Natural England Commissioned Report NECR202e

Increasing the Resilience of the UK's Special Protection Areas to Climate Change

General adaptive management recommendations

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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 annexes:

- 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
- NECR202d - Case study: Somerset Levels and Moors

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Natural England Project Manager – Mike Morecroft, Principal Specialist Climate Change, Mail Hub, Worcester County Hall, Spetchley Road, Worcester, WR5 2NP **Mike.Morecroft@naturalengland.org.uk**

Contractor - British Trust for Ornithology, The Nunnery, Thetfod, IP24 2PU and Royal Society for the Protection of Birds, The Lodge, Sandy, SG19 2DL

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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**.

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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.

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1. Summary

Outlined in the following tables are summaries of the primary climate change impacts that have the potential to impact four broad habitat categories (coastal, freshwater wetland, upland, and heathland), the principal mechanism(s) by which they would influence the habitat, and the potential ecological consequences. Key adaptive management responses to address primary climate impacts are suggested for each habitat, with an indication of the effect each response would have for relevant breeding or non-breeding populations of current and potential SPA features in that habitat.

Example: Climate impacts and consequences for intertidal, saltmarsh and shingle beach. Green = current SPA features, grey = potential SPA. The effect size of a management measure on the species or assemblages is denoted by a directional arrow. Up = strong/middling positive effect, down = strong/middling negative effect. Orange = effect on the breeding population, blue = non-breeding population (winter and passage), purple = resident population.

Cause	Consequence	Ecological outcomes
• Sea level rise; • Increased risk of storms and storm surges.	• Loss of intertidal mud and saltmarsh through coastal squeeze; • Re-profiling and/or loss of shingle beaches and sand dunes; • Greater frequency of coastal flooding.	• Long-term loss and/or reduction in quality of foraging, roosting, and breeding habitat (but perhaps a short-term gain); • Changes in biomass and species composition of benthic invertebrate prey; • May create / renew some early succession shingle areas that could benefit terns / plovers;

Climate impacts: sea level rise, increased storm surges										
Ecological outcomes: loss of habitat through coastal squeeze										
Measures	**Breeding terns / ringed plover**	**Freshwater grassland waders**	**Species that feed on bivalves**	**Intertidal species**	**Breeding gulls**	**Avocet**	**Open-water waterbirds**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Create new intertidal, saltmarsh, and shingle habitat through managed realignment and regulated tidal exchange	↑	↑	↑	↑↑	↑	↑↑		↑	↑↑	↑

2. Coastal

2.1. Primary habitat types

- Intertidal (mud flats, sand flats, estuaries), saltmarshes, coastal sand dunes and beaches;
- Coastal grazing marshes;
- Saline lagoons.

2.2. 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 coastal habitats.

Intertidal, saltmarsh, dunes and beach		
Cause	**Consequence**	**Ecological outcomes**
• Sea level rise; • Increased risk of storms and storm surges.	• Loss of intertidal mud and saltmarsh through coastal squeeze; • Re-profiling and/or loss of shingle beaches and sand dunes; • Greater frequency of coastal flooding.	• Long-term loss and/or reduction in quality of foraging, roosting, and breeding habitat (but perhaps a short-term gain); • Changes in biomass and species composition of benthic invertebrate prey through direct responses to steepening mudflat profile, changes in sedimentation, and intrusion of saline water upstream in estuaries; • May create / renew some early succession shingle areas that could benefit terns / plovers.

Coastal grazing marsh		
Cause	**Consequence**	**Ecological outcomes**
• Sea level rise; • Increased risk of storms and storm surges;	• Greater frequency of coastal flooding; • Reduced drainage capacity;	• Long-term loss and/or short-term reduction in quality of foraging, roosting, and breeding habitat; • Potential impacts on invertebrate populations;

• Increased spring and summer temperatures.	• Changes in vegetation composition, structure, and growth patterns on saltmarsh and coastal grazing marshes.	• Change in habitat suitability for marsh feeding or -nesting species.
• Increased summer temperatures and evapotranspiration and decreased summer rainfall.	• Increased rate of drawdown.	• Reduction in quality of foraging and nesting habitat; • Reduced water quality due to an increase in nutrient concentration and eutrophication.
• Increased extreme rainfall events year-round.	• Increased flood risk.	• Change in foraging habitat quality; • Increased flood risk for nests during extreme summer rainfall events[1].

Saline lagoon		
Cause	**Consequence**	**Ecological outcomes**
• Sea level rise; • Increased risk of storms and storm surges.	• Greater frequency of flooding and loss of habitat; • Reduced drainage capacity.	• Long-term loss and/or reduction in quality of foraging, roosting, and breeding habitat.
• Increased winter rainfall.	• Higher water levels and lower salinities in winter.	• Change in quality of foraging habitat; • Changes in the abundance, composition, and accessibility of invertebrate fauna.
• Increased summer temperatures and evapotranspiration and decreased summer rainfall.	• Increased rate of drawdown; • Higher salinities.	• Change in quality of foraging habitat; • Changes in the abundance, composition, and accessibility of invertebrate fauna; • Drying out of lagoons, exposing nesting islands to land predators.
• Increased extreme rainfall events year-round.	• Increased flood risk.	• Change in foraging habitat quality; • Increased flood risk for nests during extreme summer rainfall events[1].

2.3. Potential adaptive management responses

In the following tables, terns include: common, sandwich, and little tern (but might also be applied to Arctic tern). Breeding gulls include: lesser black-backed gull, black-headed gull, and herring gull (but might also be applied to Mediterranean gull and great black-backed gull). Wader species that frequently forage on freshwater & brackish wetlands (in addition to using intertidal areas to varying degrees) include: golden plover, lapwing, black-tailed godwit, curlew. Nesting redshank will use these habitats as well. Species that feed on bivalves include: oystercatcher & knot. Predominantly intertidal/estuarine wader species (that will also use freshwater & brackish wetlands to varying degrees) include: redshank, ringed plover, greenshank, grey plover, ruff, whimbrel, non-breeding avocet, dunlin, bar-tailed godwit, sanderling and shelduck. Open-water waterbirds include: common scoter, cormorant, eider, long-tailed duck, velvet scoter, great crested grebe, red-breasted merganser, red-throated diver, scaup, and Slavonian grebe. Saltmarsh or freshwater waterbirds include: pink-footed goose, wigeon, goldeneye, pochard, tufted duck, coot, mallard, whooper swan, little grebe, pintail, bittern (B and NB), shoveler, gadwall, brent goose, little egret, snipe, and teal.

2.3.1. Intertidal, saltmarsh, dunes and beach

Climate impacts: sea level rise, increased storm surges										
Ecological outcomes: loss of habitat through coastal squeeze										
Measures	**Breeding terns / ringed plover**	**Freshwater grassland waders**	**Species that feed on bivalves**	**Intertidal species (inc ringed plover)**	**Breeding gulls**	**Avocet**	**Open-water waterbirds**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Create new intertidal, saltmarsh, and shingle habitat through managed realignment and regulated tidal exchange[2,3]	↑	↑	↑	↑↑	↑	↑↑		↑	↑↑	↑

Climate impacts: sea level rise, increased storm surges										
Ecological outcomes: loss of habitat through coastal squeeze										
Measures	**Breeding terns / ringed plover**	**Freshwater grassland waders**	**Species that feed on bivalves**	**Intertidal species (inc ringed plover)**	**Breeding gulls**	**Avocet**	**Open-water waterbirds**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Increase topographic variation to ensure a range of suitable areas for roosting/nesting at different tidal heights & future sea levels: 1) Create high-tide roosting or shingle nesting islands[4], 2) maximise the variation in elevation of higher areas, 3) create nest rafts.	↑*	↑	↑	↑↑	↑	↑↑				↑

* New nesting habitat should be provided near existing colonies.

Other compensatory measures not directly related to climate change										
Measures	**Breeding terns**	**Freshwater grassland waders**	**Species that feed on bivalves**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Open-water waterbirds**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Reduce unsustainable fisheries (either fish or shellfish)[5].	↑		↑				↑			
Reduce human disturbance[6,7].	↑	↗	↗	↗↗	↑	↑		↗	↗↑	↑
Reduce predation by corvids, foxes, mustelids through electric fencing and/or lethal control.	↑	↑*		↑	↑	↑		↑	↑	↑
Reduce predation by raptors and gulls through diversionary feeding / management.	↑			↗		↗				↗

Other compensatory measures not directly related to climate change										
Measures	**Breeding terns**	**Freshwater grassland waders**	**Species that feed on bivalves**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Open-water waterbirds**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Careful siting of renewable energy schemes to reduce displacement due to disturbance / collision risk.	↑	↑	↑	↑↑	↑	↑	↑	↑		↑

*Nesting redshank

2.3.2. Coastal grazing marsh

Climate impacts: sea level rise, increased storm surges								
Ecological outcomes: loss of habitat through coastal flooding								
Measures	**Breeding terns**	**Freshwater grassland waders**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Maintenance of sea-defences to ensure managed retreat.	↗[a]	↑↑[b]	↑↑[c,d]	↗[a]	↑	↑↓ (FW or salt respect'y)	↑↑	↗
Develop infrastructure to increase control over water levels and ability to adjust inputs of fresh and sea water.		↑↑[b]	↑↑[c]		↑	↑↑	↑↑	↗

[a]Shingle sea defences provide nesting habitat, [b]nesting lapwing, [c]nesting redshank, [d]shingle sea defences also provide ringed plover nesting habitat.

Climate impacts: increased year-round temperatures								
Ecological outcomes: change in vegetation composition, structure, and growth								
Measures	**Breeding terns**	**Freshwater grassland waders**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Manage vegetation through low levels of grazing, cutting; high levels of grazing may reduce resilience to erosion and coastal squeeze; heterogeneous vegetation height for both foraging and nesting/		↑↑*	↑↑**		↑	↑↑	↑↑	

*Nesting lapwing, **nesting redshank.

Climate impacts: Decreased summer rainfall and higher temperatures leading to summer drought								
Ecological outcomes: Reduction in habitat quality								
Measures	**Breeding terns**	**Freshwater grassland waders**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Develop infrastructure to increase control over water levels.		↑*	↑**		↑	↑	↑	
Maximise efficiency of water use on site through appropriate site design, enhanced winter water storage, rotational flooding.		↑*	↑**		↑	↑	↑	
Secure new or additional water sources externally.		↑*	↑**		↑	↑	↑	

*Nesting lapwing, **nesting redshank.

Climate impacts: Extreme spring and summer rainfall leading to flooding								
Ecological outcomes: Decline in food resources, loss of breeding attempts								
Measures	**Breeding terns**	**Freshwater grassland waders**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
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.		↑*	↑**		↑	↑	↑	
Development of appropriate water infrastructure to be able to remove excess floodwater or move to other areas.		↑*	↑**		↑	↑	↑	

*Nesting lapwing,**nesting redshank.

Other compensatory measures not directly related to climate change								
Measures	**Breeding terns**	**Freshwater grassland waders**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Reduce human disturbance[6,7].		↑*	↑**		↑	↑	↑	
Reduce predation by corvids, foxes, mustelids through electric fencing and/or lethal control.		↑*	↑**		↑	↑	↑	

*Nesting lapwing,**nesting redshank.

2.3.3. Saline lagoon

Climate impacts: increased winter rainfall, increased summer temperatures and decreased summer rainfall								
Ecological outcomes: change in water levels and salinities leading to changes in abundance and composition of prey								
Measures	**Breeding terns**	**Freshwater grassland waders**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Increase control over water levels & salinity through adjusting inputs of freshwater and sea water (where possible).		↑	↑↑		↑	↗↘*	↑↓↑↓**	↑

*Certain seed species are less sensitive to salinity requirements.
**Fish species differ in their salinity requirements.

Other compensatory measures not directly related to climate change								
Measures	**Breeding terns**	**Freshwater grassland waders**	**Intertidal waterbirds**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Reduce human disturbance[6,7].	↑	↗	↗↑	↑	↑	↗	↑	↑
Reduce loss of habitat due to other land use pressures eg. Development.	↑	↑	↑↑	↑	↑	↑	↑	↑
Reduce predation by corvids/foxes through electric fencing and/or lethal control.	↑		↑*	↑	↑		↑	↑
Reduce predation by raptors through diversionary feeding / management.	↑		↑*		↗			↗

*Nesting ringed plover.

3. Freshwater wetland

3.1. Primary habitat types

- Wet grassland;
- Reedbed and open water.

3.2. Projected climate change impacts and ecological outcomes

The table below outlines the primary impacts (in no particular order) of projected climate change and the potential ecological consequences for freshwater wetland habitats.

Cause	Consequence	Ecological outcomes
• Sea level rise; • Increased risk of storms and storm surges.	• Increased frequency of coastal flooding and saline intrusion; • Increased freshwater flooding if sea level rise prevents removal or inhibits draining of fluvial floodwaters.	• Reduction in freshwater wetland (e.g. fish, aquatic invertebrates) & grassland (e.g. terrestrial invertebrate) prey and habitat quality; • Increased flood risk for nests in summer.
• Increase in winter rainfall.	• Increase in frequency and extent of winter flooding; • Higher early spring water levels.	• 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)[8]; • New habitat creation for certain groups of species; • 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.
• Increased summer temperatures and evapotranspiration and decreased summer rainfall.	• Increased rate of drawdown.	• Loss or reduction in quality of nesting habitat and foraging habitat and changes in the abundance and composition of prey populations (e.g. terrestrial/aquatic invertebrates, fish, small mammals)[8]; • Reduced water quality due to an increase in nutrient concentration and eutrophication;

		• Reduced opportunity to raise replacement clutches following nest failure due to a reduction in habitat quality associated with increased drawdown; • Increased scrub/tree incursion with drying out of wetland areas.
• Increased spring and summer temperatures.	• Changes in vegetation composition, structure, and growth patterns on saltmarsh and coastal grazing marshes.	• Change in habitat suitability for grassland feeding or -nesting species.
• 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[1].

3.3. Potential adaptive management responses

In the subsequent tables, winter waders refer to golden plover, lapwing, black-tailed godwit, snipe. Waterbirds reliant on shallow water, margins, & grassland: garganey, spotted crake, water rail, moorhen, oystercatcher (breeding only); Bewick's swan, whooper swan, bean goose (taiga), pink-footed goose, white-fronted goose (European), white-fronted goose (Greenlandic), greylag goose, barnacle goose, pintail (non-breeding only); wigeon, gadwall, teal, mallard, shoveler, coot (breeding & non-breeding). Open-water waterbirds: pochard, great-crested grebe (breeding & non-breeding); tufted duck, goldeneye, goosander, cormorant (non-breeding only).

Colonially-nesting spoonbill, great white egret, night-heron, purple heron, and glossy ibis require very large areas of wetland to sustain significant-sized breeding colonies (see Table 11[9]).

3.3.1. Wet grassland

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**	**Black-tailed godwit, lapwing, snipe & redshank**	**Crane**	**Black-winged stilt & Baillon's crake**
Wetland re-creation less than 5-10 km from existing wetlands in areas with water security and with low risk of coastal flooding[10].	↑	↑↑	↑	↑↑	↗
Sea defences.	↑	↗↑	↑	↑↑	

[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.

Climate impacts: increased winter rainfall leading to inland flooding					
Ecological outcomes: habitat loss, limitations on undertaking appropriate spring management, reduced food resources					
Measures	**Winter waders**	**Waterbirds reliant on shallow water, margins, & grassland**	**Black-tailed godwit, lapwing, snipe & redshank**	**Crane**	**Black-winged stilt & Baillon's crake**
Water level management through construction of washlands for flood storage.	↑	↑↑	↑	↑	↗
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 refugia at 5-10km distance from wetland.	↑	↑	↑		

Climate impacts: increased winter rainfall leading to inland flooding					
Ecological outcomes: habitat loss, limitations on undertaking appropriate spring management, reduced food resources					
Measures	**Winter waders**	**Waterbirds reliant on shallow water, margins, & grassland**	**Black-tailed godwit, lapwing, snipe & redshank**	**Crane**	**Black-winged stilt & Baillon's crake**
Create network of safe inland roost / feeding sites for birds in big floods.	↑	↑			

[a]Extreme water levels may reduce habitat suitability.
[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 and increased drawdown					
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**	**Black-tailed godwit, lapwing, snipe & redshank**	**Crane**	**Black-winged stilt & Baillon's crake**
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[11–13].		↑	↑	↑	↑
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**	**Black-tailed godwit, lapwing, snipe & redshank**	**Crane**	**Black-winged stilt & Baillon's crake**
Late spring grazing to create suitably heterogeneous wet grassland habitat for both nesting (longer vegetation) and foraging (shorter vegetation)[14].	↑	↑↑	↑↓[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**	**Black-tailed godwit, lapwing, snipe & redshank**	**Crane**	**Black-winged stilt & Baillon's crake**
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**	**Black-tailed godwit, lapwing, snipe & redshank**	**Crane**	**Black-winged stilt & Baillon's crake**
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[11–13].		↑	↑	↑	↑
Reduce human disturbance[6,7].		↑	↑	↑	↑

3.3.2. Freshwater reedbed and open water

Climate impacts: coastal flooding and saline incursion				
Ecological outcomes: habitat loss, decrease in habitat and prey quality, increased flood risk for nests				
Measures	**Bittern**	**Marsh harrier**	**Open-water waterbirds**	**Little egret, spoonbill, purple heron, great white egret, night-heron, glossy ibis**
Wetland re-creation less than 5-10 km from existing wetlands in areas with water security and with low risk of coastal flooding[10].	↑↑	↑↑	↑↑	↑↑
Maintenance of sea-defences to protect freshwater interest.	↑↑	↑↑	↑↑	↑↑

Climate impacts: Decreased summer rainfall and higher temperatures leading to summer drought and increased drawdown				
Ecological outcomes: Decline in food resources, changes in vegetation structure, eutrophication and evaporation of shallow wetlands				
Measures	**Bittern**	**Marsh harrier**	**Open-water waterbirds**	**Little egret, spoonbill, purple heron, great white egret, night-heron, glossy ibis**
Minimise water loss through larger sites.	↑↑	↗↗	↑↑	↑↑
Maximise efficiency of water use on site through appropriate site design, enhanced winter water storage, rotational flooding.	↑↑	↗↗	↑↑	↑↑
Secure new or additional water sources externally.	↑↑	↑↑	↑↑	↑↑
Reduce nutrient enrichment by improving water quality and reducing run-off within the catchment.	↑↑	↑↑	↑↑	↑↑

Climate impacts: Extreme rainfall events leading to flooding				
Ecological outcomes: Decline in food resources, loss of breeding attempts in summer				
Measures	**Bittern**	**Marsh harrier**	**Open-water waterbirds**	**Little egret, spoonbill, purple heron, great white egret, night-heron, glossy ibis**
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.	↑↑	↗↗	↗↗	↑↑
Development of appropriate water infrastructure to be able to remove excess floodwater or move to other areas.	↑↑	↗↗	↗↗	↑↑

Other compensatory measures not directly related to climate change				
Measures	**Bittern**	**Marsh harrier**	**Open-water waterbirds**	**Little egret, spoonbill, purple heron, great white egret, night-heron, glossy ibis**
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[11–13].	↑	↑	↑	↑
Reduce human disturbance[6,7].	↑	↑	↑	↑

Other measures required to create suitable habitat for potential SPA features in freshwater wetland				
Measures	**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.	↑	↑		↑

4. Upland

4.1. Primary habitat types

- Alpine and sub-alpine grassland, heath, scrub, upland bogs, marshes, and fens, peatland (upland and lowland).

4.2. Projected climate change impacts and ecological outcomes

The table below outlines the primary impacts (in no particular order) of projected climate change and the potential ecological consequences for upland habitats.

Cause	Consequence	Ecological outcomes
• Reduction in frequency and duration of winter snow.	• Impacts on the timing of spring phenology.	• Reductions in snow cover likely to advance spring breeding of upland birds, leading to increased potential for replacement clutches / nesting attempts, or increase mismatch in breeding phenology and food resources for migratory species.
• Decrease in summer rainfall and increase in summer temperatures and evapotranspiration.	• Increased rate of drawdown in summer; • Drought.	• Loss or reduction in quality of wetland / peatland nesting habitat and foraging habitat and changes in the abundance and composition of prey populations (e.g. terrestrial/aquatic invertebrates such as tipulids); • Reduced water quality in rivers due to an increase in nutrient concentration; • Increased risk of wildfire in dry years, leading to large-scale habitat change / loss as well as potential impacts on breeding attempts.
• Warmer temperatures.	• Advance and increase in extent of growing season.	• Changes in vegetation structure, composition, and growth rate, leading to impacts on species requiring short swards; • Potential expansion of scrub and trees into upland areas; • Promotion of dwarf shrubs (especially heather) over bog species; • Increase in plant pathogens and disease; • Altitudinal shifts in ticks and potential increases in

		strongylosis occurrence may increase disease risk for grouse.
• Increase in extreme rainfall events year-round.	• Increased flood risk.	• Increased flood risk for nests during extreme summer rainfall events, particularly for riparian and freshwater nesting species. Increased spring rainfall may affect raptor and grouse productivity; • Increased risk of peatland erosion from unvegetated surfaces.

4.3. Potential adaptive management responses

Climate impacts: Decreased summer rainfall and higher temperatures leading to summer drought												
Ecological outcomes: Decline in food resources												
Measures	**Common scoter**	**Red-throated diver**	**Merlin**	**Peregrine**	**Golden eagle**	**Hen harrier**	**Short-eared owl**	**Golden plover**	**Dunlin**	**Other breeding waders**	**Nightjar**	**Dartford warbler**
Block artificial drains on blanket bog[15,16].	↗	↗	↗					↑	↑	↑		
Re-vegetate areas of eroding peat.			↗	↗			↗	↑↓	↗	↗		
Provision of a mosaic of open habitats with heterogeneity in vegetation structure.			↗	↗	↗	↗	↗	↑	↑	↑	↗	↑↓
Remove forestry plantations from blanket bog & adjacent areas[17,18].			↑		↑	↑	↑	↑	↑	↑		
Peatland restoration using *Sphagnum* seeding.			↗					↗	↗	↗		

Climate impacts: Decreased summer rainfall and higher temperatures leading to summer drought										
Ecological outcomes: Increased risk of wildfire in dry years										
Measures	**Merlin**	**Peregrine**	**Golden eagle**	**Hen harrier**	**Short-eared owl**	**Golden plover**	**Dunlin**	**Other breeding waders**	**Nightjar**	**Dartford warbler**
Use appropriate grazing and cutting to limit fuel load and create fire breaks.	↑	↗		↑	↑	↑	↗	↗	↗	↗
Use controlled burning to limit fuel load and create fire breaks.	↑	↗		↑	↑	↑	↗	↗	↗	↑↓
Control visitor access during sensitive periods.	↗			↗	↗	↗	↗	↗	↗	↗
Provision of a mosaic of open habitats with heterogeneity in vegetation structure.	↑	↗	↗	↑	↑	↑	↑	↑	↗	↑↓
Block artificial drains on blanket bog to raise water table.						↑	↑	↑		
Improved fire detection and emergency service response.	↑			↑	↑	↑	↑	↑	↑	↑

Climate impacts: Warmer temperatures advancing growing season and increase vegetation growth, exacerbated by CO_2 fertilisation										
Ecological outcomes: Changes in vegetation structure and composition. Potential expansion of scrub and trees, and promotion of dwarf shrubs over bog species										
Measures	**Merlin**	**Peregrine**	**Golden eagle**	**Hen harrier**	**Short-eared owl**	**Golden plover**	**Dunlin**	**Other breeding waders**	**Nightjar**	**Dartford warbler**
Use appropriate grazing or cutting regimes to maintain open / heterogeneous structure.	↗	↗		↑	↗	↑	↑	↑	↗	
Use controlled burning to maintain open / heterogeneous structure.	↗	↗		↗	↗	↑	↑	↑	↗	
Provision of a mosaic of open habitats with heterogeneity in vegetation structure.	↗	↗		↗	↗	↑	↑	↗	↗	↗
Block artificial drains on blanket bog to raise water table.	↗					↑	↑			
Vegetation destruction to combat plant disease.	↘			↘	↘	↘	↘		↘	↘

Other compensatory measures not directly related to climate change										
Measures	**Merlin**	**Peregrine**	**Golden eagle**	**Hen harrier**	**Short-eared owl**	**Golden plover**	**Dunlin**	**Other breeding waders**	**Nightjar**	**Dartford warbler**
Provide suitable feeding areas on nearby agricultural land (earthworm and tipulid-rich feeding areas for golden plovers & rough grassland for hen harriers and short-eared owl).	↗			↗	↗	↑		↑		
Prevent illegal killing & disturbance.	↑	↑	↑	↑	↑					
Carry out legal control of generalist predators known to be predating eggs and chicks to boost productivity[19–21].	↗				↗	↑	↑	↑	↑	

5. Heathland

5.1. Primary habitat types

- lowland heathland, dry grassland, scrub, and surrounding arable land.

5.2. Projected climate change impacts and ecological outcomes

The table below outlines the primary impacts (in no particular order) of projected climate change and the potential ecological consequences for heathland and grassland habitats.

Cause	Consequence	Ecological outcomes
• Increased temperatures year-round.	• Increased rate of nitrogen cycling; • Changes in vegetation composition, structure, and growth; • Increased growth of competitive grasses over dwarf shrubs; • Increased growth of tall wavy hair-grass *Deschampsia flexuosa;* • Increased susceptibility of heather to pests.	• Reduced habitat suitability for species requiring heather or a short sward;
• Increased summer temperatures and decreased rainfall.	• Drought; • Increased risk of wildfire; • Decrease in extent of heather-dominated heathland; • Shorter sward height, increased annual plant cover, decreased perennial plant cover.	• Decreased habitat suitability for species preferring heather; • Increased habitat suitability for species preferring short sward.
• Increased severe rainfall events.	• Increased run-off from surrounding agricultural land.	• Nutrient enrichment and increased vegetation growth of certain species.

5.3. Potential adaptive management responses

Climate impacts: increased year-round temperatures						
Ecological outcomes: change in vegetation – increased growth of tall competitive grasses, increased in extent of habitats with short sward, decrease in extent of heather						
Measures	**Stone-curlew**	**Nightjar**	**Woodlark**	**Dartford warbler**	**Chough**	**Red-backed shrike**
Increase resistance of dwarf-shrub vegetation to becoming outcompeted by grasses through turf stripping or prescribed burning[22–24].	↗↘*	↑	↗↘*	↑	↗↘*	↑
Reduce dominance of wavy hair-grass on short grasslands through prescribed burning and grazing[25,26].	↑		↑	↓**		↑

*Short grassland and/or disturbed ground preferred, so burning/grazing may provide short-term benefit depending on extent.
** Burning can reduce scrub habitat quality.

Climate impacts: increased summer temperatures and decreased rainfall leading to drought						
Ecological outcomes: increased wildfire risk						
Measures	**Stone-curlew**	**Nightjar**	**Woodlark**	**Dartford warbler**	**Chough**	**Red-backed shrike**
Block artificial drainage to reduce risk of wildfire, particularly on wet and humid heath[23].	↗↘*	↑	↘*	↑	↑	↑
Create more firebreaks and increase fire precautions.	↗	↑	↑↓*	↑	↑	↑

*Short grassland and/or disturbed ground preferred, so burning/grazing may provide short-term benefit depending on extent.

Other compensatory measures not directly related to climate change						
Measures	**Stone-curlew**	**Nightjar**	**Woodlark**	**Dartford warbler**	**Chough**	**Red-backed shrike**
Maintain a range of different successional stages.	↑	↑	↑	↑	↑	↑
Maintain areas of early successional stages in forestry plantations.		↑	↑			
Minimise levels of human disturbance[24,26–28].	↑	↑	↑	↑		↑
Reduce predation by foxes and corvids through non-lethal and/or lethal control.	↑	↑				↑
Increase site size and reduce fragmentation through habitat re-creation on ex-arable land, former mineral extraction sites, by removing conifer plantations from afforested heathland/grassland[29].	↑	↑	↑	↑		↑

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