that didn’t match (largely relating to university type accommodation) were considered to be non-material.

Whilst there is no direct defined relationship between deprivation status and flood risk, the results of this analysis indicate that there are some areas where there is a greater chance that the properties at risk of flooding as more likely to be deprived. Nonetheless, it must be noted that this is an exploratory indicator providing information on two separate datasets. The indicator can only highlight areas where a high percentage of properties score highly on deprivation metrics and a high percentage of properties are at medium to high risk of flooding. It cannot say whether the properties in these two datasets overlap in reality.

REFERENCES

ADAS (2017) Research to provide updated indicators of climate change risk and adaptation action in England. Report for the Committee on Climate Change. Available at: https://www.theccc.org.uk/publication/updated-indicators-of-climate-change-risk-and-adaptation-action-in-england-adas/ [Accessed 27 Feb. 2023]

ADAS (2019) Research to update the evidence base for indicators of climate-related risks and actions in England. Report for the Committee on Climate Change. Available at: https://www.theccc.org.uk/publication/research-to-update-the-evidence-base-for-indicators-of-climate-related-risks-and-actions-in-england-adas/ [Accessed 27 Feb. 2023]

ADAS (2021) Research to review and update indicators of climate-related risks and actions in England. Report for the Committee on Climate Change, Available at: https://www.theccc.org.uk/publication/research-to-review-and-update-indicators-of-climate-related-risks-and-actions-in-england-adas/ [Accessed 27 Feb. 2023]

BBC News (2018a) Saddleworth Moor fire is out after more than three weeks, 18 July 2018. Available at: https://www.bbc.co.uk/news/uk-england-manchester-44880331 [Accessed 5 Apr. 2023]

BBC News (2018b) Winter Hill moorland fire 'under control', 16 July 2018. Available at: https://www.bbc.co.uk/news/uk-england-lancashire-44853173 [Accessed 5 Apr. 2023]

Belcher, C., Brown, I., Clay, G., Doerr, S., Elliott, A., Gazzard, R., Kettridge, N., Morison, J., Perry, M., Santin, C. and Smith, T., 2021. UK wildfires and their climate challenges: Expert Led Report Prepared for the third Climate Change Risk Assessment. Available at: https://research.manchester.ac.uk/en/publications/uk-wildfires-and-their-climate-challenges-expert-led-report-prepa [Accessed 31 Mar. 2023]

Berry, P. and Brown, I. (2021) National environment and assets. In: The Third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)]. Prepared for the Climate Change Committee, London. Available at: https://www.ukclimaterisk.org/wp-content/uploads/2021/06/CCRA3-Chapter-3-FINAL.pdf [Accessed 24 Feb. 2023]

Brown, I., Thompson, D., Bardgett, R., Berry, P., Crute, I., Morison, J., Morecroft, M., Pinnegar, J., Reeder, T., and Topp, K. (2016) 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. Available at: https://www.theccc.org.uk/wp-content/uploads/2016/07/UK-CCRA-2017-Chapter-3-Natural-environment-and-natural-assets.pdf [Accessed 31 Mar. 2023]

CCC (2021) Independent Assessment of UK Climate Risk. Available at: https://www.theccc.org.uk/publication/independent-assessment-of-uk-climate-risk/ [Accessed 20 Jan. 2023]

CEH (2020) Land Cover Map 2020. Available at: https://www.ceh.ac.uk/data/ukceh-land-cover-maps [Accessed: 27 Feb. 2023]

Countryside Survey (2007) Chapter 5. Boundary and Linear Features Broad Habitat. Available at: https://nora.nerc.ac.uk/id/eprint/5191/1/N005191CR%20UK%20Results.pdf http://www.countrysidesurvey.org.uk/sites/default/files/CS-England-Results2007-Chapter05.pdf [Accessed 27 Feb. 2023]

Defra (2022) Agriculture in the United Kingdom 2021. Chapter 7: Crops. Available at: https://www.gov.uk/government/statistics/agriculture-in-the-united-kingdom-2021/chapter-7-crops [Accessed 24 Feb. 2023]

Defra (2023) Environmental Improvement Plan 2023. Available at: https://www.gov.uk/government/publications/environmental-improvement-plan [Accessed 4 Apr. 2023]

English Wine (2023) Vineyards in the UK, the Republic of Ireland and the Channel Islands. Available at: http://www.englishwine.com/vineyards.htm [Accessed 27 Feb. 2023]

Environment Agency (2009) Water for people and the environment: Water Resources Strategy for England and Wales. Available at: https://webarchive.nationalarchives.gov.uk/ukgwa/20140328161417/http:/cdn.environment-agency.gov.uk/geho0309bpkx-e-e.pdf [Accessed 1 Mar. 2023]

Environment Agency (2019) What is the Risk of Flooding from Surface Water map? Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/842485/What-is-the-Risk-of-Flooding-from-Surface-Water-Map.pdf [Accessed 30/03/2023]

Forestry Commission (2019) Wildfire Statistics for England: 2009-10 to 2016-17. Available at: https://www.gov.uk/government/publications/forestry-commission-england-wildfire-statistics-for-england-2009-10-to-2016-17. [This report was withdrawn on 15 February 2023 and replaced by the Forestry Commission's Wildfire statistics for England: Report to 2020-21 published on 16 February 2023]

Forestry Commission (2023) Wildfire Statistics for England: report to 2021-21. Available at: https://www.gov.uk/government/publications/forestry-commission-wildfire-statistics-for-england-report-to-2020-21 [Accessed 24 Feb. 2023]

Fielding, J., Burningham, K., Thrush, D. and Catt, R. (2007) Public response to flood warning. R&D Technical Report SC020116. Environment Agency, Bristol. Available at: https://assets.publishing.service.gov.uk/media/602d3a81d3bf7f721c13a3ba/Public_response_to_flood_warning_technical_report.pdf [Accessed 24 Feb. 2023]

Home Office (2019) Detailed analysis of fires attended by fire and rescue services, England, April 2018 to March 2019. Available at: https://www.gov.uk/government/statistics/detailed-analysis-of-fires-attended-by-fire-and-rescue-services-england-april-2018-to-march-2019 [Accessed 5 Apr. 2023]

HR Wallingford (2012) Development of spatial indicators to monitor changes in exposure and vulnerability to flooding and the uptake of adaptation actions to manage flood risk in England. Available at: N/A [Link broken]

HR Wallingford (2015) Update analysis of the number of properties located in areas at risk of flooding and coastal erosion in England. Available at: https://www.theccc.org.uk/publication/hr-wallingford-2015-for-the-asc-update-analysis-of-the-number-of-properties-located-in-areas-at-risk-of-flooding-and-coastal-erosion-in-england/ [Accessed 27 Feb. 2023]

Knox, J.W., Kay, M.G., Weatherhead, E.K., Burgess, C. and Rodriguez-Diaz, J.A., 2009. Development of a Water Strategy for Horticulture. HDC Technical Report. Available at: https://projectbluearchive.blob.core.windows.net/media/Default/Research%20Papers/Horticulture/CP%2064%20Final%20Report%202009.pdf [Accessed 28. Feb 2023]

Lowe, D., Ebi, K.L. and Forsberg, B., 2013. Factors increasing vulnerability to health effects before, during and after floods. International journal of environmental research and public health, 10(12), pp.7015-7067. Available at: https://www.mdpi.com/1660-4601/10/12/7015 [Accessed 24 Feb. 2023]

Met Office (2012) UK Monthly Climate Summary – Summer 2012. Available at: https://digital.nmla.metoffice.gov.uk/IO_25bbb8e6-0299-4de0-b802-c604f00b42b1/ [Accessed 27 Feb. 2023]

Met Office (2019) UKCP18 Factsheet: Derived projections. Available at: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-fact-sheet-derived-projections.pdf [Accessed 27 Feb. 2023]

Met Office (2022) UK Climate Projections: Headline Findings, August 2022, Version 4. Available at: https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18_headline_findings_v4_aug22.pdf [Accessed 20 Jan. 2023]

Morison, J.I.L. and Matthews, R.B., 2016. Agriculture and forestry climate change impacts summary report. *Living With Environmental Change*. Available at: https://www.ukri.org/wp-content/uploads/2021/12/131221-NERC-LWEC-AgricultureForestryClimateChangeImpacts-ReportCard2016-English.pdf [Accessed 24. Feb 2023]

National Farmers Union (2019) Learning Lessons from the 2018 Agricultural Drought. Available at: https://www.nfuonline.com/media/mcbh24td/learning-lessons-from-the-2018-agricultural-drought.pdf [Accessed 30 Jan. 2023]

Office for National Statistics (2021) Households by deprivation dimensions. Available at: https://www.ons.gov.uk/datasets/TS011/editions/2021/versions/2 [Accessed 1 Mar. 2023]

Ordnance Survey (2010) OS MasterMap Topography Layer: User guide and technical specification. Available at: https://digimap.edina.ac.uk/help/files/resource-hub/downloads/osmanuals/os-mastermap-topography-layer-user-guide_v1_9.pdf [Accessed 30 Mar. 2023]

Ordnance Survey (2021) AddressBase, AddressBase Core, AddressBase Plus, AddressBase Premium – Overview. Available at: https://www.ordnancesurvey.co.uk/documents/product-support/support/addressbase-product-overview.pdf [Accessed 30 Mar. 2023]

Ordnance Survey (2023) AddressBase Premium support. Available at: https://www.ordnancesurvey.co.uk/business-government/tools-support/addressbase-premium-support [Accessed 30 Mar. 2023]

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Liberta`, G., Boccacci, F., Di leo, M., Perez, J. and Schulte, E. (2016) Forest Fires in Europe, Middle East and North Africa 2015; EUR 28158, EN; doi:10.2788/914. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC103326 [Accessed 24 Feb. 2023]

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Liberta`, G., Branco, A., De Rigo, D., Ferrari, D., Maianti, P., Artes Vivancos, T., Schulte, E. and Loffler, P. (2017) Forest Fires in Europe, Middle East and North Africa 2016. EUR 28707 EN, Publications Office, Luxembourg, 2017, ISBN 978-92-79-71292-0, doi: 10.2760/17690. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC107591 [Accessed 24 Feb. 2023]

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Liberta`, G., Branco, A., De Rigo, D., Ferrari, D., Maianti, P., Artes Vivancos, T., Costa, H., Lana, F., Loffler, P., Nuijten, D., Ahlgren, A. and Leray, T. (2018) Forest Fires in Europe, Middle East and North Africa 2017, EUR 29318 EN, Publications Office, Luxembourg, 2018, ISBN 978-92-79-92832-1, doi: 10.2760/27815. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC112831 [Accessed 24 Feb. 2023]

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Liberta`, G., Branco, A., De Rigo, D., Ferrari, D., Maianti, P., Artes Vivancos, T., Pfeiffer, H., Loffler, P., Nuijten, D., Leray, T. and Jacome Felix Oom, D. (2019) Forest Fires in Europe, Middle East and North Africa 2018, EUR 29856 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-11234-1 (online), 978-92-76-12591-4 (print), doi:10.2760/1128 (online), 10.2760/561734 (print), JRC117883. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC117883 [Accessed 24 Feb. 2023]

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Maianti, P., Liberta`, G., Artes Vivancos, T., Jacome Felix Oom, D., Branco, A., De Rigo, D., Ferrari, D., Pfeiffer, H., Grecchi, R., Nuijten, D. and Leray, T. (2020) Forest Fires in Europe, Middle East and North Africa 2019, EUR 30402 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-23209-4 (online), 978-92-76-23208-7 (print), doi:10.2760/468688 (online), 10.2760/893 (print), JRC122115. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC122115 [Accessed 22 Feb. 2023]

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Maianti, P., Libertá, G., Artés-Vivancos, T., Oom, D., Branco, A., de Rigo, D., Ferrari, D., Pfeiffer, H., Grecchi, R., Onida, M., Löffler, P. (2021) Forest Fires in Europe, Middle East and North Africa 2020, EUR 30862 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-42351-5, doi:10.2760/216466, JRC1267665. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC126766 [Accessed 22 Feb. 2023]

San-Miguel-Ayanz, J., Durrant, T., Boca, R., Maianti, P., Liberta`, G., Artes Vivancos, T., Jacome Felix Oom, D., Branco, A., De Rigo, D., Ferrari, D., Pfeiffer, H., Grecchi, R., Onida, M. and Loffler, P. (2022) Forest Fires in Europe, Middle East and North Africa 2021, EUR 31269 EN, Publications Office of the European Union, Luxembourg, 2022, ISBN 978-92-76-58616-6, doi:10.2760/058256, JRC130846. Available at: https://publications.jrc.ec.europa.eu/repository/handle/JRC130846 [Accessed 22 Feb. 2023]

Skelton, S. (2016) UK harvest 2016. Available at: http://www.englishwine.com/uk_harvest_report_2016.pdf [Accessed 27 Feb. 2023]

Skelton, S. (2019) Harvest Report – 2018. Available at: http://www.englishwine.com/uk_harvest_report_2018.pdf [Accessed 27 Feb. 2023]

Skelton, S. (2020) Vineyard Harvest Report for Great Britain – 2020. Available at: http://www.englishwine.com/uk_harvest_report_2020.pdf [Accessed 27 Feb. 2023]

Slingo, J. (2021) Latest scientific evidence for observed and projected climate change. In: The third UK Climate Change Risk Assessment Technical Report [Betts, R.A., Haward, A.B. and Pearson, K.V. (eds.)] Prepared for the Climate Change Committee, London. Available at: https://www.ukclimaterisk.org/wp-content/uploads/2021/06/CCRA3-Chapter-1-FINAL.pdf [Accessed 24 Feb. 2023]

Tapsell, S.M., Penning-Rowsell, E. C. Tunstall, S. M. and Wilson, T. L. (2002) Vulnerability to flooding: health and social dimensions Phil. Trans. R. Soc. Lond. A 360, 1511-1525. Available at: https://royalsocietypublishing.org/doi/abs/10.1098/rsta.2002.1013 [Accessed 24 Feb. 2023]

The Guardian (2018) Firefighters tackle large grass fire in east London, 15 July 2018. Available at: https://www.theguardian.com/uk-news/2018/jul/15/firefighters-tackle-large-grass-fire-east-london-wanstead-flats [Accessed 5 Apr. 2023]

Walker, G. and Burningham, K., 2011. Flood risk, vulnerability and environmental justice: Evidence and evaluation of inequality in a UK context. Critical social policy, 31(2), pp.216-240. Available at: https://journals.sagepub.com/doi/abs/10.1177/0261018310396149?journalCode=cspa [Accessed 24 Feb. 2023]

Wheeler, R., Lobley, M., 2021. Managing extreme weather and climate change in UK agriculture: Impacts, attitudes and action among farmers and stakeholders. Climate Risk Management, 100313. Available at: https://www.sciencedirect.com/science/article/pii/S2212096321000425 [Accessed 24. Feb 2023]

WineGB (2021) Industry Press Briefing 2021. Available at: https://winegb.co.uk/wp-content/uploads/2021/11/WineGB-Industry-Press-Briefing-2021-final-002.pdf [Accessed 20 Jan. 2023]

WineGB (2022) Industry Report 2021-2022. Available at: https://winegb.co.uk/wp-content/uploads/2022/09/WGB_Industry-Report_2021-2022FINAL.pdf [Accessed 27 Feb. 2023]