Natural England Commissioned Report NECR202d

Increasing the resilience of the UK's Special Protection Areas to climate change

Case study: Somerset Levels and Moors

First published 17 November 2016

www.gov.uk/natural-england

Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

Understanding the ecological consequences of climate change for Special Protection Areas (SPAs) is critical if site managers are to develop adaptive management strategies. This series of case studies highlights how current management might be adapted at site level to address future climate change impacts.

The study identifies some of the greatest barriers to delivering adaptive management, which will require a consensus across a wide number of organisations if the priority actions to increase the resilience of SPAs to climate change are to be delivered. This report is supported by the following:

- NECR202 - Overview and key messages
- NECR202a - Case study: Minsmere-Walberswick
- NECR202b - Case study: North Norfolk Coast and Great Yarmouth North Denes
- NECR202c - Case study: Peak District and South Pennine Moors
- NECR202e - General adaptive management recommendations

This report should be cited as: FRANKS, S.E, PEARCE-HIGGINS, J.W., AUSDEN, M. & MASSIMINO, D. 2016. *Increasing the Resilience of the UK's Special Protection Areas to Climate Change – Case study: Somerset Levels and Moors*. Natural England Commissioned Reports, Number 202d.

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Keywords - climate change, conservation strategy, Special Protection Areas (SPAs)

Further information
This report can be downloaded from the Natural England website: **www.gov.uk/government/organisations/natural-england**. For information on Natural England publications contact the Natural England Enquiry Service on 0300 060 3900 or e-mail **enquiries@naturalengland.org.uk**.

ISBN 978-1-78354-366-3

Note

This report has been prepared for Natural England and represents a contribution to the evidence base informing the development of adaptive management strategies for the UK's SPAs in relation to climate change. The report's aim is to outline the potential ecological consequences of climate change for SPAs and to discuss potential adaptive management responses. Current management activities and potential adaptive responses for each SPA case study were informed by the discussion deriving from site workshops where major stakeholders for the SPA were represented. The report makes no specific policy recommendations, and the information contained may not be in agreement with other existing management and/or policy-related documents.

Stakeholder participation

This workshop was attended by representatives from the RSPB and Natural England.

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1. Site summary

Location: 51 10 14 N 02 52 00 W

Area: 63.9 km^2

Habitat: humid grassland (52%), improved grassland (26%), inland water bodies (5%), marshes and fens (5%), towns and villages (5%), broad-leaved deciduous woodland (4%), woody plant cultures (2%), arable land (1%).

Original citation for qualifying species[1]: *over winter*: Bewick's Swan (191 individuals), Golden Plover (3,029 individuals), Lapwing (36,316 individuals), Wigeon (13,661 individuals), Teal (13,307 individuals), Shoveler (501 individuals). Note that due to subsequent population changes following citation, these values may not completely reflect current population usage of the SPA, or current national / international importance. For example, Bewick's swan has undergone a large population decline with few birds now regularly overwintering on the Somerset Levels but has increased on the Severn Estuary[2].

Climate change adaptive management is considered for the following species groups (both current and potential SPA features):

- Waders (non-breeding);
- Waterbirds reliant on shallow water, margins, and grassland (breeding and non-breeding);
- Bittern (breeding and non-breeding);
- Breeding waders (lapwing, snipe, redshank, and curlew);
- Marsh harrier (breeding and non-breeding);
- Crane (breeding and non-breeding);
- Black-winged stilt and Baillon's crake (breeding);
- Great white egret, little egret, little bittern, purple heron, night-heron (breeding and non-breeding);
- Bluethroat.

Site description: The Somerset Levels and Moors are located in south-west England and are one of the largest and most biodiverse areas of traditionally managed wet grassland and fen habitats in lowland UK. The SPA is within this area, and covers 6,388 ha of the combined 35,000 ha of the floodplains of the Rivers Axe, Brue, Parrett, Tone and their tributaries. The moors lie within inland basins surrounded by the Mid Somerset Hills. The majority of the inland moors lie approximately three metres below mean high water spring and drain through a large network of ditches, rhynes, drains and rivers. Flooding may affect large areas in winter depending on rainfall and tidal conditions. Parts of the site in the Brue Valley include areas of former raised peat bog that have now been substantially modified by agricultural intensification and peat extraction. This has created areas of open water, fen and reedbed. The site attracts important numbers of waterbirds (swans, ducks and waders) in winter.

Sedge peat extraction occurs in parts of the Brue Valley. Although a number of permissions exist within the SPA, they are subject to review processes which will lead to eventual revocation of any permissions which threaten to adversely affect the integrity of the SPA. Under current national policy there will be no new peat sites on the Levels. Trends in

agriculture and support schemes have a critical influence on the area's biodiversity as improvement with conversion of grassland to arable, intensification of land drainage and floodwater management, increased applications of inorganic fertilisers and cutting of silage are major threats to vulnerable peat soils and the nature conservation value of the site. Less intensive practices are encouraged through Higher Level Stewardship (HLS) agreements. Water level management is critical and is being addressed through the Water Level Management Plans process and the development of Raised Water Level Areas through HLS.

2. Current management activities

2.1. Land ownership and management

Land-ownership in the Somerset Levels and Moors SPA is very complex. While Natural England, the RSPB and Somerset Wildlife Trust own and/or manage large areas of the SPA (Figure 1), there are also many small landowners, primarily farmers with beef cattle or sheep. Owned land parcels are dispersed across the Levels, and while most farmers also own land on higher ground away from the flood plain, a few own the majority of their land on the floodplain.

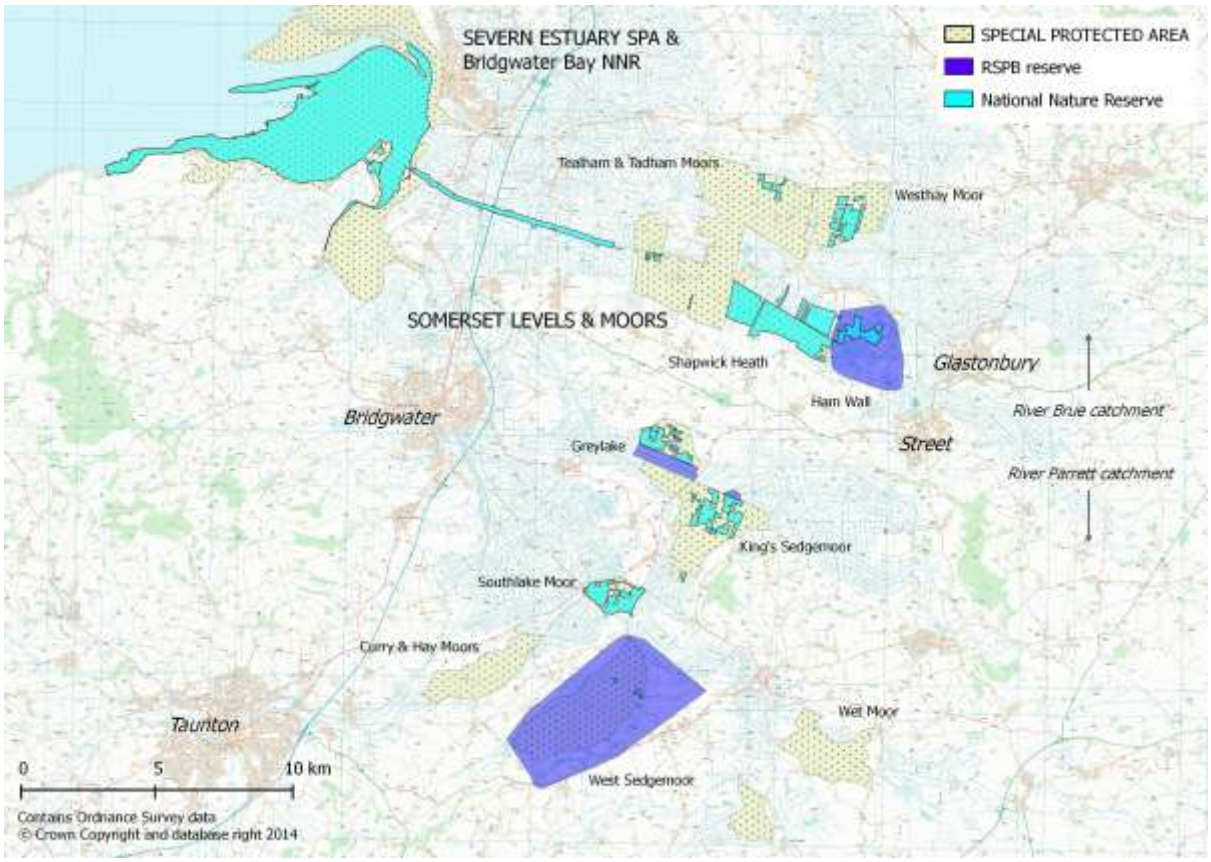


Figure 1. Map of the Somerset Levels and Moors SPA and surrounding area.

2.2. Water management

Most of the water on the Somerset Levels floodplain drains from the surrounding hills. The floodplain has a large catchment, with about two-thirds of the water draining into the southern Parrett catchment. The Brue has a relatively small catchment, unlike the Parrett and the Tone. Water abstraction is limited.

Winter habitat management for conservation purposes focuses on providing raised water level areas (RWLAs) for winter waders and waterfowl, supported by often extensive flooding within non-RWLA SSSIs and surrounding floodplain. The latter areas are particularly important for wintering lapwing and golden plover. The largest RWLA is managed by the RSPB on West Sedgemoor and can support 50,000 wintering waterbirds. RWLAs are either

rain-fed or river-fed (none are groundwater-fed), with penstocks, tiling weir sluices and other infrastructure operated to regulate winter water levels. Winter water levels are normally set from early December. Ninety percent of RWLAs are farmed under environmental stewardship agreements, while the remaining 10% are mainly reedbed and open-water areas on ex-peat cuttings (peat voids) and are also managed under Higher Level Stewardship.

Summer water levels on RWLAs are usually set from 1 April, providing raised water levels in ditches, which act as wet fences for livestock and allow surface splash and wet soils in fields to provide suitable wet conditions for a range of specialist wildlife, including breeding waders, ditch invertebrates, and localised and rare grassland communities requiring inundation. Summer drawdown is managed through sluices, but there is also natural evapotranspiration. Summer water levels on wet grassland are managed so that habitat dries out slowly from March through mid-June, with splashy pools appropriate for breeding waders remaining into June. In July through October, water levels should be at their lowest with no surface water on grassland areas. Some areas in the northern Brue valley catchment (e.g. Westhay) are entirely rain-fed during the winter, and tend to dry out too quickly in spring to act as ideal habitat for breeding waders.

Spring and summer flooding can prove challenging for habitat management. Prolonged flooding eliminates the ability to provide appropriate grassland management, and can also kill vegetation, producing anoxic conditions that can effectively prevent grassland recovery until part way through the following summer. Prolonged spring or summer flooding can thus make it difficult to maintain appropriate habitat for conservation for one or two years after the event, and can lead to changes in vegetation communities. In addition, flooding will also result in nest failure or displacement of nesting birds, resulting in reduced productivity in the flood year, with potential knock-on effects in subsequent years depending on habitat changes that occur as a result of flooding.

Prolonged winter flooding may prove beneficial for species such as pintail and shoveler, as suggested by their apparently increased abundance in surveys conducted during the winter of 2013-14. However, extreme events may lead to overly high water levels in early spring, reducing the ability to appropriately manage wet grassland for breeding waders.

2.3. Vegetation management

Cattle (mainly beef) are turned out to graze in May-June, and are left out until November. Grazing manages the vegetation height on wet grasslands to provide suitable sward conditions for breeding waders such as snipe and lapwing, and other breeding species such as yellow wagtail and some wintering wildfowl. Farmed grasslands are increasingly being converted to improved silage rye grass and maize crops in the wider ESA area away from SSSIs and this poses a long term threat to landscape scale conservation of these vulnerable habitats.

Some former peat voids have been converted to reedbeds which are mechanically cut in spring and autumn, although large-scale management is being carried out on Ham Wall through water level and grazing management. There is significant potential for expansion of these in the future, with large areas of peat workings on the periphery of the SPA, although there remain significant difficulties in achieving further widespread conservation use because

of the conditions attached to many mineral permissions do not require effective conservation restoration.

2.4. Predator control

Corvids and mink are controlled on NNRs and some Somerset Wildlife Trust land, though work by the RSPB suggest that foxes are the biggest threat to breeding waterbirds on the Levels. A predator exclusion fence at Greylake RSPB reserve has proved successful in reducing fox predation on breeding wader nests. The RSPB also carries out limited fox control on its reserves.

3. UKCP09 Climate Projections

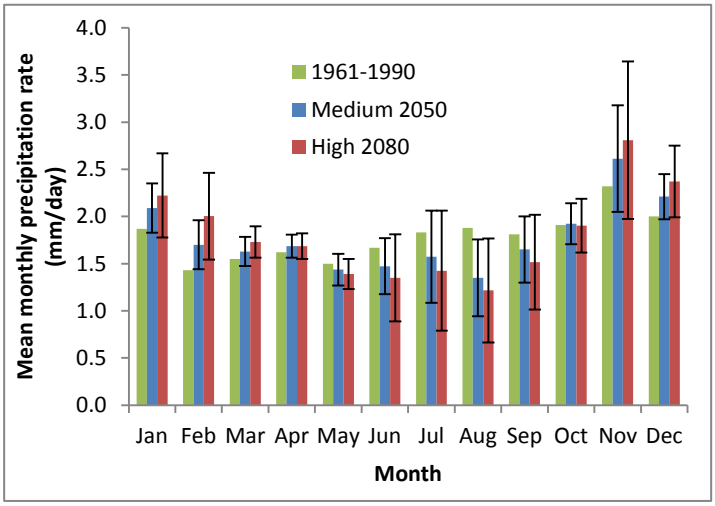
3.1. Changes in precipitation and temperature

Using the UKCP09 climate projections online user interface (http://ukclimateprojections-ui.metoffice.gov.uk/), we calculated the mean absolute and projected changes in climate variables (precipitation and maximum mean daily temperature) for the HadRM3 regional climate model 25 x 25 km grid cell containing the Somerset Levels and Moors under a 2050 medium and a 2080 high emissions scenario (Figure 2). The UKCP09 projections predict that the Somerset Levels will get progressively wetter in winter, and warmer and drier during the summer, a pattern which mirrors the general trend expected across the UK:

- Precipitation: 16-30 % increase during the winter, largest increase in February; 22-29% decrease during the summer, largest decrease in August;
- Temperature: overall increase year-round of between 2-6°C, but particularly elevated Jul-Sep.

Figure 2. a) Absolute mean monthly precipitation rate (mm/day) and b) mean daily maximum temperature (°C) vs the UKCP09 climate projections for the HadRM3 25 x 25 km grid cell (1620) containing Somerset Levels & Moors SPA. Relative change in c) mean monthly precipitation rate (%) and d) mean daily maximum temperature (°C) for the UKCP09 climate projections for the grid cell containing Somerset Levels & Moors SPA. Climate values for 2050 medium emissions and 2080 high emissions scenarios were produced from the mean ± SD of 10,000 model projections.

a)



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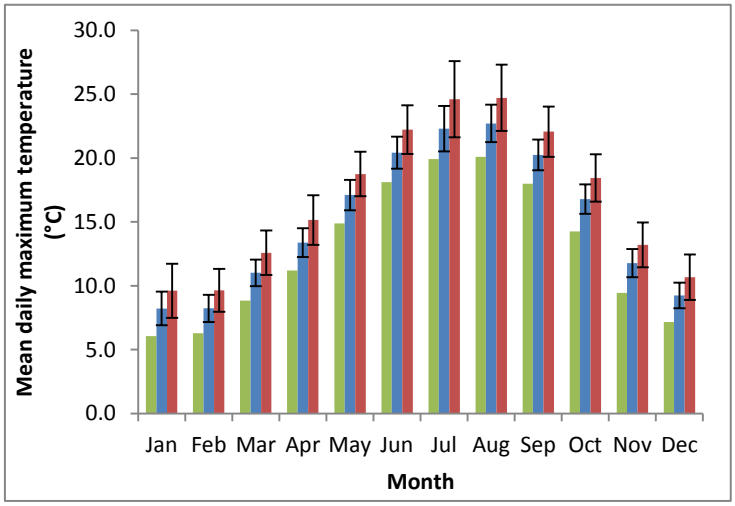

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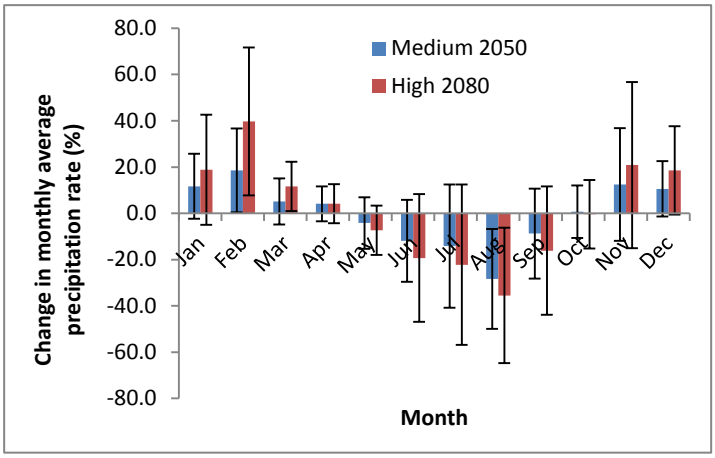

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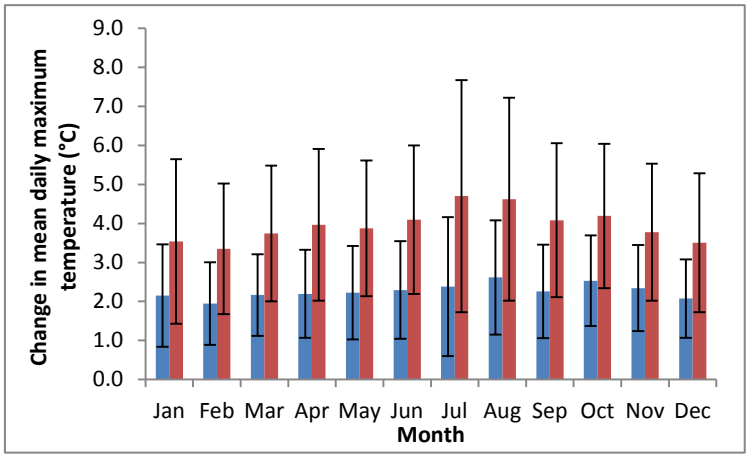

3.2. Sea level rise

Despite being located 15-20 km inland from the coast at Bridgwater Bay, the Somerset Levels is likely to be subject to the impacts associated with sea level rise. Saline water can currently penetrate 12-15 km inland up the Parrett River in the southern water catchment of the SPA, and even now, a particularly high tidal surge could result in saline water over-topping the river banks and draining onto the Levels. Sea levels on Bridgwater Bay are predicted to rise by between 22-73 cm under a medium emissions scenario and by 25-89 cm under a high emissions scenario by 2100, increasing the risk of a tidal surge flooding the Levels with saline water. A further impact associated with sea level rise is the likely increase in the period of “tide lock” particularly during high spring tides, when fluvial floodwater cannot drain into the Severn Estuary. This would reduce the duration of gravity conveyance of fluvial floodwater and could exacerbate the problems of drainage, increasing the duration of prolonged floods on key moors.

4. Projected climate change impacts and ecological outcomes

The tables below outline the primary impacts (in no particular order) of projected climate change and the potential ecological consequences for the freshwater habitats of the Somerset Levels and Moors.

Cause	Consequence	Ecological outcomes
• Sea level rise; • Increased risk of storms and storm surges.	• Increased frequency of coastal flooding and saline intrusion; • Increased frequency, duration and extent of freshwater flooding if tide lock associated with sea level rise inhibits draining of fluvial floodwaters.	• Reduction in freshwater wetland (e.g. fish, aquatic invertebrates) & grassland (e.g. terrestrial invertebrates) prey and habitat quality; • Coastal squeeze may reduce the intertidal resource for some of the waterbirds which move to the coast to feed; • Saline flooding of coastal lagoons and managed realigned habitats (e.g. Steart Peninsula) used by waterbirds which move to the coast; • Indirect effects of land management associated with changes in farming practices (e.g. land abandonment, changes in crop types, reduced sward management).
• Increase in winter rainfall.	• Increase in frequency, duration and extent of winter flooding, particularly if tide lock inhibits draining of floodwaters; • Higher early spring water levels.	• Reduction in areas of suitable roosting and foraging habitat for wintering waders (lapwing, golden plover); • Greater reliance on potentially less-suitable areas outside the SPA, or reduced use of the SPA; • May benefit some wildfowl by providing additional foraging habitat; • Loss or reduction in quality of foraging habitat and changes in the abundance and composition of prey populations (e.g. terrestrial/aquatic invertebrates, fish, small mammals)[3]; • Loss or reduction in nesting habitat quality and phenological mismatch if breeding is delayed by high spring water levels; • Prolonged suitability of nesting habitat if high winter water levels buffer against increased summer drawdown; • Indirect effects of water management (e.g. enhanced pump infrastructure and river dredging) to reduce flood risk on agricultural and developed land likely to exacerbate summer water loss, particularly in normal years (see below); • Indirect impacts associated with changes in farming practices and habitat management, with less early management possible during years of high spring flood.
• Decrease in summer rainfall and increase in spring/summer temperatures and evapotranspiration.	• Increased rate of drawdown in summer; • Drought.	• Loss or reduction in quality of nesting and foraging habitat and changes in the abundance and composition of prey populations; • Reduced water quality due to an increase in nutrient concentration and eutrophication; • Reduced opportunity for waders to raise replacement clutches following nest failure due to a

		reduction in habitat quality associated with increased drawdown; • Indirect effects of land management associated with changes in farming practices; • Complex ecosystem changes associated with changing phenology of flooding and water levels.
• Increase in extreme rainfall events year-round.	• Increased flood risk.	• Loss or reduction in foraging habitat quality • Increased flood risk for nests during extreme summer rainfall events[4].

5. Projected population trends

Population trends under a 2050 medium emissions scenario and a 2080 high emissions scenario were produced only for those species (mainly waterbirds) which were modelled as part of the CHAINSPAN report [5]. Population trends were modelled based upon projected changes in summer and winter temperature and precipitation from UKCP09 data. Annex I SPA qualifying species are in **bold underline**, migratory SPA qualifying species are in **bold**, species part of a qualifying assemblage are underlined, and potential Annex I colonists are in *italics*. Vertical arrows represent projected population changes greater than 50%, diagonal arrows changes between 25-50%, and horizontal arrows changes less than 25%. N=non-breeding, PS=spring passage migrant, PA=autumn passage migrant. Red arrows represent those populations which are declining, black arrows represent stable populations, and green arrows represent increasing populations. The outcome from a national risk assessment for these species summarises the likely effects of climate change across the country from high opportunity to high risk. For this, species in *italics* have outputs of particularly low confidence, and projections in **bold** are for species with moderate or good confidence.

Population projections for certain species, particularly new and/or potential colonists, were not modelled as part of the CHAINSPAN report due to insufficient data. Species include bittern (breeding and non-breeding), little egret (breeding), great white egret (breeding and non-breeding), and crane (breeding and non-breeding), as well as potential colonists purple heron, night-heron, little bittern, black-winged stilt, Baillon's crake, and bluethroat.

	Species	National risk assessment	Season	Model quality	2050 medium	2080 high
Winter waders	**Golden plover**	HIGH OPP	N	moderate	↓	↓
	Lapwing	*MED RISK*	N	good	↓	↓
	Black-tailed Godwit	HIGH OPP	N	poor	↘	↘
	Ringed Plover	*MED OPP*	PS	moderate	↘	↓
	Green sandpiper	LTD IMPACT	N	poor	↘	→
	Black-tailed Godwit	HIGH OPP	PA	very poor	→	→
	Whimbrel	LTD IMPACT	PS	poor	↑	↘
	Curlew	HIGH OPP	N	moderate	↑	↑
	Snipe	HIGH OPP	N	moderate	↑	↑
Waterbirds reliant on shallow water, margins, grassland	**Bewick's swan**	*MED RISK*	N	very poor	↓	↓
	Whooper swan	*MED RISK*	N	poor	↓	↓
	Coot	*MED RISK*	N	good	↓	↓
	Gadwall	*MED RISK*	N	very poor	↓	↓
	Wigeon	*MED RISK*	N	poor	↓	↓
	Pintail	LTD IMPACT	N	poor	↓	↓
	Mallard	HIGH RISK	N	good	↘	↓
	Shoveler	HIGH OPP	N	very poor	→	→
	Teal	HIGH OPP	N	poor	↑	↑
	Shelduck	HIGH OPP	N	poor	↑	↑
	Little Egret	**HIGH OPP**	*N*	*moderate*	↑	
Open-water waterbirds	Cormorant	MED RISK	N	very poor	↓	↓
	Goldeneye	*RISK & OPP*	N	moderate	↓	↓
	Goosander	*MED RISK*	N	poor	↓	↓
	Tufted duck	*MED RISK*	N	moderate	↓	↓
	Little Grebe	*MED RISK*	N	very poor	↓	↓
	Pochard	HIGH RISK	N	very poor	↘	↘
	Great Crested Grebe	*MED RISK*	N	moderate	→	↓
	Great Crested Grebe	*MED RISK*	PA	moderate	→	↑
	Red-crested Pochard	HIGH OPP	*N*	*moderate*	↑	↑

6. Potential adaptive management responses

Given the projected climate change impacts likely to influence bird populations (see Section 4) at Somerset Levels and Moors SPA, we outline in the below tables some of the key adaptive management measures that could be undertaken to help mitigate the effects of climate change for current (green) and potential (grey) SPA features.

The effect size of these measures on the species or species assemblages is denoted by a directional arrow. Orange arrows indicate an effect on the breeding population, blue arrows the non-breeding population (winter and passage). While qualifying SPA features comprise non-breeding populations for the site, we also include management considerations for breeding populations of these features as they may achieve qualifying status in the future. Adaptive management measures targeting climate impacts in a particular season may influence both the population in the season of interest as well as the population in a subsequent season. If there are carry-over effects between seasons of a particular management action (e.g. increasing removal of late winter flood waters through pumping may have negative effects on wet grassland breeding populations if too much water is removed, leading to an inadequate ability to compensate for increased summer drawdown).

On the subsequent sheets, winter waders refer to golden plover, lapwing, and snipe. Waterbirds reliant on shallow water, margins, & grassland are Bewick's swan, shoveler, teal, wigeon, pintail, gadwall, teal, and mute swan.

Climate impacts: coastal flooding and saline incursion									
Ecological outcomes: habitat loss, decrease in habitat and prey quality, increased flood risk for nests									
Measures	**Winter waders**	**Waterbirds reliant on shallow water, margins, & grassland**	**Bittern**	**Breeding waders**	**Marsh harrier**	**Crane**	**Great white egret, little egret, little bittern, purple heron, night-heron**	**Black-winged stilt & Baillon's crake**	**Bluethroat**
Freshwater wetland re-creation less than 5-10 km from existing wetlands in areas with water security and with low risk of coastal flooding[6]	↑	↑↑	↑↑	↑	↑↑	↑↑	↑↑	↗	
Surge barrier across River Parrett, which could reduce tidal surges but prevent small and medium-sized floods	↘	↗↘↑↘[a]		↑↓[b]		↗↗			
Managed retreat on the Severn Estuary would provide additional foraging / roosting habitat outside, but close to, the SPA	↑	↗↑							

[a]Saline incursion kills plants and therefore reduces vegetative and seed food for wintering waterbirds and cranes. Therefore, the barrier could have some benefit for these species. However, if this leads to a reduction in small and medium sized floods, then the longer-term reductions in habitat quality could be more detrimental for these species.

[b]Although saline incursion can negatively affect breeding wader habitat, if the surge barrier were associated with increasing drainage of the Levels and greater agricultural intensification then it could be detrimental. As with waterbirds, any reduction in small and medium-sized floods would also affect habitat quality.

Climate impacts: increased winter rainfall leading to inland flooding									
Ecological outcomes: habitat loss, limitations on undertaking appropriate management, reduced food resources									
Measures	**Winter waders**	**Waterbirds reliant on shallow water, margins, & grassland**	**Bittern**	**Breeding waders**	**Marsh harrier**	**Crane**	**Great white egret, little egret, little bittern, purple heron, night-heron**	**Black-winged stilt & Baillon's crake**	**Bluethroat**
Water level management through construction of washlands for flood storage (e.g. above Taunton)	↑	↑↑	↑↑	↑	↗↗	↑↑	↑↑	↗	
Appropriate water level management using pump and sluice water infrastructure, and widening channels if necessary, to mitigate extreme flood events[c]	↑↓ **a**	↗↓ ↗↓ **b**	↓↓	↗↓ **b**		↑↓ ↑↓ **b**	↓	↓	
Create / maintain heterogeneous habitat by increasing topographic variation such that suitable seasonal and permanent wet areas of variable depth are present over a proportion of site	↑	↑↑	↑↑	↑	↗↗	↗↗	↑↑	↑	
Create / protect high-ground wetland refugia at 5-10km distance from wetland (e.g. above Glastonbury)	↑	↑	↑			↑	↑		

Create nearby network of high quality safe coastal and inland roost / feeding sites for birds in big floods	↑	↑							

[a]Extreme water levels may reduce winter habitat suitability, but excessive pumping and water removal in less extreme events may also do the same.

[b]Water in late spring may help maintain water availability through the summer, but if flooded through the breeding season, can prevent nesting and appropriate summer management for future years. Extreme water levels may reduce habitat suitability.

[c]This is associated with the risk of increasing agricultural intensification which would be widely detrimental to bird species of conservation concern. It would also increase rates of summer drawdown, with potential negative consequences for breeding birds (see below).

Climate impacts: Decreased summer rainfall and higher temperatures leading to summer drought

Ecological outcomes: Decline in food resources, changes in vegetation structure, eutrophication and evaporation of shallow wetlands

Measures	Winter waders	Waterbirds reliant on shallow water, margins, & grassland	Bittern	Breeding waders	Marsh harrier	Crane	Great white egret, little egret, little bittern, purple heron, night-heron	Black-winged stilt & Baillon's crake	Bluethroat
Minimise water loss through good soil management, larger sites and restoration of adjacent drained land to improve water level buffering	↑	↑↑	↑↑	↑	↗	↑	↑↑	↑	
Maximise efficiency of water use on site through appropriate site design, enhanced winter water storage, rotational flooding, footdrain creation		↑	↑	↑		↑	↑	↑	
Secure new or additional water sources externally, such as large upstream storage reservoirs		↑	↑	↑		↑	↑	↑	

Reduce nutrient enrichment by improving water quality and reducing run-off within the catchment. This is a key issue for plants and invertebrates		↗↘[a]	↗	↗↘[a]		↗	↗	↗↘[a]	
Create heterogeneous habitat by increasing topographic variation such that suitable seasonal and permanent wet areas of variable depth are present over a proportion of site		↑	↑	↑		↑	↑	↑	
Reduce predation by foxes and corvids through non-lethal and/or lethal control, or buffer edge effects by enlarging wetland habitat by restoring adjacent grassland & arable land[7–9]		↑	↑	↑	↑	↑	↑	↑	
Reduce human disturbance through larger sites or access restrictions		↗	↗	↗	↗	↗	↗	↗	

[a]Increased nutrients may promote invertebrate bird food (earthworms, leatherjackets), but also stimulate faster vegetation growth.

Climate impacts: Warmer winter and spring temperatures advancing growing season									
Ecological outcomes: More rapid vegetation growth reducing quality of foraging habitat and re-nesting opportunities									
Measures	**Winter waders**	**Waterbirds reliant on shallow water, margins, & grassland**	**Bittern**	**Breeding waders**	**Marsh harrier**	**Crane**	**Great white egret, little egret, little bittern, purple heron, night-heron**	**Black-winged stilt & Baillon's crake**	**Bluethroat**
Late spring grazing to create suitably heterogeneous wet grassland habitat for both nesting (longer vegetation) and foraging (shorter vegetation)[10]	↑	↑↑		↑↓[a]	↗↗	↗↗	↗	↑↓[a]	

[a]Vegetation structure of primary importance for lapwing, but heavy grazing levels during breeding could result in nest trampling.

Climate impacts: Extreme spring and summer rainfall leading to flooding									
Ecological outcomes: Decline in food resources, loss of breeding attempts									
Measures	**Winter waders**	**Waterbirds reliant on shallow water, margins, & grassland**	**Bittern**	**Breeding waders**	**Marsh harrier**	**Crane**	**Great white egret, little egret, little bittern, purple heron, night-heron**	**Black-winged stilt & Baillon's crake**	**Bluethroat**
Create heterogeneous habitat by increasing topographic variation such that suitable seasonal and permanent wet areas of variable depth are present over a proportion of site		↑	↑	↑	↑	↑	↑	↑	
Increase extent of semi-natural grassland which has greater tolerance to prolonged submersion	↑	↑↑		↑	↑↑	↑	↑↑	↑	
Maximise efficiency of water use on site through appropriate site design, enhanced winter water storage, rotational flooding, footdrain creation		↑	↑	↑		↑	↑	↑	

Other compensatory measures not directly related to climate change									
Measures	**Winter waders**	**Waterbirds reliant on shallow water, margins, & grassland**	**Bittern**	**Breeding waders**	**Marsh harrier**	**Crane**	**Great white egret, little egret, little bittern, purple heron, night-heron**	**Black-winged stilt & Baillon's crake**	**Bluethroat**
Reduce human disturbance[11,12]	↑	↑↑	↑↑	↑	↗↗	↑↗	↑↗	↑↑	
Reduce loss of habitat or functional connectivity between sites due to other land use pressures eg. development	↑		↑↑	↑	↑↑	↑↑	↑↗	↑↑	
Reduce predation by corvids/foxes through electric fencing and/or lethal control		↑	↑↑	↑		↑	↑	↑	

Other measures required to create suitable habitat for potential SPA features									
Measures	**Winter waders**	**Waterbirds reliant on shallow water, margins, & grassland**	**Bittern**	**Breeding waders**	**Marsh harrier**	**Crane**	**Great white egret, little egret, little bittern, purple heron, night-heron**	**Black-winged stilt & Baillon's crake**	**Bluethroat**
Create areas of wet woodland and scrub surrounded by water of variable depths, reedbed, and vegetation-fringed ditches			↑		↑	↑	↑		↑
Convert new peat-cuttings into suitable habitat for reedbed and other species			↑↑		↑↑	↑	↑↑		↑

7. Practical assessment of suggested adaptive management responses

Discussion with Natural England and RSPB staff responsible for directing and overseeing land management at Somerset Levels and Moors provided an assessment of the suggested adaptive management measures to improve the SPA's resilience to climate change. Synergies with current management practices were identified, as were constraints associated with implementing suggested measures. The discussion also highlighted some potential areas for future development of adaptive management measures.

Before these points are discussed in relation to potential adaptation measures, the importance of non-climatic factors in also influencing land management decisions on the site should be emphasised. There is a certain amount of uncertainty associated with the long-term viability of the management approach to flood control which favours the economic farming interest and maximises agricultural output. Much of the current pump and waterway infrastructure requires replacing and enhancing, which would represent a substantial investment in an economy with a potentially uncertain future. Were significant investment in that infrastructure to be made, an increase in the intensity of agricultural management on the Levels would be feasible, following the Dutch model, but this would be detrimental to most of the bird interest on the SPA. Alternatively, a more natural approach to water management could be undertaken, making most use of the existing topographical gradient across the site, and ensuring that washlands are used to hold and store water during flood periods, and to release water during dry periods. This would maximise biodiversity benefit, but may prove to be unacceptable to local land holders. Without a proper cost-benefit analysis and the engagement of the full range of stakeholders, it is not possible to identify the future of the Levels. Furthermore, it is likely that the human response to water level management on the Levels will have a greater impact on the SPA than the precise details of future climatic changes. Future management decisions on the site will need to be made in light of the tensions between the local agricultural economy and actions most benefiting conservation.

7.1. Adaptation in response to sea-level rise

One of the most important drivers of climate-associated change for the Somerset Levels and Moors could be sea level rise and the accompanying effects of coastal flood defence measures. The construction of a tidal barrier on the Parrett River to protect Bridgwater from tidal surges could increase the severity and extent of fluvial flooding by reducing the ability of floodwaters to drain off the Levels during winter and summer extreme rainfall events. This would result in a reduced ability to provide appropriate habitat management for wet grassland species, but also freshwater reedbed species if floods were extensive. Concern was also expressed that the barrier may reduce the frequency of small and medium-sized floods that are beneficial to both wintering waterbirds and breeding waders. If that was the case, the net effect of the barrier could be negative. These risks must be weighed against the potentially more severe impacts of saline flooding on these freshwater habitats, particularly the wet grassland habitats used by breeding waders on the lower land in the Parrett catchment and the reedbeds at Ham Wall and Shapwick Heath. Saline incursion would also detrimentally affect a range of other freshwater breeding species (cuckoo, reed warbler, yellow wagtail), which are current SSSI features.

Managed realignment may be facilitated in conjunction with the tidal barrier to allow inundation of coastal parts of Bridgwater Bay NNR. This would probably benefit species that breed or feed on saltmarsh habitats. From the perspective of the Somerset Levels, this could create additional feeding habitat for wintering wildfowl such as wigeon and pintail, strengthening the link between the Levels and coastal SPA. In addition, coastal-breeding waders such as avocet and ringed plover could conceivably spread inland with increased saline incursion, and the Somerset Levels and Moors has the potential to see a dynamic shift in its bird populations with future climate change if its freshwater bird assemblage transitions towards a more coastal assemblage of species, particularly in the lowest parts of the SPA.

7.2. Freshwater management

Reduced summer water availability poses the greatest challenge to the ornithological interest of the Somerset Levels and Moors SPA. The entire Levels currently acts as a large washland, storing winter rainfall for use during the summer. This benefits downstream communities such as Bridgwater by reducing river water levels and risk of winter flooding, but can conflict with the local farming interest. On-site, management to minimise water loss, particularly during the summer, could benefit a wide-range of species, particularly by managing larger sites as integrated hydrological units and reducing the degree of drainage of adjacent land. However, this is likely to conflict with current agricultural interests, as it is even a challenge to negotiate with farmers the maintenance of just 2,000 ha of RWLA out of 16,000 available hectares. This could be solved through partnership working across land holdings, although the current complexities of multiple land ownership in small areas make this a very considerable challenge. Consideration should be given for the potential for HLS targeting to be used to help achieve this by incentivising private landowners to adopt biodiversity-friendly water management regimes. In some situations, targeted acquisition by nature conservation organisations of land adjacent to existing sites may be desirable.

The efficiency of water usage across the site could also be enhanced by increasing the number of moors that remain flooded during the winter to provide additional water storage capacity, which may then be released during the summer to alleviate the effects of drought. Again, there are significant conflicts between this and the agricultural management of these sites, particularly if water is maintained on them through the spring. Less controversially, old peat extraction sites could also be used for additional water storage, but pumps would be needed to extract the stored water. Other water storage options include the creation of a reservoir higher upstream of the Levels (e.g. above Taunton) which could greatly reduce flood risk in all seasons and potentially act as a water storage area to be drawn on during dry summers to maintain wet grassland habitats and wet fences. However, a reservoir would be a costly measure to implement and its construction would be driven by considerations outside those pertaining to conservation (e.g. flood protection for Taunton). Improving the water management infrastructure (connectivity and internal drainage) between ditches and fields would increase the ability to move water quickly where and when it is needed, and may potentially provide greater flexibility.

Existing topographical heterogeneity between the higher, drier Brue catchment to the north and the lower, wetter Parrett catchment to the south should provide resilience to both winter

and summer flooding and reduced summer water availability. Although winter flooding is regarded as less of a threat to the bird interest at the site, in high flood years, some wintering species (e.g. plovers and some wildfowl) may be restricted in their use of the site – the RSPB has been conducting some surveys during the 2013/14 winter to test this. Improving functional connectivity between the Somerset Levels and Moors and coastal habitats on the nearby Severn Estuary could enhance the ability of birds on the Levels to switch to using coastal habitats during periods of deep winter flooding. Alternatively, heterogeneous habitat is available outside the SPA (e.g. Queen's Sedgemoor near Glastonbury) that could provide high-ground *refugia* during deep winter flooding or coastal flooding, but water level and vegetation management would need to be improved to ensure such areas were of suitable habitat quality for birds. Such improvements may have potential implications for their agricultural management. Similarly, in wet years and particularly if high precipitation levels continue into the summer, then spring and summer flooding may have a significant impact on the ability of land managers to maintain suitable conditions for breeding waders. Thus, through time, the lowest parts of the Levels may become less suitable for breeding waders, which will need to be accommodated in higher areas. Due to significant archaeological interest, there is limited potential on semi-natural sites to create topographical heterogeneity through digging (e.g. to create foot drains) or building up the surface to increase resilience to flood or drought, as this could damage covered features of interest. This may be possible on areas of ex-farmland, although would only achieve a localised benefit.

The Somerset Levels and Moors already provides good habitat for colonising species such as little bittern and great white egret, and there is excellent potential for their population to increase. Continued reedbed development in ex-peat voids in and outside the SPA provides capacity for expanding available habitat for potential SPA features such as bittern, little bittern, little egret, and great white egret, and should continue to be a conservation priority. Encouraging wet woodland and scrub expansion in some areas would also provide additional habitat for these and other potential colonist species such as bluethroat. Curry Moor's current management for wet grassland may be unsustainable, and water levels could be allowed to move towards a higher, more natural state, thus encouraging such scrub and woodland expansion. This would, however, be in direct conflict with the current farming interest on the moor, and would require flood defences to be built around a village on a neighbouring moor.

Many of the current and proposed future habitat management activities benefiting the bird interests of the Somerset Levels and Moors, particularly those associated with water level management, are in conflict with the interests of local landowners. Maintaining RWLAs throughout the winter is of great benefit to both wintering waterbirds and to ensure sufficiently wet grassland habitat through the breeding season, but conflicts with requests from farmers to increase pumping activity so that their lands are drained more quickly in summer to accommodate an earlier start to the growing season. Extreme flood years such as the summer of 2012 and winter of 2013-14, however, may present a substantial challenge for both conservation land managers and land and property owners. Extreme flood events can result in loss of land and property value, and may displace birds to less suitable areas, flood nests, or render appropriate habitat management difficult. However, flood management should be carefully considered so as not to adversely impact conservation interests, and any infrastructure put in place to reduce extreme flood events should be used appropriately

during non-flood years so as not to negatively impact the conservation interests of the site. This could happen if improved pumping infrastructure and channel widening increased the rate of drying of peat soils during the spring and summer.

7.3. Vegetation management

Wet and warm early springs will present a substantial challenge in achieving appropriate vegetation heights for breeding waders, particularly lapwing which are a sensitive and difficult species to manage for. Present spring grazing is limited to reduce the chances of trampling nests, but improved spring growing conditions under climate change may necessitate trading off the risk of trampling with providing appropriate habitat. Even small heritage breeds that are accustomed to grazing wet grasslands would be a challenge on wet peaty soils, creating excessive poaching. It is possible that in the future, grazing management for lapwing in particular may become more difficult or potentially conflict with management for other species.

Even for farmers attempting to manage the land to meet conservation objectives, adverse flooding conditions may limit their ability to maintain areas in favourable condition by preventing livestock access on the land during the summer. This could result in a failure to maintain favourable habitat condition for wintering waterfowl and breeding waders, as particularly wet summers (such as 2012) may lead to long-term effects on wet grasslands over one or two years. The conversion of semi-natural grasslands to improved grasslands which produce better silage crops will reduce the ability of those grasslands to cope with prolonged flooding events. There is a need to ensure that such compliance failures due to weather conditions do not result in a loss of Environmental Stewardship payment to farmers, which would penalise them from joining agri-environment schemes. Further, the schemes themselves should retain sufficient flexibility so that specified dates for undertaking particular grazing, hydrological or other options are sufficiently flexible to allow farmers to adapt to severe weather conditions. The development of the New Environmental Land Management Scheme (NELMS) may provide the opportunity to develop a system that is better able to accommodate uncertainty and variability in conditions.

7.4. Predator management

Predation, particularly by foxes but also by corvids, may be a significant factor limiting breeding wader productivity and therefore their populations. Controlling predators may be an effective compensatory adaptation measure to boost wader productivity, as well as potentially reducing the vulnerability of populations to changes in the timing or length of breeding seasons. As the Somerset Levels and Moors covers such a large area, acquiring the resources to undertake extensive predator control is difficult, particularly as part-time and volunteer-based predator control over such areas tends to be ineffective. Predator exclusion, while effective, is both physically and economically impractical over such a large area, but may be effective for small sites where breeding waders are concentrated. Depending upon the long-term importance of the Levels for breeding waders in a national context, this issue may be an important one for managers to solve, potentially requiring significant resourcing.

8. Priority actions to improve resilience

The greatest challenge for the future management of the Somerset Levels and Moors is that of freshwater management, especially in summer. Holding water levels high enough over winter to compensate for increased rates of drawdown during the breeding season will become increasingly important. Management for conservation interests, however, will be strongly dependent on collaboration with outside agencies, including the Environment Agency and Internal Drainage Boards, and may be heavily constrained by the agricultural interest in the area. Climate change projections are broadly for decreases in many wintering wader and waterbird species. Priority responses to improve resilience of the SPA to future climate change are listed below. Those which are **synergistic with current actions**, or least likely to be restricted by other constraints, are in **bold**. Those which are the *most constrained* are in *italics* and the primary constraints identified. Those which are ***synergistic with current management but that may be constrained*** in the future are in ***bold italics***.

Action	Synergies	Constraints
Create new washlands and storage reservoirs upstream for winter flood storage.	Potential dual benefit of flood protection for towns.	Reservoir is extremely costly so implementation would be for other reasons. New washlands may conflict with local agricultural interests.
Maximise water use on-site through enhanced winter storage.	Winter water levels kept high on RWLAs within conservation organisation-owned land. Potential dual benefit of providing secure water for conservation and agriculture during summer drought.	Conflicts with agricultural interest to keep winter water levels low. Maintaining high water levels through the winter will increase the risk of flooding during extreme precipitation events. Insufficient and out-dated water infrastructure.
Wetland recreation in areas with water security and low risk of coastal flooding.		Resource-intensive and potential conflicts with agriculture to develop suitable land near Glastonbury.
Create and manage high-ground habitat refugia *at 5-10km from existing wetland areas.*		Same as above. More information required on bird movements to surrounding refugia during extreme high water years.
Minimise water loss through larger sites and restoration of adjacent drained land.		Conflicts with surrounding agricultural interests.
Reduce predation by foxes and corvids.		Resource-intensive and dependent upon local expertise.
Increase flexibility of	Delivery of greater	Limited by current prescriptions of HLS

environmental stewardship and designations to improve ability to respond to dynamic conditions.	biodiversity benefits through well-designed and targeted agreements.	programme and features of designated sites.
Develop peat working areas outside the SPA to create new reedbed and open-water habitats, and potential winter water storage areas.	Ex-peat voids currently being developed as reedbed. Will provide suitable habitat for likely breeding colonists in response to warming.	Requires suitable pump infrastructure to be used as winter water storage.
Convert wet grassland habitat that is particularly difficult to manage into woodland scrub.		
Improving the functional connectivity between the Somerset Levels and Moors and the Severn Estuary SPA.		More information required on bird movements between inland and coastal areas.

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