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Species and habitat climate change adaptation options for seabirds within the INTERREG VA area

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1. Introduction and approach

This document summarises the potential climate change impacts and adaptation options for seabirds within the INTERREG VA region (Figure 1) as part of the MarPAMM project. It is intended to help those wanting to use the modelling results from the MarPAMM project (Davies et al. 2021, Cleasby et al. 2021), informed by the *literature* review of mechanisms by which climate change affects seabirds (Johnston et al. 2021), to develop policies and management plans for seabirds that consider how best to adapt our conservation of seabirds to climate change. The document does not present a comprehensive synthesis of the subject, but is instead a quick reference guide. Although focused on the INTERREG VA region, many of the same actions are likely to be relevant more widely.

A total of 25 seabird species breed within the region. We identify the species most likely to be associated with particular habitats and using the results of Davies et al. (2021), summarise their vulnerability to climate change. The main mechanisms by which each habitat is likely to be affected by climate change and the potential adaptation responses listed are summarised and interpreted by the project team using information from previous work (Ausden et al. 2011, Franks et al. 2016, Natural England & RSPB 2019), and the review of climate change mechanisms undertaken specifically for this project (Johnston et al. 2021). These sources used a combination of peer-reviewed literature and the expertise and experience of staff in Natural England, the RSPB, the Environment Agency and the Forestry Commission. Additional evidence and detail about each of the suggested adaptation options can therefore be found within those references (Ausden et al. 2011, Franks et al. 2016, Natural England & RSPB 2019). The Natural England *Climate Change Adaptation Manual* in particular contains useful summary material on key concepts and approaches to adaptation. As a final check, the content of this report has been reviewed by a project steering group and work package T5 of the MarPAMM project and RSPB Conservation Officers with knowledge of the INTERREG VA region.

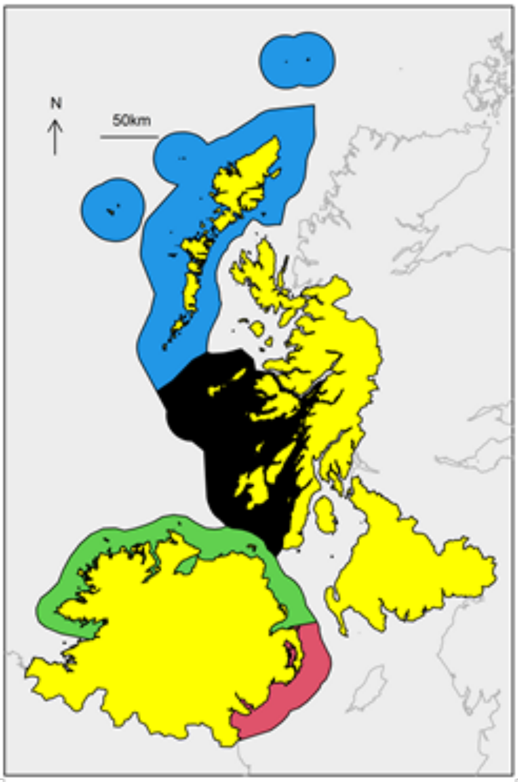

Figure 1. INTERREG VA area (yellow) and MarPAMM management regions (blue, Outer Hebrides; black, Argyll; purple, Co. Down – Co. Louth; green, North Coast Ireland – North Channel).

It is worth noting that there is generally a lack of good evidence for many adaptation actions which means that most of the suggested options are associated with a high uncertainty about their likely importance and effectiveness. This is particularly the case for the marine environment, which previous studies have not specifically covered. As a result of this uncertainty, suggested actions are made for groups of similar species, rather than for each species in turn, using the authors' expert judgement guided by the cited earlier works. We would recommend that monitoring and evaluation protocols are put in place to track the effectiveness of any adaptation measures adopted, not just so that management can be adapted as required, but to improve the evidence-base about their effectiveness in the longer-term.

Following Green & Pearce-Higgins (2010) and Pearce-Higgins & Green (2014) adaptation responses are split into **counteracting adaptation** responses which directly address particular climate change impact mechanisms, and **compensatory adaptation** responses which are designed to benefit the species, but are not directly targeted at particular impact mechanisms. These are summarized in habitat-specific accounts where the impacts of suggested adaptation options relevant for that habitat are listed, along with an assessment of the likely impacts on particular species or species-groups. Section 2 summarises the seabird species associated with each habitat and the vulnerability of each species to climate change. The following sections then provide more detail for each of these habitat-types:

- 3. Marine
- 4. Intertidal, saltmarsh, machair, dunes and beaches
- 5. Coastal grazing marsh
- 6. Blanket bog and moorland
- 7. Cliffs
- 8. Remote island habitats

Under each habitat, we provide the following set of tables:

- The main mechanisms by which climate change may affect each habitat, the environmental consequences of those mechanisms and the likely ecological impact.
- Potential counteracting adaptation responses for that habitat, and the likely benefits to seabird species.
- Potential compensatory adaptation responses for that habitat, and the likely benefits to seabird species.

In combination, this should provide an accessible way to link the species-specific review and model outputs produced by MarPAMM Lot 5 (Johnston et al. 2021, Davies et al. 2021, Cleasby et al. 2021), with existing guidance on climate change adaptation as referenced above, to inform the use of the MarPAMM project outputs for conservation within the INTERREG VA area and beyond. In many circumstances, there are likely to be synergistic or complementary combinations of adaptation measures that are required to be successful, such as the protection of food resources, maintenance of suitable breeding/foraging habitat and control of predators. In other circumstances, particular combinations of climate change impacts and other drivers or threats may influence the importance of particular adaptation options, or indeed constrain the options that can be employed at a particular site. These complexities are beyond the scope of this document and are best resolved through workshops and discussions with key stakeholders and managers within each region or for each individual site. Note, we have also not undertaken an assessment of the likely complexity, feasibility or cost of the interventions listed, which should form part of any conservation management plan advocating their use.

2. Species vulnerability to climate change and their habitat associations

Table 2.1. List of breeding seabird species, vulnerability to climate change (NA – not assessed due to there being insufficient data for modelling by Davies et al. 2020) and habitat associations. Most assessments were associated with a poor level of confidence apart from those for species with concordance between high magnitude observed and projected declines supported by additional literature about supporting climate change mechanisms, which were associated with a moderate confidence. These four species are listed in **bold**. Climate change vulnerabilities are from Tables 5 and 6 of Davies et al. (2020) for Britain and Ireland and the INTERREG VA region respectively)

Species		Vulnerability (Britain and Ireland)	Vulnerability (INTERREG VA region)	HABITATS					
				MARINE	TIDAL, DUNE	GRAZ. MAR.	BOG, MOOR	CLIFF	REM. IS.
Northern fulmar	*Fulmarus glacialis*	HIGH RISK	HIGH RISK	■	■			■	
Manx shearwater	*Puffinus puffinus*	NA	NA	■					■
Leach's petrel	*Oceanodroma leucorhoa*	NA	NA	■					■
Storm-petrel	*Hydrobates pelagicus*	HIGH RISK	HIGH RISK	■					■
Northern gannet	*Morus bassanus*	NA	NA	■				■	
Great cormorant	*Phalacrocorax carbo*	HIGH RISK	LOW	■				■	
European shag	*Phalacrocorax artistotelis*	MEDIUM RISK	MEDIUM RISK	■				■	
Arctic skua	***Stercorarius parasiticus***	**HIGH RISK**	**HIGH RISK**	■		■	■		■
Great skua	*Stercorarius skua*	NA	NA	■		■	■		■
Black-headed gull	*Chroicocephalus ridibundus*	HIGH OPPORTUNITY	HIGH OPPORTUNITY	■	■	■	■		■
Mediterranean gull	*Ichthyaetus melanocephalus*	NA	NA	■	■	■			
Common gull	*Larus canus*	MED. OPPORTUNITY	HIGH RISK	■		■	■		■
Great black-backed gull	*Larus marinus*	HIGH RISK	LOW	■	■	■	■	■	■
Herring gull	*Larus argentatus*	HIGH RISK	HIGH RISK	■	■	■	■	■	■
Lesser black-backed gull	*Larus fuscus*	HIGH OPPORTUNITY	HIGH OPPORTUNITY	■	■	■	■	■	■
Black-legged kittiwake	***Rissa tridactyla***	**HIGH RISK**	**HIGH RISK**	■				■	
Arctic tern	***Sterna paradisaea***	**HIGH RISK**	**HIGH RISK**	■	■	■	■		■
Common tern	*Sterna hirundo*	HIGH OPPORTUNITY	HIGH OPPORTUNITY	■	■	■	■		■
Roseate tern	*Sterna dougallii*	NA	NA	■	■	■			■
Little tern	***Sternula albifrons***	**HIGH RISK**	**HIGH RISK**	■	■				■
Sandwich tern	*Thalasseus sandvicensis*	MEDIUM RISK	MEDIUM RISK	■	■				■
Black guillemot	*Cepphus grylle*	HIGH RISK	HIGH RISK	■				■	
Atlantic puffin	*Fratercula arctica*	HIGH RISK	HIGH RISK	■				■	■
Razorbill	*Alca torda*	MEDIUM RISK	MEDIUM RISK	■				■	
Common guillemot	*Uria aalge*	MEDIUM RISK	MEDIUM RISK	■				■	

3. Marine habitats

With the potential exception of black-headed gull and common gull which are the most terrestrial of the seabird species considered, individuals of all species make significant use of marine habitats at some point in their annual cycle. Most forage at sea for at least some of the breeding season, although some of the other larger gulls, particularly herring gull and lesser black-backed gull also extensively use terrestrial habitats such as farmland and urban areas, and some common terns breed on inland freshwaters. Outside of the breeding season, black-legged kittiwake*,* auks, skuas, petrels, northern fulmars and northern gannets are entirely pelagic with some species migrating from the Northern Ireland Zone and Scottish Waters covered by this project across the entire range of Atlantic Ocean. In this report, we focus on the impacts and potential adaptation responses relevant to the waters of the INTERREG VA region.

There are no potential counteracting adaptation responses to directly address the impacts of climate change on the marine environment. Instead, we suggest that marine responses should seek to reduce the impacts of other pressures on seabirds (compensatory adaptation responses), making those populations more resilient to potentially negative climate change impacts. Such adaptation responses should also be informed by the action plans currently being developed by the Scottish Seabird Conservation Strategy.

Table 3.1. Summary of the main mechanisms by which climate change will affect marine habitats, the environmental consequences of each mechanism and the likely ecological impact.

Cause	Consequence	Ecological outcomes
Warmer temperatures	Generally poleward shift in the distribution, abundance, quality and diversity of prey species	Reductions in abundance of cold-associated zooplankton leading to an ecological cascade of reduced productivity, growth and survival of key fish species (e.g. sandeels *Ammodytes* spp.). Consequent reductions in the availability and quality of fish prey species.
		Reductions in the abundance of high-quality, cold-associated fish species reducing availability and quality of prey species.
		Increases in the abundance and diversity of low-quality, warm-associated fish species reducing the quality of prey available
	Advance in the timing of spring phytoplankton / zooplankton flush	Mismatch between plankton peaks and fish / bird requirements reduces the availability of fish prey species
	Reduced oxygen concentration	Reductions in the growth of fish species affect prey quality
	Increased energetic demands of dormant fish overwinter	Increased overwinter energy use by fish (e.g. sandeels), leading to reduced growth and fecundity
Greater frequency and intensity of storms	Greater frequency and intensity of storms	Increased seabird mortality during severe autumn / winter storm events in particular but can also affect seabird foraging in the breeding season.

Table 3.2. Potential at-sea compensatory adaptation responses (rows) for each bird species/species group (columns) for marine habitats. The likely effectiveness of adaptation measures based on the literature and expert judgement is summarised as: **↑** - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances **↓** – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect.

Compensatory adaptation responses not directly related to climate change	**Blacklegged kittiwake**	**Small gulls**	**Large gulls**	**Terns**	**Skuas**	**Auks**	**Fulmar**	**Petrels / Manx shearwater**	**Northern gannet**	**Shag / cormorant**
Sustainably manage fisheries (either fish or shellfish)	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Monitoring of fisheries and identification of measures to mitigate against bycatch	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Monitoring of fin fish aquaculture and identification of measures to mitigate against bycatch	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Manage marine recreational pressure to reduce human disturbance to birds engaging in foraging or maintenance behaviours				↑		↑	↑			
Strategic siting of renewable energy schemes to reduce displacement / barrier effects / collision risk	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Appropriate management of shipping pressure	↑		↑	↑	↑	↑	↑	↑	↑	↑
Appropriate management pollution and other contamination events	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Appropriate management of marine litter to reduce risk of entanglement/ingestion	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
Improved demographic monitoring of colonies (e.g. SMP, RAS studies) to document impacts and to inform and evaluate	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
adaptation responses										

4. Intertidal, saltmarsh, machair, dunes and beaches

Most of the bird features of interest associated with these habitats are not seabirds, but breeding waders and wintering and passage waterbirds, which need to be considered when designing conservation responses to climate change. Their needs are described in detail by Ausden *et al.* (2011) and Franks *et al.* (2016). This summary focuses primarily gulls and terns that nest on low-lying coastal habitats (Table 2.1); black-headed gull, Mediterranean gull, great black-backed gull, herring gull, lesser black-backed gull, Arctic tern, common tern, roseate tern, little tern and Sandwich tern, but also includes northern fulmar which can nest in dunes on some.

Table 4.1. Summary of the main mechanisms by which climate change is expected to affect intertidal, saltmarsh, machair, dune and beach habitats, the environmental consequences of each mechanism and the likely ecological impact.

Cause	Consequence	Ecological outcomes
Sea level rise Increased risk of storms and storm surges	Altered coastal dynamics, erosion and changes to sediment load	Changes to estuarine habitat (micro topography, sedimentation and salinity), altering biomass and composition of benthic invertebrate prey, potentially impacting fish prey Loss of saltmarsh or machair breeding habitat through coastal squeeze unless sediment loading sufficient for accretion Re-profiling and loss of shingle beaches and sand dunes May create / renew some early succession shingle areas that could benefit terns Changes in dune hydrology can alter the flow of water from dune slacks Increased rate of scouring during storms may create new shingle / sand nest sites
	Greater frequency of coastal flooding	Increased erosion of saltmarsh habitat Changes in sward composition towards more brackish species may affect vegetation structure, nest site availability / predation risk Direct loss of seabird breeding attempts through flooding of nests / chicks
Warmer temperatures	Longer growing season	Increased rate of successional change & loss of open/ arly successional habitats affecting nest site availability Changes in cropping / farming practices on machair affecting nest site availability Increased stability of dune systems due to grass growth increasing the rate of successional change Potential increase in invasive non-native species
Hotter, drier summers	Reduced water table	Increased salinity affecting plant and invertebrate composition Risk of drying out of dune slacks
	Increased visitor pressure	Increased disturbance and risk of nest trampling
Increased extreme rainfall events	Increased flood risk	Increased spring rainfall may negatively affect chick survival in open nests Increased erosion of terrestrial habitats in extreme rainfall events

Table 4.2. Potential counteracting adaptation responses (rows) for each bird species / group (columns) for intertidal, saltmarsh, machair, dune and beach habitats. The likely effectiveness of adaptation measures is summarised as: **↑** - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances **↓** – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect.

Counteracting adaptation responses	**Gulls**	**Terns**	**Northern fulmar**
Create new intertidal, saltmarsh, and shingle habitat through managed realignment and regulated tidal exchange	**↑**	**↑**	
Support landward movement of saltmarsh and shingle habitats through land-purchase / management agreements of existing agricultural land / agri-environment schemes	**↑**	**↑**	
Realign designated site boundaries to match coastal evolution, with the aim of creating larger functional units	↑	↑	↑
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 2) Maximise the variation in elevation of higher areas 3) Create nest rafts	**↑**	**↑**	
Where grazed, protect dunes from large-scale erosion through flexible grazing management depending upon conditions	↑	↑	↑
Active management of dunes, planting grasses to stabilise and reduce erosion	↑	↑	↑

Table 4.3. Potential compensatory adaptation responses (rows) for each bird species (columns) for intertidal, saltmarsh, machair, dune and beach habitats. The likely effectiveness of adaptation measures is summarised as: **↑** - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances **↓** – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect.

Compensatory adaptation responses not directly related to climate change	**Gulls**	**Terns**	**Northern fulmar**
Manage recreational use of coastal habitats to reduce human disturbance to breeding colonies	**↑**	**↑**	↑
Adopt a strategic approach to coastal development and visitor infrastructure to reduce visitor pressure at the most sensitive sites	**↑**	**↑**	↑
Manage marine recreation pressure to reduce human disturbance to colonies and foraging birds	↑	↑	↑
At coastal grazed sites adjust stocking density and timing of grazing to maintain appropriate vegetation structures, reduce erosion risk and limit trampling risk to nests	↑	↑	↑
Reduce other sources of anthropogenic erosion (e.g. dredging of sediment, wash from shipping)	↑	↑	
Reduce predation by corvids, foxes, mustelids through electric fencing and/or lethal control	**↑**	**↑**	**↑**
Remove / control invasive non-native species (e.g. rats, mink) negatively impacting seabird species	**↑**	**↑**	**↑**
Reduce predation by raptors and gulls through diversionary feeding / management (e.g. removal of eggs)	↓	**↑**	
Potential gull licensing decisions should be considered carefully when applied to populations vulnerable to climate change	**↑**		
Strategic siting of coastal onshore renewable energy schemes to reduce displacement due to disturbance / collision risk	**↑**	**↑**	**↑**
Implement biosecurity measures and monitor for potentially invasive non-native species on islands	**↑**	**↑**	**↑**
Restrict removal of coastal seaweed deposits for bioenergy or other purposes from important coastal and foraging areas	↑	↑	↑

5. Coastal grazing marsh

Most of the bird features associated with these habitats are not seabirds, but breeding waders, wintering and passage waterbirds, which need to be considered when designing conservation responses to climate change. Their needs are particularly described in detail by Ausden *et al.* (2011) and Franks *et al.* (2016). This summary focuses on the seabirds that need to be considered, which are primarily gulls, terns and skuas nesting on low-lying coastal grassland; specifically Arctic skua, great skua, black-headed gull, Mediterranean gull, common gull, great black-backed gull, herring gull, lesser black-backed gull, Arctic tern, common tern, roseate tern (Table 2.1).

Table 5.1. Summary of the main mechanisms by which climate change is expected to affect coastal grazing marshes, the environmental consequences of each mechanism and the likely ecological impact.

Cause	Consequence	Ecological outcomes
Sea level rise Increased risk of storms and storm surges	Altered coastal dynamics	Potential loss of coastal grazing marsh habitat through coastal squeeze unless sediment loading sufficient for accretion
	Greater frequency of coastal flooding	Increased erosion of grazing marsh Changes in sward composition towards more brackish species may affect vegetation structure, nest site availability / predation risk Direct loss of seabird breeding attempts through flooding of nests / chicks
	Reduced drainage capacity, raising water levels	Variable impacts on soil invertebrates depending on whether this leads to excessive flooding or helps to maintain water table in summer
Warmer temperatures	Longer growing season	Reduced availability of short swards for nesting Changes in sward height may affect predation risk Changes in sward composition may affect vegetation structure and nest site availability /predation risk
Drier summers	Reduced water table	Increased salinity affecting plant and invertebrate composition, potentially exacerbated by water abstraction Reduction in soil invertebrate availability during the summer Reduced water quality due to an increase in nutrient concentration and eutrophication Loss of open water may increase access to colonies by mammalian predators (e.g.fox) Changes in sward composition may affect vegetation structure and nesting availability / predation risk Increase potential for conversion to arable or intensive grazing, leading to direct habitat loss Loss of pools reduce bathing opportunities for skuas in hot weather, increasing the risk of nest predation
Wetter winters	Winter flooding	Winter flooding may increase availability of open nesting habitats Changes in sward composition may affect vegetation structure and nesting availability / predation risk Wet ground conditions may make it difficult to maintain appropriate grazing levels
Increased extreme rainfall events	Increased flood risk	Increased flood risk for nests during extreme summer rainfall events Changes in sward composition may affect vegetation structure and nesting availability / predation risk More frequent flooding may make it difficult to maintain appropriate grazing levels Increased disturbance could increase susceptibility to the spread of invasive plant species

Table 5.2. Potential counteracting adaptation responses (rows) for each bird species (columns) for coastal grazing marshes. The likely effectiveness of adaptation measures is summarised as: **↑** - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances **↓** – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect. Cells with contrasting arrow directions indicate the effects may be positive or negative depending upon the context.

Counteracting adaptation responses	**Skuas**	**Gulls**	**Terns**
Maintenance of sea-defences to protect coastal grazing marsh from loss	**↑**	**↑**	**↑**
Managed retreat to protect vulnerable saltmarsh / shingle communities seaward may be at the expense of coastal grazing marshes unless extent of grazing marshes maintained by conversion of other habitats	**↓↑**	**↓↑**	**↓↑**
Realign designated site boundaries to match coastal evolution, with the aim of creating larger functional units	↑	↑	↑
Increase topographic variation to ensure suitable nesting locations at different tidal heights & future sea levels: 1)Create raised islands for nesting 2}Maximise the variation in elevation of higher areas 3) Create deeper channels / pools to maintain areas of open water during the breeding season to help protect against mammalian predators	↑	**↑**	**↑**
Develop infrastructure to increase control over water levels and ability to adjust inputs of fresh and sea water, reducing risk of flooding or to reduce drawdown during summer	**↑**	↑	↑
Maximise efficiency of water use on site through appropriate site design, enhanced winter water storage, rotational flooding to maintain water levels during the summer	**↑**	↑	↑
Secure new or additional water sources externally to help maintain water levels during the summer	**↑**	↑	↑
Maintain appropriate levels of grazing or cutting to manage swards as high levels of grazing may increase rates of erosion and coastal squeeze, whilst high swards may limit nesting opportunities. Given potentially rising water tables, this may require mechanical cutting or grazing by breeds that can cope with wet conditions.	↑	↑	↑
Increase areas of grazing marsh by introducing appropriate water level management on adjacent	↑	↑	↑
arable and pasture as part of developing a functioning coastal floodplain			

Table 5.3. Potential compensatory adaptation responses (rows) for each bird species (columns) for coastal grazing marshes. The likely effectiveness of adaptation measures is summarised as: **↑** - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances **↓** – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect. Cells with contrasting arrow directions indicate the effects may be positive or negative depending upon the context.

Compensatory adaptation responses not directly related to climate change	**Skuas**	**Gulls**	**Terns**
Manage recreational use of coastal habitats to reduce erosion pressure on vulnerable vegetation and to reduce human disturbance to breeding colonies	**↑**	**↑**	**↑**
Adopt a strategic approach to coastal development and visitor infrastructure to reduce visitor pressure at the most sensitive sites	**↑**	**↑**	**↑**
Manage marine recreation pressure to reduce human disturbance to colonies and foraging birds	↑	↑	↑
At coastal grazing sites adjust stocking density and timing of grazing to limit trampling risk to nests	↑	↑	↑
Reduce other sources of anthropogenic erosion (e.g. dredging of sediment, wash from shipping)		↑	↑
Minimise adverse impacts of drainage and abstraction	**↑**	↑	↑
Reduce predation by corvids, foxes, mustelids through electric fencing and/or lethal control	**↑**	**↑**	**↑**
Remove / control invasive non-native species (e.g. rats, mink) negatively impacting seabird species	**↑**	**↑**	**↑**
Reduce predation by raptors, skuas and gulls through diversionary feeding / management	↓↑	↓	**↑**
Potential gull licensing decisions should be considered carefully when applied to populations vulnerable to climate change		**↑**	
Strategic siting of coastal onshore renewable energy schemes to reduce displacement due to disturbance / collision risk	**↑**	**↑**	**↑**
Implement biosecurity measures and monitor for potentially invasive non-native species on islands	**↑**	**↑**	**↑**

6. Blanket bog and moorland

Most of the bird features associated with these habitats are breeding waders and raptors, but they can support large colonies or loose aggregations of some breeding gull and skua species. The needs of these other species are described in detail by Ausden *et al.* (2011) and Franks *et al.* (2016). This summary focuses on Arctic skua, great skua, black-headed gull, common gull, great black-backed gull, herring gull, lesser black-backed gull, Arctic tern, common tern (Table 2.1).

Table 6.1. Summary of the main mechanisms by which climate change is expected to affect blanket bog and moorland habitats, the environmental consequences of each mechanism and the likely ecological impact.

Cause	Consequence	Ecological outcomes
Decrease in summer rainfall and increase in summer temperatures and evapotranspiration	Increased rate of drawdown in summer	Loss or reduction in quality of wetland / peatland habitat, leading to changes in the composition and structure of vegetation Changes in the abundance and composition of soil / aquatic invertebrates Reduced water quality in rivers due to an increase in nutrient concentration Risk of wind-blow of dry bare peat leading to erosion Increased risk of wildfire in dry years, leading to large-scale habitat change / loss as well as risk of catastrophic breeding losses in particular years Loss of pools reduce bathing opportunities for skuas in hot weather, increasing the risk of nest predation
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 and potential invasion of bracken Burning on peat soils becomes unacceptable, altering vegetation composition and structure unless replaced with cutting Potential changes in grazing regimes in response to longer growing seasons may affect nesting habitat quality Increase in plant pests, pathogens and disease Increases in the abundance of ticks and other potential parasites
Increase in extreme rainfall events year-round	Increased flood risk	Increased flood risk for nests during extreme summer rainfall events, particularly nests near freshwaters Increased spring rainfall may negatively affect chick survival in open nests Increased risk of peatland erosion from un-vegetated surfaces

Table 6.2. Potential counteracting adaptation responses (rows) for each bird species (columns) for blanket bog and moorland habitats. The likely effectiveness of adaptation measures is summarised as: **↑** - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances **↓** – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect.

Counteracting adaptation responses	**Skuas**	**Gulls**	**Terns**
Block artificial drains / channels in erosion complexes on blanket bog to raise water table	**↑**	↑	↑
Secure new or additional water sources externally to help maintain water levels during the summer	**↑**	↑	
Re-profile / re-vegetate areas of eroding peat / historical peat cutting	↑	↑	↑
Provision of a mosaic of open habitats with heterogeneity in vegetation structure	↑	↑	↑
Remove forestry plantations from blanket bog & adjacent areas and consider limiting planting on shallow peats to reduce impact on water tables	**↑**	**↑**	**↑**
Peatland restoration using *Sphagnum* seeding	↑	↑	↑
Use appropriate management techniques to limit fuel load and create fire breaks by maintaining areas of open structure	**↑**	**↑**	**↑**
Control visitor activity during high fire risk periods	**↑**	**↑**	**↑**
Improved fire detection and emergency service response	**↑**	**↑**	**↑**

Table 6.3. Potential compensatory adaptation responses (rows) for each bird species (columns) for blanket bog and moorland habitats. The likely effectiveness of adaptation measures is summarised as: ↑ - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances ↓ – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect. Cells with contrasting arrow directions indicate the effects may be positive or negative depending upon the context.

Compensatory adaptation responses not directly related to climate change	**Skuas**	**Gulls**	**Terns**
Manage recreational use of habitats to reduce human disturbance to breeding colonies	↑	↑	↑
At coastal grazed sites adjust stocking density and timing of grazing to maintain appropriate vegetation structures, reduce erosion risk and limit trampling risk to nests	↑	↑	↑
Reduce predation by corvids, foxes, mustelids through electric fencing and/or lethal control	↑	↑	↑
Reduce predation by raptors, gulls and skuas through diversionary feeding / management (e.g. removal of eggs)	↓↑	↓	↑
Potential gull licensing decisions should be considered carefully when applied to populations vulnerable to climate change		↑	
Careful siting of onshore renewable energy schemes to reduce displacement due to disturbance / collision risk	↑	↑	↑

7. Cliffs

A large number of seabird species are associated with cliffs, either nesting on the rock faces as in the case of black-legged kittiwake, auks and northern gannets, or on the flatter tops, as with the larger gulls and puffins, whilst black guillemots, cormorants and shags will tend to nest in boulders closer to the sea surface (Table 2.1). The full list of species considered here is northern fulmar, northern gannet, great cormorant, European shag, great black-backed gull, herring gull, lesser black-backed gull, black-legged kittiwake, black guillemot, Atlantic puffin, razorbill, common guillemot

Table 7.1. Summary of the main mechanisms by which climate change is expected to affect seabird colonies on cliffs, the environmental consequences of each mechanism and the likely ecological impact.

Cause	Consequence	Ecological outcomes
Changes in prevailing weather patterns	Alter suitability of certain nest sites	Affect ability of birds to land / provision chicks at nest sites
Sea level rise Increased risk of storms and storm surges	Increased rate of cliff erosion	Changes in nest site availability and potential nest loss during the breeding season Basal cliff erosion leading to slope instability and loss of colony-nesting burrows through landslips
	Reduction in height of cliffs above sea level	Gradual loss of nesting habitat at the bottom of cliffs, and altered profile of exposure to waves and spray, affecting habitat availability for species associated with the bottom of cliffs
	Increased frequency and severity of extreme wave action / storms washing out nesting attempts	Direct loss of seabird breeding attempts through flooding of nests / chicks, particularly affecting species nesting low-down Loss of toe material at cliff foot, reducing nesting opportunities and increasing erosion
Warmer temperatures	Longer growing season	Increased rate of successional change and loss of open / early successional habitats Increased length of grass / vegetation at the top of cliffs May favour invasive non-native plant species
Increased extreme rainfall events year-round	Increased flood risk	Increased flood risk for open nests / burrows during extreme summer rainfall events Increased spring rainfall may negatively affect chick survival in open nests Increased risk of erosion of burrow nests at the top of cliff

Table 7.2. Potential counteracting adaptation responses (rows) for each bird species (columns) for seabird colonies on cliffs. The likely effectiveness of adaptation measures is summarised as: ↑ - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances ↓ – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect.

Counteracting adaptation responses	**Gulls**	**Kittiwake**	**Cliff nesting auks**	**Puffin**	**Gannet / fulmar**	**Shag / cormorant**
Maintenance of sea defences to prevent retreat of cliffs	↑	↑	↑	↑	↑	↑
Realign designated site boundaries to match coastal evolution, with the aim of creating larger functional units	↑	↑	↑	↑	↑	↑
Maintain extent of seminatural habitat on the top of a retreating cliff through reversion of intensive farmland.	↑			↑		
Maintain appropriate levels of grazing or cutting to maintain short swards on cliff tops for open / burrow nesting species, whilst minimising the risk of erosion / nest trampling.	↑			↑		
Creation of artificial platforms	↑	↑				↑

Table 7.3. Potential compensatory adaptation responses (rows) for each bird species (columns) for seabird colonies on cliffs. The likely effectiveness of adaptation measures is summarised as: **↑** - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances **↓** – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect.

Compensatory adaptation responses not directly related to climate change	Gulls	Kittiwake	Cliff nesting auks	Puffin	Gannet/ fulmar	Shag/ cormorant
Manage recreational use of habitats to reduce erosion pressure on vulnerable vegetation and to reduce human disturbance to breeding colonies	**↑**	**↑**	**↑**	**↑**	**↑**	**↑**
Protect against coastal defence works during the breeding season	**↑**	**↑**	**↑**	**↑**	**↑**	**↑**
Manage offshore recreation pressure to reduce human disturbance to colonies and foraging birds	↑	↑	**↑**	**↑**	↑	**↑**
Reduce predation by corvids, foxes, mustelids through electric fencing and/or lethal control	**↑**			**↑**		
Remove / control invasive non-native species (e.g. rats, mink) negatively impacting seabird species to increase the extent of predator-free cliff habitat	**↑**			**↑**		
Reduce predation by raptors, gulls & skuas through diversionary feeding/ management (e.g. removing eggs)	↓	**↑**	**↑**	**↑**	**↑**	
Potential gull licensing decisions should be considered carefully when applied to populations vulnerable to climate change	**↑**					
Implement biosecurity measures and monitor for	**↑**	**↑**	**↑**	**↑**	**↑**	**↑**
potentially invasive non-native species on islands						

8. Remote island habitats

Here, we focus on burrow-nesting seabirds or those which nest in the open on grass dominated or other short vegetation on relatively flat ground or gently sloping faces of remote islands. Cliff-nesting species around these islands are covered in the previous section, therefore we focus on the following seabird species; Manx shearwater, Leach's petrel, storm-petrel, Arctic skua, great skua, black-headed gull, common gull, great blackbacked gull, herring gull, lesser black-backed gull, Arctic tern, common tern, roseate tern, little tern, Sandwich tern, Atlantic puffin (Table 2.1). The key reason for separating these species is to highlight the potential issues of predation by non-native mammal species which can be a feature of such islands.

Table 8.1. Summary of the main mechanisms by which climate change is expected to affect remote island habitats, the environmental consequences of each mechanism and the likely ecological impact.

Cause	Consequence	Ecological outcomes
Sea level rise Increased risk of storms and storm surges	Altered coastal dynamics, erosion and changes to sediment load	Changes to coastal habitats, altering biomass and composition of benthic invertebrate prey, potentially impacting fish prey Loss of coastal breeding habitat through coastal squeeze unless sediment loading sufficient for accretion Re-profiling and loss of shingle beaches and sand dunes Increased rate of scouring during storms may create new shingle / sand nest sites Changes in nest site availability and potential nest loss during the breeding season Basal cliff erosion leading to slope instability and loss of colony-nesting burrows through landslips
	Greater frequency of coastal flooding	Increased erosion of coastal habitat Changes in sward composition towards more brackish species may affect vegetation structure, nest site availability / predation risk May create / renew some early succession shingle areas that could benefit terns Direct loss of seabird breeding attempts through flooding of nests / chicks
Warmer temperatures	Longer growing season	Increased rate of successional change and loss of open / early successional habitats affecting nest site availability Increases in non-native mammalian rodents due to longer growing season
	Reduced winter severity	Increases in mammalian herbivores impacting vegetation structure, causing soil erosion and risking nest trampling Increases in non-native mammalian predators due to reduced winter mortality
Drier summers	Reduced water table	Increased salinity affecting plant and invertebrate composition Reduction in soil invertebrate availability during the summer Reduced water quality due to an increase in nutrient concentration and eutrophication
Increased extreme rainfall events year-round	Increased flood risk	Increased flood risk for open nests / burrows during extreme summer rainfall events Increased spring rainfall may negatively affect chick survival in open nests Increased disturbance may promote the spread of invasive plant species Increased risk of erosion of burrow nests

Table 8.2. Potential counteracting adaptation responses (rows) for each bird species (columns) for remote island habitats. The likely effectiveness of adaptation measures is summarised as: ↑ - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances ↓ – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect.

Counteracting adaptation responses	Skuas	Gulls	Terns	Puffin	Petrels / shearwaters
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 2) maximise the variation in elevation of higher areas		↑	↑		
Maintenance of sea-defences to protect coastal habitats from loss		↑	↑		
Secure new or additional water sources externally to help maintain water levels during the summer	↑	↑			
Maintain appropriate levels of grazing to maintain short swards for open / burrow nesting species, whilst minimising the risk of erosion / nest trampling	↑	↑	↑	↑	
Use appropriate grazing / cutting / burning to limit fuel load and create fire breaks by maintaining areas of open structure	↑	↑	↑	↑	↑
Control visitor access during high fire risk periods	↑	↑	↑	↑	↑

Table 8.3. Potential compensatory adaptation responses (rows) for each bird species (columns) for remote island habitats. The likely effectiveness of adaptation measures is summarised as: ↑ - high likelihood of benefit in most circumstances ↑ - may benefit in some circumstances ↓ - may have negative impact in some circumstances ↓ – high likelihood of negative impact in most circumstances. Blank cells indicate no likely effect. Cells with contrasting arrow directions indicate the effects may be positive or negative depending upon the context.

Compensatory adaptation responses not directly related to climate change	**Skuas**	**Gulls**	**Terns**	**Puffin**	**Petrels / shearwaters**
Creation of artificial burrows / stone walls for burrow nesting species				↑	↑
Manage recreational use of habitats to reduce human disturbance to breeding colonies	↑	↑	↑	↑	↑
Manage marine recreation pressure to reduce human disturbance to colonies and foraging birds		↑	↑	↑	
Reduce other sources of anthropogenic erosion (e.g. dredging of sediment, wash from shipping)		↑	↑		
At coastal grazed sites adjust stocking density and timing of grazing to limit trampling risk to nests	↑	↑	↑	↑	↑
Eliminate non-native mammalian predators (e.g. rats, mink) to increase the area/number of predator-free islands with potentially suitable nesting habitat	↑	↑	↑	↑	↑
Reduce predation by raptors, gulls and skuas through diversionary feeding / management (e.g. removal of eggs)	↓↑	↓	↑	↑	↑
Potential gull licensing decisions should be considered carefully when applied to populations vulnerable to climate change		↑			
Strategic siting of coastal onshore renewable energy schemes to reduce displacement due to disturbance / collision risk	↑	↑	↑	↑	↑
Implement biosecurity measures and monitor for potentially invasive non-native species on islands	↑	↑	↑	↑	↑

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9. Disclaimer

The views and opinions expressed in this report do not necessarily reflect those of the European Commission or the Special EU Programmes Body (SEUPB).

10. Key references

Ausden, M., Pearce-Higgins, J.W., Dodd, A. & Johnston, A. (2011) The implications of climate change for the management of the UK's Special Protection Areas (SPAs). Appendix 4 of the *Climate Change Impacts on Avian Interests of Protected Area Networks (CHAINSPAN) Project*. Defra Ref: WC0750/CR0440

Cleasby, I. *et al.* (2021) *MarPAMM Lot 5: Projecting the at-sea distribution of seabirds within the INTERREG VA area under climate change.* Project report to Agri-Food and Biosciences Institute and Marine Scotland Science

Davies, J.G., Humphreys, E.M. & Pearce-Higgins, J.W. (2021) *MarPAMM Lot 5: Projecting future seabird abundance within the INTERREG VA area under climate change.* Project report to Agri-Food and Biosciences Institute and Marine Scotland Science

Franks, S.E, Pearce-Higgins, J.W., Ausden, M. & Massimino, D. (2016) Increasing the Resilience of the UK's Special Protection Areas to Climate Change – General adaptive management recommendations. Natural England Commissioned Reports, Number 202e.

Green, R.E. & Pearce-Higgins, J.W. (2010) Species management in the face of a changing climate. In Baxter, J.M. & Galbraith, C.A. (eds) Species Management: Challenges and Solutions for the 21st Century. TSO Scotland, Edinburgh Pp 517-536.

Johnston, D.T., Humphreys, E.M., Davies, J.G. & Pearce-Higgins, J.W. (2021) *MarPAMM Lot 5: Review of climate change mechanisms affecting seabirds within the INTERREG VA area.* Project report to Agri-Food and Biosciences Institute and Marine Scotland Science

Natural England & RSPB (2019) *Climate Change Adaptation Manual - Evidence to support nature conservation in a changing climate*, 2nd Edition. Natural England, York, UK.

Pearce-Higgins, J.W. & Green, R.E. (2014) *Birds and Climate Change: Impacts and Conservation Responses*. Cambridge University Press, Cambridge.

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