Natural England Commissioned Report NECR202b

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

Case study: North Norfolk Coast and Great Yarmouth North Denes-Walberswick

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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:

- NECR202 - Overview and key messages
- NECR202a - Case study: Minsmere-Walberswick
- NECR202c - Case study: Peak District and South Pennine Moors
- NECR202d - Case study: Somerset Levels and Moors
- NECR202e - General adaptive management recommendations

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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.

Stakeholder participation

This workshop was attended by representatives from the North Norfolk Coast SPA, including Norfolk Wildlife Trust (Holme Dunes National Nature Reserve), RSPB (Titchwell reserve), and National Trust (Blakeney National Nature Reserve). Stakeholder representation with an interest in Great Yarmouth-North Denes SPA included RSPB and Natural England.

Table of Contents

1. Site summary

1.1. North Norfolk Coast

Location: 52 58 13 N   00 35 55 E

Area: 78.9 km^2

Habitat: estuaries and mudflats (48%), salt marshes (28%), improved grassland (10%), sand (9%), marshes and fens (2%), shingle (1%), arable land (1%), mixed woodland (1%).

Original citation for qualifying species[1]: *during the breeding season*: Avocet (177 pairs), Bittern (3 individuals), Common Tern (460 pairs), Little Tern (377 pairs), Marsh Harrier (14 pairs), Mediterranean Gull (2 pairs), Roseate Tern (2 pairs), Sandwich Tern (3457 pairs), Redshank (700 pairs), Ringed Plover (220 pairs); *on passage*: Ringed Plover (1,256 individuals); *over winter*: Avocet (153 individuals), Bar-tailed Godwit (1,236 individuals), Bittern (5 individuals), Golden Plover (2,667 individuals), Hen Harrier (16 individuals), Ruff (54 individuals), Dark-bellied Brent Goose (11,512 individuals), Knot (10,801 individuals), Pink-footed Goose (23,802 individuals), Pintail (1,139 individuals), Redshank (2,998 individuals), Wigeon (14,039 individuals).

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

- Terns (breeding);
- Waders using freshwater wetlands or grassland (non-breeding);
- Bivalve-feeding species (non-breeding);
- Waders using predominantly intertidal or estuarine habitat (non-breeding, also breeding redshank and ringed plover);
- Rocky coast waders (non-breeding);
- Gulls (breeding);
- Avocet (breeding and non-breeding) and potentially black-winged stilt (breeding);
- Open-water waterbirds (non-breeding);
- Waterbirds using saltmarsh or freshwater wetlands (breeding and non-breeding).

Notes: The North Norfolk Coast SPA encompasses much of the northern coastline of Norfolk in eastern England. It is a low-lying barrier coast that extends for 40 km from Hunstanton to Weybourne and includes a great variety of coastal habitats. The main habitats – found along the whole coastline – include extensive intertidal sand- and mud-flats, saltmarshes, shingle and sand dunes, together with areas of freshwater grazing marsh and reedbed, which has developed in front of rising land. The site contains some of the best examples of saltmarsh in Europe. There are extensive deposits of shingle at Blakeney Point, and major sand dunes at Scolt Head, Holkham and Holme. Extensive reedbeds are found at Brancaster, Cley and Titchwell with smaller but ornithologically significant reedbeds elsewhere in the site, notably at Holme, Burnham Overy and Burnham Norton. Maritime pasture is present at Cley and extensive areas of grazing marsh are present all along the coast. The grazing marsh at Holkham has a network of clear water dykes holding a rich diversity of aquatic plant species. The great diversity of high-quality freshwater, intertidal and marine habitats results in very large numbers and a high diversity of waterbirds occurring throughout the year. In summer, the site holds large breeding populations of waders, five species of gulls, four species of terns, Bittern *Botaurus stellaris* and wetland raptors such as Marsh Harrier *Circus aeruginosus*. In winter, the coast is used by very large numbers of geese, sea, diving and dabbling ducks, and waders, as well as passerines such as snow buntings and twite. The coast is also of major importance for staging waterbirds in the spring and autumn migration periods. Breeding terns, particularly Sandwich Tern *Sterna sandvicensis*, and wintering sea-ducks regularly feed outside the SPA in adjacent coastal waters which are of importance to seabirds throughout the year. To the west, the coastal habitats of North Norfolk Coast SPA are continuous with The Wash SPA, with which area the ecology of this site is intimately linked and to the east not far from The Broads, to which it is also linked.

The site is vulnerable to sea level rise, storm surges and consequent changes in erosion and accretion patterns which are increasingly likely to affect coastal habitats. The requirement for establishment of freshwater habitats to replace losses, as a result to a change in flood management where the SPA bird features are adversely affected by the change, is mainly the responsibility of the Environment Agency (EA). A shoreline management for the North Norfolk Coast has been approved for this coast which address issues linked to coastal erosion and flood management

Increasing interest in abstraction of groundwater for irrigation of arable land may affect freshwater spring flows onto grazing marshes and should be addressed through the review of consents for the corresponding SSSIs whose boundaries are co-terminus with the SPA. Large parts of the site are managed as Nature Reserves either directly by Natural England (Scolt Head Island, foreshore of Holkham NNR), private owners (Holkham Estate and terrestrial habitats of Holkham NNR) or through voluntary sector (Holme, Blakeney, Titchwell, and Cley). The site is visited by a large number of tourists especially in the summer and a visitor management strategy has been developed through the Norfolk Coast Project.

1.2. Great Yarmouth North Denes

Location: 54 44 02 N 01 41 10 E

Area: 1.49 km^2

Habitat: sand (100%)

Original citation for qualifying species[1]**:** *during the breeding season:* Little Tern (220 pairs)

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

- Terns (breeding).

Notes: Great Yarmouth North Denes is located on the east coast of Norfolk in East Anglia about 30 km east of Norwich. Behind a wide shingle beach, the North Denes dune system is actively accreting. These low dunes are stabilised by Marram *Ammophila arenaria* and there are extensive areas of Grey Hair-grass *Corynephorus canescens*. The location supports important numbers of breeding Little Tern *Sterna albifrons* that feed outside the SPA in nearby waters and breed in a narrow strip in front of the extensive dune system at the top of the sloping foreshore.

2. Current management activities

2.1. Land ownership and management

The majority of the North Norfolk Coast SPA is managed by conservation organisations, including National Trust, Natural England, the RSPB, and Norfolk Wildlife Trust, but there are numerous small private landowners within the boundaries of the SPA (Figure 1). Great Yarmouth North Denes is managed jointly by Natural England and the RSPB (Figure 2). Much of the discussion presented here focuses on little tern management, but we include details on other species and management options important for the SPA and how these options can be adapted to climate change.

Figure 1. Map of the North Norfolk Coast SPA.

2.2. Little tern management

Many of the management measures targeting little terns may also affect other tern species (common and sandwich) as well as ringed plover, all of which nest on shingle areas of beach. Little terns are the only qualifying feature for the Great Yarmouth and North Denes SPA, but the precise locations of the colonies shift from year to year, with growing numbers nesting on the coast outside the SPA. Over 100 breeding pairs may now nest on the newly re-emergent offshore sandbank of Scroby Sands, but little is known about the long-term viability of this shifting sandbank. The number of breeding pairs at Scroby Sands varies yearly (presumably in association with habitat availability and disturbance elsewhere in the SPA), and a colony has only become established there in the last 2-3 years, the first time since the 1970s. Along the North Norfolk coast, colonies occur at Holme, Scolt Head Island, Blakeney Point, and Holkham, but have been lost from Titchwell and Brancaster. There are concerns that through time, vegetation succession has reduced the suitability of some sites for breeding terns, for example in the North Denes unit of Great Yarmouth North Denes SPA, where recreating open sand and shingle areas would damage SSSI features. At Winterton Dunes, which is a SAC and SSSI, the Environment Agency's maintenance of shingle and dune sea defences as a means of protecting the Norfolk Broads SAC from saline inundation may have increased breeding habitat for little terns. Winterton Ness, where the breeding colony within Great Yarmouth North Denes SPA is currently located (colonies have formerly been located further south in the North Denes unit), is a natural formation which may have been enhanced by EA beach-feeding. It is possible that the December 2013 storm surge will provide additional new breeding habitat through sediment deposition and scouring of vegetation.

Figure 2. Map of Great Yarmouth North Denes SPA and surrounding area.

Although there are few formal studies examining the relative impacts of different threats to tern productivity, existing evidence[2,3] indicates that aside from loss of breeding habitat, the main threats to the terns are visitor disturbance and predation. The incidence and severity of the latter is likely to be dependent on the former for some predators. High spring tides often wash out nests located low on the beach. This has been a particular problem at the Scolt Head, Blakeney, and Holkham colonies with large numbers of nests lost in some years (e.g. Blakeney in 2012, Holkham in 2013). Primary management actions include attempts at limiting visitor disturbance and the numbers of foxes through fencing, wardening, and lethal control around breeding colonies. While applying such management across large areas of suitable habitat is widely seen as necessary to achieve a successful colony (small isolated colonies are most vulnerable to predation), this is difficult to achieve. Ideally, both fencing and round-the-clock wardening are required to reduce human disturbance and predation risk, and these have been extremely effective for the Winterton Dunes tern colony since 24-hour wardening was introduced in 2012 (see Table 1). Intensive fox control in the surrounding area has also been a significant contributing factor to breeding success at Winterton, as fencing alone is inadequate for keeping out determined individuals. Fencing on its own is less effective, but more widely applied, and can be used to encourage terns to settle at the start of the breeding season in an area of low disturbance where they can be better protected. There is a lack of manpower and funding for effective legal predator control across much of the SPA, which can result in predation events causing catastrophic chick mortality in particular years. Raptor predation has been a problem in the past for the North Denes colony, potentially due to its semi-urban location, and while resource-intensive, was solved by diversionary feeding at kestrel nests. This has not been used at Winterton and kestrel predation during the last two years has been low, possibly due to an abundance of food in the surrounding countryside. There is little vegetation management at colonies to avoid disturbing embryonic dune features. Gull predation is an increasing problem for both breeding terns and ringed plovers on the North Norfolk Coast, and control is practiced at a number of sites where conflict occurs. For ringed plovers, caging nests to reduce mammalian predation has proved ineffective, leading to increased mortality of adults, for example as a result of sparrowhawk predation.

Table 2.1. Little tern breeding success over the last five years on the Norfolk Coast. Brancaster and Titchwell sites had 0 nests in every year. Flexibility in location of 24-hour wardening is due to habitat changes that result in birds relocating to other sites. Data with permission of the Norfolk Little Tern Working Group.

		Scroby Sands	Great Yarmouth North Denes	Caister	Winterton	Eccles	Blakeney	Holkham	Scolt Head	Holme
2009	N	0	339	0	87	0	86	95	126	*
	F	0	20	0	0	0	52	17	30	-
	P	0	0.06	0	0	0	0.6	0.18	0.24	-
2010	N	0	0	10	45	0	75	122	169	*
	F	0	0	1	1	0	15	62	100	-
	P	0	0	0.1	0.02	0	0.2	0.51	0.59	-
2011	N	120	5	38	114	21	160	144	105	18
	F	80	0	22	0	13	140	132	70	0
	P	0.67	0	0.58	0	0.62	0.88	0.92	0.67	0
2012	N	35	5	10	197	56	139	114	220	38
	F	15	0	2	410	0	28	20	175	0
	P	0.43	0	0.2	2.08	0	0.2	0.18	0.8	0
2013	N	120	0	0	200	22	121	101	287	8
	F	?**	0	0	328	0	24	16	175	0
	P	?**	0	0	1.64	0	0.2	0.16	0.61	0
Fence		None	Electric	Electric	Electric	Electric	Electric	Electric	Electric	String
24-hour wardening	2009	N	Y	N	N	N	N	N	N	N
	2010	N	Y	N	N	N	N	N	N	N
	2011	N	N	Y	N	N	N	N	N	N
	2012	N	N	N	Y	N	N	N	N	N
	2013	N	N	N	Y	N	N	N	N	N

N = # of nests; F = # fledged; P = productivity. *Only 3 years of data for Holme. **Fledging success of re-lay nests at Scroby Sands not known.

2.3. Water management

Much of the habitat management in the North Norfolk Coast SPA depends on the appropriate regulation of saline and freshwater to provide suitable brackish and freshwater habitats for wintering and breeding birds. At the core of this strategy is cooperation with the Environment Agency and their management of sea defences, operating in conjunction with a system of gravity-draining sluices. Freshwater habitats (coastal grazing marshes, open water and reedbeds) are fed by rainwater, springs, and rivers and creeks including the Rivers Hun, Burn, Stiffkey, and Glaven through a system of ditches and sluices. Holme has reliable and powerful springs, however much of the freshwater remains uncaptured and drains out across private land through a series of ditches into the Hun River. Freshwater demands are highest during the summer and coincide with peak use for agriculture, but at present, there is little conflict with water abstraction for agriculture on the North Norfolk Coast. Management for breeding waders requires maintenance of surface water for as long as possible through the summer, to provide invertebrate food close to the soil surface. In practice, the infrastructure for achieving this at a number of sites is limited. The health of the reedbed relies on preventing saline incursion, for example through effective sea defences to prevent storm surges leading to flooding, and through maintaining freshwater inputs into the reedbed. The value of reedbed habitat to species such as bitterns depends greatly on maintaining high water levels until mid-summer.

There has long been uncertainty associated with the current management of the North Norfolk Coast and this is especially evident following storm surges, such as that on 5 December 2013. Large areas of freshwater habitats were inundated with saltwater when both sea wall defences and shingle and dune features were either over-topped or breached. While saltwater was evacuated from some freshwater areas through undamaged sluices, breaches below the high spring tide line and the low topography (below sea level) of many freshwater marshes mean that these habitats will continue to flood on spring tides if breaches remain unrepaired. The long-term shoreline management plan for the North Norfolk Coast suggests managed realignment for large stretches of coastline which include areas of low-lying freshwater marsh, albeit conditionally and dependent on future monitoring. Whether the timeline for this process is moved forward following the changes wrought by the storm surge remains to be decided, but the future conversion of large areas of freshwater habitat into intertidal saltmarsh should be expected if sea defences remain unrepaired. At time of writing (February 2015) many breached floodwalls have been repaired, and at Blakeney Freshes, partners have worked together to implement and adaptive scheme with lower, broader, more flood risk resilient defences, with the aim of conserving the freshwater SPA interest in situ into the medium term. Much of the future management will depend on decisions taken by the Environment Agency in consultation with Natural England, NGOs and local communities.

2.4. Vegetation management on coastal grazing marsh

Most vegetation management on coastal freshwater wet grasslands is delivered through Higher Level Stewardship grazing options using mainly cattle. An increase in early season vegetation growth on National Trust grazing marsh has proved difficult to manage as a result of restrictions on turning cattle out earlier due to conflicts between the timing of grazing according to HLS prescriptions and breeding waders. At Holme, there is less conflict between cattle and breeding waders: stocking density is lower, and cattle don’t tend to target the areas where waders nest, so can be turned out earlier.

3. UKCP09 Climate Projections for the Norfolk Coast

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 (1438) centred on the Norfolk Coast under a 2050 medium and a 2080 high emissions scenario (Figure 1). The UKCP09 projections predict that the Norfolk Coast 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: 14-26% increase during the winter, largest increase in February; 18-26% decrease during the summer, largest decrease in August;
- Temperature: overall increase year-round of between 2-5°C by 2080.

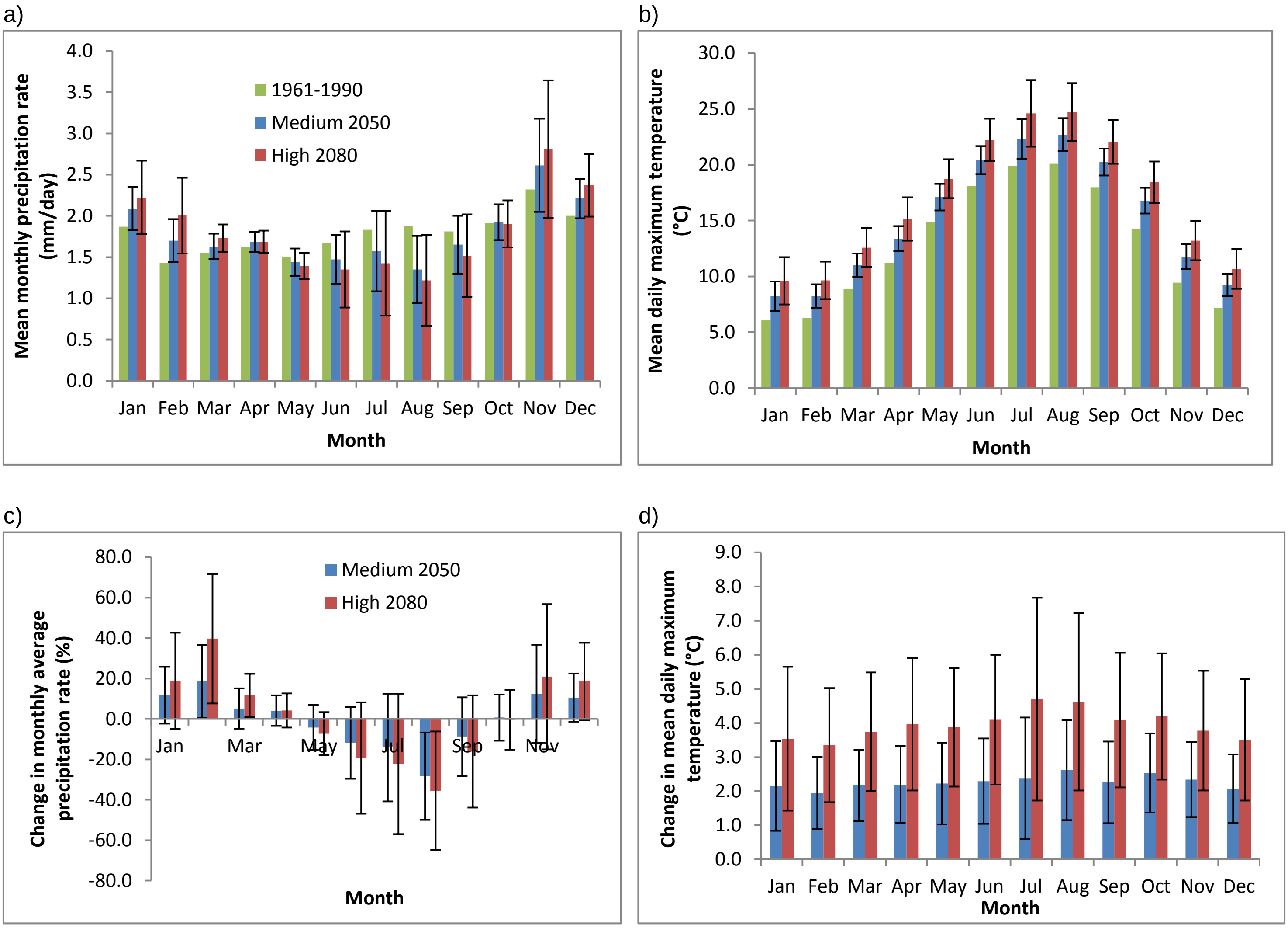

Figure 3. a) Absolute mean monthly precipitation rate (mm/day) and b) mean daily maximum temperature (°C) vs the UKCP09 climate projections for the HadRM3 25 x 25 km grid cell (1438) centred on the North Norfolk Coast SPA. Relative change in c) mean monthly precipitation rate (%) and d) mean daily maximum temperature (°C) for the UKCP09 climate projections for the same grid cell. Climate values for 2050 medium emissions and 2080 high emissions scenarios were produced from the mean ± SD of 10,000 model projections.

3.2. Sea level rise

The Norfolk coast is low-lying and vulnerable to coastal flooding as a result of sea level rise and storm surges. Relative sea levels on the coast are predicted to rise by between 11-34 cm under a medium emissions scenario and by 13-41 cm under a high emissions scenario by 2050. By 2100, sea levels are predicted to rise by between 24-75 cm and 26-91 cm under a medium and high emissions scenario, respectively. More difficult to predict is the frequency and extent to which storms and tidal surges will impact the Norfolk coast, as there is considerable uncertainty in generating predictions of increased frequency and intensity of storms affecting the UK coast[4].

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 habitats on the Norfolk coast.

Intertidal, saltmarshes, shingle beaches, and sand dunes		
Cause	**Consequence**	**Ecological outcomes**
• Sea level rise; • Increased severity and frequency 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). Redistribution of tern breeding habitat; • 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; • Re-profiling may provide a positive outcome where shingle features are restoring to their natural function after years of mechanical intervention; • May create / renew some early succession shingle areas that could benefit breeding terns / plovers and other shorebirds.

Coastal grazing marshes		
Cause	**Consequence**	**Ecological outcomes**
• Sea level rise; • Increased as above risk of storms and storm surges.	• Greater frequency of coastal flooding.	• 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, including impacts on invertebrate populations; • 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[5].

Saline lagoons		
Cause	**Consequence**	**Ecological outcomes**
• Sea level rise; • Increased as above risk of storms and storm surges.	• Greater frequency of flooding and loss of habitat.	• 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.
• Increased extreme rainfall events year-round.	• Increased flood risk;	• Change in foraging habitat quality; • Increased flood risk for nests during extreme summer rainfall events[5].

Freshwater reedbeds		
Cause	**Consequence**	**Ecological outcomes**
• Sea level rise; • Increased as above risk of storms and storm surges;	• Greater frequency of coastal flooding; • Eventual loss of coastal freshwater wetlands.	• Reduction in freshwater wetland prey and habitat quality.
• Increased summer temperatures and evapotranspiration and decreased summer rainfall.	• Increased rate of drawdown.	• Reduction in quality of foraging habitat; • Reduced water quality due to an increase in nutrient concentration and eutrophication.
• 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[5].

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[6]. 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 **<u>bold underline</u>**, migratory SPA qualifying species are in **bold**, species part of a qualifying assemblage are <u>underlined</u>, 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.

Great Yarmouth North Denes

Species	Season	National risk assessment	Model quality	2050 medium	2080 high
<u>Little Tern</u>	B	*MED OPP*	moderate	↑	↑

North Norfolk Coast

	Species	National risk assessment	Season	Model quality	2050 medium	2080 high
Terns	Arctic tern	HIGH RISK	B	poor	↓	↓
	Common Tern	*LTD IMPACT*	B	very poor	↑	↑
	Little Tern	*MED OPP*	B	moderate	↑	↑
	Sandwich tern	*HIGH RISK*	B	very poor	↑	↑
	Sandwich tern	*HIGH RISK*	PA	poor	→	↘
Freshwater or grassland waders	**Golden plover**	HIGH OPP	N	moderate	↓	↓
	Lapwing	*MED RISK*	N	good	↓	↓
	Curlew	HIGH OPP	N	moderate	↓	↓
	Black-tailed Godwit	HIGH OPP	N	poor	↘	→
	Black-tailed Godwit	HIGH OPP	PA	very poor	→	→
	Snipe	HIGH OPP	N	moderate	↑	↑
Bivalve-feeding species	**Knot**	LTD IMPACT	N	moderate	↓	↓
	Oystercatcher	*MED RISK*	N	moderate	↓	↓
Intertidal waterbirds	**Bar-tailed Godwit**	MED RISK	N	poor	↓	↓
	Sanderling	**HIGH OPP**	PA	poor	↓	↓
	Redshank	LTD IMPACT	N	moderate	↓	↓
	Sanderling	**HIGH OPP**	N	moderate	↘	↘
	Greenshank	HIGH OPP	N	moderate	↘	↘
	Avocet	**HIGH OPP**	N	moderate	↓	→
	Ringed Plover	*MED OPP*	PS	moderate	→	↓
	Greenshank	HIGH OPP	PA	very poor	→	→
	Grey Plover	HIGH OPP	N	moderate	→	→
	Redshank	LTD IMPACT	PA	poor	→	→
	Ruff	*MED OPP*	PA	very poor	→	→
	Sanderling	**HIGH OPP**	PS	very poor	→	→
	Ringed Plover	*MED OPP*	N	moderate	→	↑
	Shelduck	HIGH OPP	N	poor	→	→
	Whimbrel	LTD IMPACT	PA	poor	↗	↗
	Ringed Plover	*MED OPP*	PA	moderate	↑	↑
	Dunlin	*MED OPP*	N	poor	↑	↑
	Whimbrel	LTD IMPACT	PS	poor	↑	↑
Rocky coast waders	Turnstone	MED OPP	N	good	↘	→
Breeding gulls	Black-headed gull	MED OPP	B	poor	→	↓
	Lesser Black-backed Gull	HIGH OPP	B	very poor	→	→
	Common Gull	*MED RISK*	B	very poor	↑	↑
	Herring Gull	MED OPP	B	poor	↑	↑
	Great Black-backed Gull	**LTD IMPACT**	B	moderate		↑
Open-water waterbirds	Common Scoter	HIGH OPP	N	poor	↓	↓
	Cormorant	*MED RISK*	N	very poor	↓	↓
	Eider	HIGH RISK	N	moderate	↓	↓
	Long-tailed Duck	HIGH RISK	N	poor	↓	↓
	Velvet Scoter	*MED RISK*	N	very poor	↓	↓
	Great Crested Grebe	*MED RISK*	N	moderate	↘	↓
	Great Crested Grebe	*MED RISK*	PA	moderate	↘	↗
	Cormorant	HIGH OPP	B	poor	→	↘
	Red-breasted merganser	MED OPP	N	moderate	→	→
	Red-throated Diver	HIGH OPP	N	moderate	↑	→
	Scaup	*MED OPP*	N	poor	↑	↑
	Slavonian Grebe	HIGH OPP	N	moderate	↑	↑

Saltmarsh or freshwater waterbirds	**Pink-footed goose**	*MED RISK*	N	poor	↓	↓
	Wigeon	*MED RISK*	N	poor	↓	↓
	Goldeneye	*RISK & OPP*	N	moderate	↓	↓
	Pochard	HIGH RISK	N	very poor	↓	↓
	Tufted duck	*MED RISK*	N	moderate	↓	↓
	Coot	*MED RISK*	N	good	↓	↓
	Mallard	HIGH RISK	N	good	↓	↓
	Whooper swan	*MED RISK*	N	poor	↓	↓
	Little Grebe	*MED RISK*	N	very poor	↘	↘
	Pintail	LTD IMPACT	N	poor	→	↓
	Bittern	**LTD IMPACT**	B	very poor	→	→
	Shoveler	HIGH OPP	N	very poor	→	→
	Gadwall	*MED RISK*	N	very poor	↗	↗
	Brent Goose	HIGH OPP	N	moderate	↑	↑
	Little Egret	**HIGH OPP**	PA	moderate	↑	↑
	Teal	HIGH OPP	N	poor	↑	↑
	Purple Heron	MED OPP	B	poor	↑	

In addition, populations of a number of other qualifying species also occur on the North Norfolk Coast, but were not modelled as part of the CHAINSPAN report, largely due to insufficient data. Population projections for breeding avocet were not modelled as part of CHAINSPAN. This species depends strongly on saline lagoon habitats in the breeding season. Populations for several freshwater colonists species were also not modelled. These include little egret, spoonbill, purple heron, great white egret, night-heron, and glossy ibis. For all of these species, an indication of their likely sensitivity to climate change can be assessed from a national risk assessment of vulnerability to climate change.

Species	National risk assessment
Redshank (B)	LTD IMPACT
Ringed Plover (B)	*HIGH OPP*
Avocet (B)	*HIGH OPP*
Marsh Harrier (B)	*HIGH OPP*
Mediterranean Gull (B)	*HIGH OPP*
Roseate Tern (B)	*HIGH OPP*
Bittern (N)	**LTD IMPACT**
Hen Harrier (N)	HIGH RISK
Ruff (N)	

6. Potential adaptive management responses

Given the projected climate change impacts likely to influence bird populations (see Section 4) at North Norfolk Coast and Great Yarmouth North Denes SPAs, we outline some of the key adaptive management responses 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 responses 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).

On the following sheets, wader species that frequently also 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: grey plover, knot, sanderling, bar-tailed godwit, whimbrel, redshank (B and NB), greenshank, ringed plover (B and NB), dunlin, ruff, and shelduck. Offshore open-water waterbirds (species using principally marine rather than inland open-waters) 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 (which may include species using inland open-waters, in contrast to previous group) 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.

6.1. Intertidal, saltmarshes, and shingle beaches

Climate impacts: sea level rise, increased storm surges											
Ecological outcomes: loss of habitat through coastal squeeze											
Responses	**Breeding terns / ringed plover**	**Wader species that also feed on freshwater & brackish wetlands**	**Species that feed on bivalves**	**Intertidal / estuarine wader species (inc ringed plover)**	**Rocky coast wader species**	**Breeding gulls**	**Avocet**	**Offshore open-water waterbirds**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Create new intertidal, saltmarsh, and shingle habitat through managed realignment[7,8]	↑	↑	↑	↑↑		↑	↑		↑	↑↑	
Provide areas of regulated tidal exchange, creating exposed mudflat and shallow water during periods of the tide when other nearby intertidal areas are covered by deeper water		↑	↑	↑↑		↑	↑	↑	↗	↑↑	↑
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[9], 2) maximise the variation in elevation of higher areas, 3) create nest rafts	↑*	↑	↑	↑↑	↑	↑	↑				↑

Climate impacts: sea level rise, increased storm surges

Ecological outcomes: loss of habitat through coastal squeeze

Responses	Breeding terns / ringed plover	Wader species that also feed on freshwater & brackish wetlands	Species that feed on bivalves	Intertidal / estuarine wader species (inc ringed plover)	Rocky coast wader species	Breeding gulls	Avocet	Offshore open-water waterbirds	Saltmarsh or freshwater waterbirds	Little egret, spoonbill	Black-winged stilt
Maintenance of sea-defences to conserve SPA feature	↗↘*			↗↘*		↗↘*	↗	↑	↑↓ (FW or salt respect'y)	↑↑	↗
Create and maintain suitable refuge habitats inland in case of inundation		↑	↗	↗↗		↗			↗	↗↗	

* New nesting habitat should be provided near existing colonies

Other compensatory measures not directly related to climate change											
Responses	**Breeding terns**	**Wader species that also feed on freshwater & brackish wetlands**	**Species that feed on bivalves**	**Intertidal / estuarine wader species**	**Rocky coast wader species**	**Breeding gulls**	**Avocet**	**Offshore open-water waterbirds**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Reduce unsustainable fisheries (either fish or shellfish)[10]	↑		↑					↑			
Reduce human disturbance[2,11]	↑	↗	↗	↗↗	↗	↑	↑		↗	↗↑	↑
Reduce loss of habitat due to other land use pressures eg. development	↑	↑	↑	↑↑	↑	↑	↑		↑	↑↑	↑
Reduce predation by corvids, foxes, mustelids, gulls through electric fencing and/or lethal control	↑			↑		↑	↑			↑	↑
Reduce predation by raptors through diversionary feeding / management	↑			↗			↗				↗
Create suitable breeding habitats (scrub and small trees surrounded by wetland) adjacent to foraging habitat for potential nesting waterbirds				↘**						↑*	
Careful siting of renewable energy schemes to reduce disturbance / collision risk / habitat loss	↑	↑	↑	↑↑	↗	↑	↑	↑	↑	↑	↑

* Large areas of appropriate breeding habitat will be required for colonially-nesting spoonbills, within commuting distance (30-50km) of coastal feeding areas. Large foraging areas also required.
** Careful siting will be required to avoid potential conflict with breeding wader interest.

6.2. Coastal grazing marsh

Climate impacts: sea level rise, increased storm surges

Ecological outcomes: loss of habitat through coastal squeeze

Responses	Breeding terns / ringed plover	Wader species that also feed on freshwater & brackish wetlands	Intertidal / estuarine wader species (inc ringed plover)	Breeding gulls	Avocet	Saltmarsh or freshwater waterbirds	Little egret, spoonbill	Black-winged stilt
Maintenance of sea-defences to conserve SPA feature	↗↘*		↗↘*	↗↘*	↗	↑↓ (FW or salt respectively	↑↑	↗
Create and maintain suitable refuge habitats inland in case of inundation		↑	↗↗	↗		↗	↗↗	

* Depends on dynamics of system.

Climate impacts: increased year-round temperatures

Ecological outcomes: change in vegetation composition, structure, and growth

Responses	Breeding terns	Wader species that also feed on freshwater & brackish wetlands	Intertidal / estuarine wader species	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 redshank

Climate impacts: Decreased summer rainfall and higher temperatures leading to summer drought								
Ecological outcomes: Reduction in habitat quality								
Responses	**Breeding terns**	**Wader species that also feed on freshwater & brackish wetlands**	**Intertidal / estuarine wader species**	**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 redshank

Climate impacts: Extreme spring and summer rainfall leading to flooding								
Ecological outcomes: Decline in food resources, loss of breeding attempts								
Responses	**Breeding terns**	**Wader species that also feed on freshwater & brackish wetlands**	**Intertidal / estuarine wader species**	**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 redshank

Other compensatory measures not directly related to climate change								
Responses	**Breeding terns**	**Wader species that also feed on freshwater & brackish wetlands**	**Intertidal / estuarine wader species**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Reduce human disturbance[2,11]	↑	↗	↗↗	↑	↑	↗	↗↑	↑
Reduce predation by corvids, foxes, mustelids, gulls through electric fencing and/or lethal control	↑		↑	↑	↑		↑	↑

6.3. Saline lagoons

Climate impacts: sea level rise, increased storm surges								
Ecological outcomes: loss of habitat through coastal squeeze								
Responses	**Breeding terns**	**Wader species that also feed on freshwater & brackish wetlands**	**Intertidal / estuarine wader species**	**Breeding gulls**	**Avocet**	**Saltmarsh or freshwater waterbirds**	**Little egret, spoonbill**	**Black-winged stilt**
Create shallow saline water bodies as part of management realignment and allow saline lagoons to develop naturally where the local topography allows it.	↑	↑	↑↑	↑	↑	↑	↑↑	↑

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								
Responses	**Breeding terns**	**Wader species that also feed on freshwater & brackish wetlands**	**Intertidal / estuarine wader species**	**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		↑	↑↑		↑	↗↘*	↑↓↑↓**	↑

* 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

Responses	Breeding terns	Wader species that also feed on freshwater & brackish wetlands	Intertidal / estuarine wader species	Breeding gulls	Avocet	Saltmarsh or freshwater waterbirds	Little egret, spoonbill	Black-winged stilt
Reduce human disturbance[2,11]	↑	↗	↗↑	↑	↑	↗	↑	↑
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

6.4. Freshwater reedbeds

Climate impacts: coastal flooding and saline incursion			
Ecological outcomes: habitat loss, decrease in habitat and prey quality, increased flood risk for nests			
Responses	**Bittern**	**Marsh harrier**	**Little egret, spoonbill, purple heron, great white egret, night-heron, glossy ibis**
Wetland re-creation, preferably less than 5-10 km from existing wetlands in areas with water security and with low risk of coastal flooding, but with scope to explore opportunities in locations further afield if local sites are not forthcoming or suitable[12]	↑↑	↑↑	↑↑
Maintenance of sea-defences to protect SPA feature where it is sustainable to do so	↑↑	↑↑	↑↑

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			
Responses	**Bittern**	**Marsh harrier**	**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: 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			
Responses	**Bittern**	**Marsh harrier**	**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[13–15]	↑	↑	↑
Reduce human disturbance	↑	↑	↑

Climate impacts: Extreme spring and summer rainfall leading to flooding			
Ecological outcomes: Decline in food resources, loss of breeding attempts			
Responses	**Bittern**	**Marsh harrier**	**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	↑	↗	↑

7. Practical assessment of suggested adaptive management responses

Discussion with conservation organisation representatives responsible for directing and overseeing land management on the North Norfolk Coast and Great Yarmouth North Denes provided an assessment of the suggested adaptive management responses to improve the SPA's resilience to climate change. Synergies with current management practices were identified, as were constraints associated with implementing suggested responses. The discussion also highlighted some potential areas for future development of adaptive management responses.

7.1. Adaptation in response to sea-level rise

North Norfolk Coast

Future sea level rise and an increased frequency in storm surges, as exemplified by the December 2013 event, have the largest role to play in shaping future habitat management on the North Norfolk coast. The Environment Agency's (EA) shoreline management plan (SMP) for the North Norfolk Coast (http://www.eacg.org.uk) outlines the most sustainable management course over the next 100 years, although the scale of the December 2013 storm surge is an example of why the management intent in the SMP should be regularly monitored and reviewed. The decisions taken by the EA on future coastline management in response to this and future storm surges will lay the groundwork for habitat management within the SPA, which may involve challenging judgement calls between the conservation of different habitats or species, as well as with other interests. The feasibility and economic viability of sea defence measures will by necessity likely be focussed on the protection of property and infrastructure, agricultural land, and protected habitats, but it is possible that managed realignment of certain sections of coastline may be undertaken in order to allow other areas to be better defended. However, compensatory habitat creation must be undertaken before realignment takes place over existing freshwater sites, preferably as close as possible to lost habitats, to ensure maintenance of SPA feature populations and the continued integrity of the SPA network. The recent surge, and those in the future may result in the timing of an intended managed realignment scenario being a reviewed, particularly in areas where natural sea defences were pushed landward or where defences were breached. There is recognition that these will be difficult decisions, as managed realignment will result in considerable economic losses for landowners in relation to grazing income, HLS payments, and capital land value. Management must ultimately balance the wishes of different groups within the community (homeowners, landowners, visitors, conservation organisations) with economic sustainability, and sacrifices and compromises will undoubtedly have to be made, both for people and for wildlife. There will therefore be significant constraints on the adaptive management that may ideally be implemented from a nature conservation perspective for reasons of these wider considerations. In reality, these constraints may limit the ability of SPA stakeholders to agree on adaptive climate-related action, particularly in areas managed for more than just conservation interests, thus making it more difficult for effective strategic decisions to be made. In this context, managed realignment involving the deliberate sacrifice of certain coastal areas may be difficult to achieve, and instead, sudden and unpredictable events resulting in unplanned coastal realignment may be the principal drivers of change.

This aside, given that large areas of the North Norfolk coast are owned by conservation organisations, there is considerable potential for managed realignment approaches to be adopted within existing nature reserves. Indeed, this is already happening as exemplified by recent work at Titchwell RSPB reserve as part of their Coastal Change project; however, even here, realignment was only adopted once appropriate compensatory habitat was secured at nearby reserves (Freiston Shore and Frampton Marsh, which are within the Wash SPA). Although realignment may benefit breeding terns and other species, particularly if associated with the creation of new sand and shingle habitat, and will certainly result in new or sustained amounts of saltmarsh habitat, this will be at the expense of freshwater habitats. An increasing loss of freshwater habitat, both grassland and reedbed, through managed realignment will result in a decline in lapwing and breeding waterbirds, and will reduce the amount of habitat available for freshwater wetland species which may colonise from continental Europe (e.g. spoonbill, purple heron, glossy ibis, little bittern, night-heron). Developing compensatory habitat nearby or in the surrounding region is an important measure to counter these potential losses and to maintain the integrity of the protected areas network. Importantly, the current protection of these freshwater habitats may facilitate such colonisations[16], yet this is unlikely to be viable in the long-term as a result of coastal squeeze. The long-term viability of coastal grazing marshes which currently act as breeding habitat for lapwing but are located behind sea walls and below sea-level was questioned as a result of the same pressures. However, any associated increase in the extent of saltmarsh habitat through realignment together with regulated tidal exchange will benefit other species by providing additional foraging, roosting, and breeding habitat (e.g. breeding redshank, wintering waterbirds). Although many of these are projected to suffer declines in climatic suitability on the Norfolk Coast, depending upon the underpinning mechanism, this may be partly compensated for by an increase in habitat quality. Blakeney Freshes has a scheme in place that is intended to be part of a managed adaptive approach to conserve the freshwater interest in situ for the short to medium term; other potential areas include Brancaster West Marsh.

In response to this tension, managed realignment should attempt to compromise between allowing the loss of some freshwater habitat (ideally compensating elsewhere in less vulnerable locations) while providing short to medium-term enhanced protection of remaining freshwater areas and maximising the diversity of habitats along the coast. Ideally, enhancement of existing sluice or pump infrastructure or installation of new infrastructure for freshwater habitats designated for protection would provide the ability to quickly evacuate any saltwater from future storm surges and may further increase the resilience of such habitats to saline incursion; however, responsibility for such infrastructure will likely lie with the Environment Agency and will depend on their resources and priorities. In addition, using gravity-draining sluices to drain saltwater following a storm surge may become more difficult with increasing levels of sediment accretion and tide lock.

Maximising topographic and temporal habitat heterogeneity across the SPA to provide a range of foraging, roosting, and nesting sites may improve the resilience of the SPA to different levels of saline inundation and facilitate possible managed realignment scenarios, and there is considerable habitat and micro-topographical heterogeneity across the SPA which does partly achieve this. However, most sites are currently managed independently, and there may be considerable potential to improve coordination across the SPA's conservation landowners and cooperation with private landowners (e.g. through HLS agreements) to enhance this further. Unfortunately, given the intensity of agricultural management immediately inland, combined with the rising topography south of the main coast road, there is only a small potential for compensatory freshwater habitat creation or creation of suitable refugia within 5-10km of the SPA (e.g. Holme, Burnham Norton). However, opportunities may exist for wider coordination of management and habitat creation across other coastal or nearby inland SPAs and extending a landscape approach to maximising diversity of habitats and topography by considering e.g. the Wash and the Fens would improve the adaptive capacity of the SPA network as a whole and increase the resilience of regional bird populations.

Most of the conservation considerations regarding coastal protection and realignment / retreat on the North Norfolk coast will likely be associated with the short- to medium-term protection of freshwater habitat, but in anticipation of likely long-term loss, with a further consideration of maintaining and extending the extent of saline and brackish saltmarsh and lagoon habitats. Future decisions will have an important part to play in determining the long-term availability of tern nesting habitat across the SPA.

Great Yarmouth North Denes

Breeding little terns, the SPA's only feature, depend on appropriate dune and beach habitat, which are strongly linked to the Environment Agency's work to maintain and re-charge the beach as the primary defence protecting coastal towns and the Norfolk Broads, in itself a Special Conservation Area (SAC), Ramsar site, and SPA. The future of Great Yarmouth North Denes SPA is therefore strongly tied to the EA's long-term strategy for this section of the coast, and is also closely linked with the future of the Norfolk Broads and the Winterton-Horsey Dunes SAC. If beach sea defences are maintained, they will likely continue to provide suitable breeding habitat for little terns. Alternatively, should a less interventionist policy of managed realignment be implemented leading to progressive salinization of the Broads, and potential conversion of the Winterton-Horsey area to more natural tidal exchange and saltmarsh, then the availability and/or suitability of breeding tern habitat may be diminished. There is no potential for this habitat to be realigned inland, due to urban areas inland of the SPA in the south, and low-lying marshland to the north. The current SMP maintains the present line of defence for the short- and medium-term, while assessing the potential environmental, social, and economic impacts of realignment in the long-term should the current hold-the-line policy become unsustainable.

It is worth emphasising that the breeding terns are relatively mobile, particularly as they are tied to early successional habitats. Different sections of coast may provide suitable breeding tern habitat if natural sea defences (beaches and dunes) remain resilient to coastal erosion and/or if the EA's management of existing sea defences elsewhere provides appropriate habitat. Indeed, little tern colonies already exist outside the SPA's current boundaries, and have moved up and down the coast naturally in a complex way that isn't fully understood or predictable. In particular, the re-emergence of Scroby Sands has provided an important nest site for them in recent years, free from land predators but subject to disturbance from boaters beaching on the sandbank. It will therefore be interesting to see how the terns distribute themselves in 2014 in response to the redistribution of shingle in some coastal areas as a result of the December 2013 surge. There is some potential to manage the terns' settlement, as they tend not to nest in disturbed areas. Early fencing to exclude visitors may therefore encourage the birds to nest in particular places, an approach which may remain useful in the future in an attempt to ensure appropriate areas of habitat are occupied where colonies can be appropriately managed. Should the terns eventually nest largely or wholly outside of the SPA, then it may be worth considering a more flexible approach to the SPA's boundaries, enabling them to shift according to the distribution of a highly mobile feature of interest, although this flexibility is not currently achievable within the existing legislation.

7.2. Habitat compensation

Habitat compensation is an essential component in maintaining the integrity of the SPA network. Sea level rise is projected to result in the eventual loss of freshwater habitats along the North Norfolk Coast and their conversion to brackish or intertidal habitats. While this in itself may compensate for loss of saltmarsh and mudflats in other areas due to coastal squeeze, as a result of topographical constraints and conflicting land-use demands, there is limited potential for freshwater habitats to migrate inland by way of compensation of freshwater losses on the existing SPA. Opportunities to create compensatory freshwater habitat should be sought as close as possible to the SPA, and certain areas around the Wash may be suitable. However, creating new wetlands further inland on the fens (e.g. around the Ouse or Nene washes) may be the most sustainable option, although compensation must be of a suitable scale to ensure that newly created habitat is effective. Compensation on the fens, however, is likely to be also constrained by competing land-use demands. A habitat compensation project is currently underway at Hilgay, where Norfolk Wildlife Trust and the Environment Agency (part of the EA's Anglian Regional habitat creation Programme) are developing freshwater reedbed habitat to compensate losses predicted at Cley Marshes. There are few suitable areas closer to the coast for large-scale wetland development other than the Norfolk Broads, which are themselves vulnerable to increasing levels of saline intrusion with sea level rise and an increased frequency of storm surges. The conversion of higher-elevation arable land to provide freshwater wet grassland could potentially offset the loss of coastal grazing marsh, but would be difficult given the sandy soils. This may be more achievable along river valleys (e.g. the rivers Stiffkey, Glaven, or Wensum) although here, complex landownership would make this challenging to achieve across a large enough scale. Currently, such management would depend on the options available under Natural England's Environmental Stewardship programme and working with local private landowners, and as a result, may be managed less effectively than the current nature reserves. National Trust have managed to achieve this at Blakeney using agri-environment schemes to deliver appropriate management across a number of landowners, but there appears to be limited additional potential to extend this further.

7.3. Predator management

Managing predation is currently one of the key emphases of little tern management. Fencing can reduce disturbance and predation, and terns will often preferentially target fenced areas during the nest site selection period if they are erected early enough. Wardening and lethal control of foxes are also essential components of predator management, but are the most difficult to implement due to insufficient funding resources and a shortage of qualified personnel. Surrounding shooting estates provide a certain level of predator control, but any positive effect is likely countered by the associated annual release of large numbers of pheasants which support a larger predator population. A coordinated approach between the conservation organisations and estates to control mink has been effective, but there are constraints on extending that approach to foxes, namely access to and liability associated with shooting on private land and constraints on where control is possible due to public safety issues. Pig units in the surrounding area are associated with an increase in corvid and gull populations. Improving the equipment used for predator control by acquiring motion-sensitive or thermal cameras would provide the ability to target areas where control would be most effective. Providing additional resources for 24-hour wardening and lethal control near fenced areas would greatly improve the effectiveness of fencing. Kestrel and other raptor predation has also limited breeding success at some colonies in some years. This may be mitigated by diversionary feeding, but this is expensive and difficult to achieve across many sites, as it depends upon locating the nests of the offending individuals. Projected increases in climate suitability for breeding terns will only result in population increases if predation is adequately managed. Otherwise, as at present, predation will limit productivity. Such management will also benefit breeding ringed plovers.

Shifts in breeding phenology with climate change have the potential to change the timing of when fences are erected. Any increase in storminess with climate change, particularly storms which coincide with high spring tides during the nesting period, may result in an increasing number of losses for birds nesting low on the beach, already a factor limiting productivity in some years at Scolt Head Island, Blakeney, and Holkham. Providing fenced areas high enough up the beach, if suitable habitat exists, could reduce the potential for nest loss.

Increasing abundance and range expansion of breeding gulls predicted to occur with climate change, may pose a new challenge for predator control. Increasing numbers of herring, common, and Mediterranean gulls and potential predation of little tern nests presents a possible conflict between protection and control of listed species.

In order to effectively manage predation, more information is required on the relative impact of different ground and avian predators on limiting productivity. Some predators may be either protected species themselves or have low population numbers, and widespread control may not be possible. Work planned by the National Trust to use trail and nest cameras will allow managers to gain a better understanding of the key predator species and identify the most effective management measures.

7.4. Disturbance

Human disturbance presents one of the greatest challenges on the Norfolk coast. Wildlife conservation which requires limiting disturbance can conflict with demands for increasing visitor access and enabling people to enjoy such cultural ecosystem services. Nature reserves can be viewed as key recreational resources within local management plans, potentially exacerbating conflict. Management limiting the impact of disturbance upon breeding terns is currently a key component of their conservation. This is achieved through a combination of fencing, signs and active wardening. Whilst fencing and signs may reduce the impacts of visitor disturbance for nesting birds, they are rarely effective on their own, and regular human disturbance together with uncontrolled dogs can result in significant losses, particularly when coinciding with bad weather. The additional deployment of staff to patrol and observe breeding colonies is resource-intensive and is constrained by insufficient funding, but would have the greatest positive impact. Similarly, increasing the level of public education and awareness, engaging local communities, and encouraging their involvement in protection could play a role in reducing the impact of human disturbance.

Due to the twin processes of increasing spring and summer temperatures, and increasing housing development across the region, the number of visitors to coastal sites is only likely to increase over time. As with predation, given projected increases in climatic suitability, this is likely to continue to be a significant constraint on the potential for terns and shore-nesting waders to take advantage of such improving conditions. Reducing disturbance at key areas during particularly sensitive periods (e.g. nest site selection) would greatly reduce the negative impact on beach-nesting species, but as just outlined, achieving this is very difficult – not least because the start of the breeding season coincides with several bank holidays and even heavier visitor use of coastal areas. Restricting coastal access by means other than fencing colonies is not currently possible due to open access rights.

Further, any future climate-related changes in breeding phenology may alter the sensitivity of terns to disturbance. Human activity during this period will depend upon the weather and any overlap with public holidays. Further, sea-level rise or increased in storminess may reduce the width of the beach, potentially exacerbating the likely overlap between terns and visitor activity. It is difficult to see an effective long-term solution to this pressure, although one potential innovation may be to encourage local communities to take responsibility for their local colonies.

7.5. Fisheries management

Breeding terns are reliant on a good supply of small fish close to the colonies for their success. Prey fish taken by breeding adults to feed to chicks may be more vulnerable to the impacts of windfarm development than environmental factors[17], but there is still a lack of information about the fish that are taken by foraging adults, trends in the availability of forage fish in relation to climatic variables, and their potential vulnerability to climate change. Any long-term changes to forage fish populations as a result of climate change could have a significant impact on terns as well as other SPA features relying on forage fish (e.g. the offshore open-water waterbird species such as divers and grebes); these climate-induced changes may need to be countered by changes in any associated fishery. Also, continued consideration of the potential impacts of offshore renewable energy development on terns and other SPA features should be a priority during impact assessment of such development.

7.6. Freshwater management

While water abstraction for agriculture does not presently conflict with habitat management of freshwater habitats on the North Norfolk Coast, rising summer temperatures and decreasing rainfall may increase the pressure on freshwater availability in summer. Availability of freshwater for cattle indirectly impacts grazing management on wet coastal grasslands, as decreasing availability of freshwater and/or increasing salinity makes it increasingly difficult to provide sufficient freshwater for cattle at the stocking densities prescribed to deliver the appropriate grazing management scheme. Maintaining sufficiently wet grassland habitat through the summer is also important to deliver breeding wader habitat. At present, this is difficult to achieve on many sites.

There may be some potential for greater compartmentalisation of sites to provide greater flexibility for the management of freshwater pools and scrapes, enabling water to be concentrated in some compartments when scarce, and facilitating a rotational approach through time. This can deliver significant benefits for a range of species by providing more invertebrate prey and seeds for both breeding and wintering birds. Alternatively, the construction of a reservoir to store winter rainfall may be used to provide water for both farmers and conservation managers of freshwater habitats during the summer. It is difficult to see how this could be achieved within the current SPA, although Blakeney Freshes, Burnham Norton, Burnham Overy, and arable land at Holme could be developed to act as a water storage area to capture and store winter rainfall for use during the summer (though adequate habitat compensation would be required to offset habitat losses). This would require significant investment in infrastructure, both to protect it from saline inundation and to pump the water into the storage area in winter and to where it is needed in summer. Alternatively, water storage could be developed inland, outside of the SPA where it would be safe from saline inundation and could provide gravity-fed water in the summer. Any of these options would require significant infrastructure investment in terms of the construction of dams, banks and pumps to store and move water, and would need to be balanced against potentially competing land-use demands. Greater cooperation between conservation organisations, the Environment Agency, Internal Drainage Boards, and local landowners could greatly improve the potential for water capture and storage from rainfall, rivers, and springs on the Norfolk Coast. Freshwater management could be delivered through appropriate stewardship options if the appropriate water infrastructure were in place.

7.7. Vegetation management

Delivering appropriate grazing regimes on coastal wet grassland may become increasingly difficult with climate change. Conflicts between high early spring water levels and increased vegetation growth may create a need for increasing flexibility in the timing of grazing as prescribed by environmental stewardship. The development of a 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. Cattle-grazing may become progressively more challenging if it becomes difficult to provide adequate freshwater through the summer, and may result in a reduction in stocking densities. The economic risk of keeping cattle on grazing marsh may also increase in areas which are particularly vulnerable to saline inundation and where quick evacuation is difficult.

8. Priority actions to improve resilience

The greatest challenge for future management on the Norfolk coast is adapting to sea level rise and an increase in the frequency of storm surges, as well as managing the ecological effects of increasing summer drought. Habitat management strategies will largely depend upon the response of the Environment Agency, in consultation with NE, NGOs and local communities, particularly in the short-term as they respond to the December 2013 storm surge and adapt the coast's shoreline management plan. Climate change projections are for increases in breeding terns, while projections for wintering waterbirds are a mix of increases and declines; however, the potential for beach breeding terns and plovers to benefit from improving climatic conditions will be limited unless disturbance and predation can be properly controlled. Whilst protecting freshwater sites for conservation priority and colonising breeding species will be important in the short- to medium term, such habitats are likely to be lost in the long-term due to coastal retreat, making compensatory freshwater habitat creation an essential adaptive action. 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
Cooperate with Environment Agency on maintenance of shingle sea defences to maintain tern breeding habitat.	Part of current tern management.	
Reduce predation during the breeding season using fencing, round-the-clock wardening, and intensive lethal control.	Currently implemented to various degrees at main tern colonies (see Table 2.1).	Resource-demanding and constrained by insufficient funding.
Reduce visitor disturbance by restricting access during sensitive periods, education and round-the-clock wardening.	Fences limit access to most major tern colonies, wardening at some colonies is very effective.	Conflicts over access rights and increasing visitor numbers to coastal areas. Resource constraints limit amount of wardening possible.
Managed realignment / development of tidal exchange habitats.	Intertidal habitat creation Flood/storm surge protection.	Likely at the long-term expense of freshwater habitats in favour of brackish / saline habitats, but may buy time for compensatory creation. Opposition from local stakeholders.

Increase flexibility of environmental stewardship and improve funding security to ensure sufficient time exists to deliver management options.	Delivery of greater biodiversity benefits through well-designed and targeted agreements.	Limited by current prescriptions of HLS programme and long-term funding security of agri-environment schemes.
Compensatory freshwater habitat creation inland to offset coastal losses.	Compensatory habitat for Cley Marshes being developed on the fens at Hilgay.	Cost of land, incentives to change land use, perceived conflict between conservation and food security.
Improve freshwater capture and storage for habitat management and agriculture by increasing cooperation between conservation organisations, the Environment Agency, Internal Drainage Boards, and local landowners.	Support work being delivered against Water Framework Directive targets.	Requires land for storing water. If on site, this may conflict with other potential conservation uses. If off site, then this may conflict with other land-uses e.g. farming.
Increase cooperation and coordination across conservation organisations and agencies to develop a landscape-scale habitat management strategy for the Norfolk and Suffolk coasts and ensure functional connectivity.	Support work of the Norfolk and Suffolk little tern groups that bring all organisations carrying our management together to share expertise and resources. Support the work of a range of partnerships around the coast e.g. Norfolk Coast Partnership, Norfolk Biodiversity Partnership.	Different objectives between organisations may be difficult to reconcile.

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