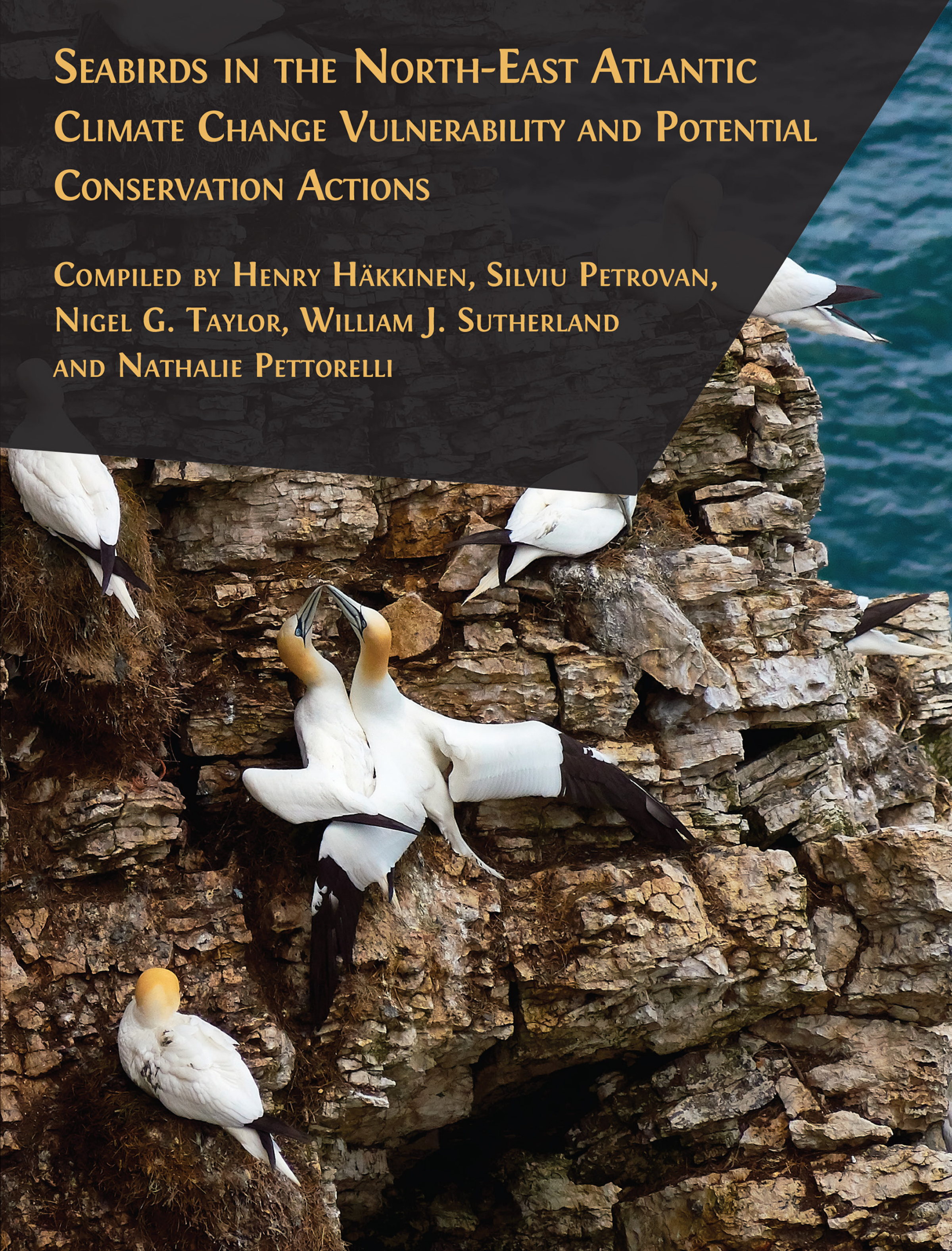
Seabirds in the North-East Atlantic Climate Change Vulnerability and Potential Conservation Actions

Compiled by Henry Häkkinen, Silviu Petrovan, Nigel G. Taylor, William J. Sutherland and Nathalie Pettorelli



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Auks

(Alcidae)

An assessment of climate change vulnerability and potential conservation actions for auks in the North-East Atlantic

UNIVERSITY OF CAMBRIDGE

ZSL Institute of Zoology

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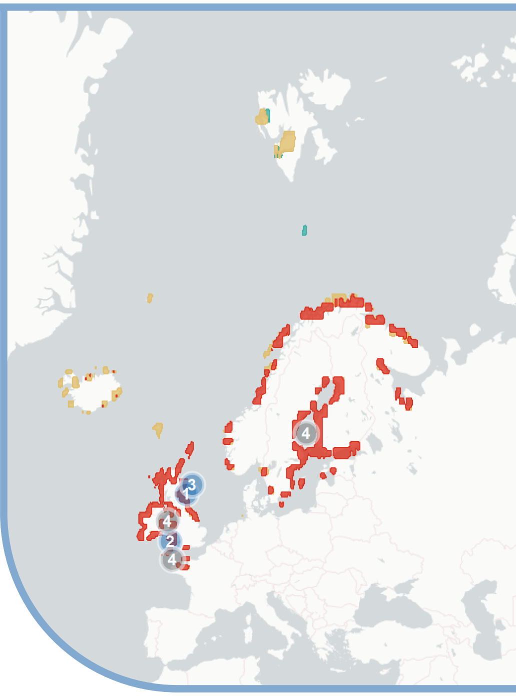
1 Razorbill *(Alca torda)*



1.1 Evidence for exposure

1.1.1 Potential changes in breeding habitat suitability (by 2100):

Current breeding area that is likely to become less suitable (80% of current range).

Current breeding area that is likely to remain suitable (18%).

Current breeding area that is likely to become more suitable (2%).

1.1.2 Current impacts climate change:

1 **Negative Impact:** Extreme storms during the razorbill breeding season have led to wide-spread nest destruction, nesting failure and a net reduction in annual population production.

2 **Negative Impact:** As sea temperatures have increased over time, razorbill productivity has decreased, most likely due to changes in prey availability.

3 **Neutral Impact:** Key prey species have shifted their life-cycle, likely in response to climate change, but razorbills have not adjusted in response. There is concern this could result in trophic mismatch, but no overall effect on breeding success has so far been observed.

1.1.3 Predicted changes in key prey species:

4 Key prey species are likely to decline in abundance in the Baltic, the Irish Sea and the English Channel.

1.2 Sensitivity

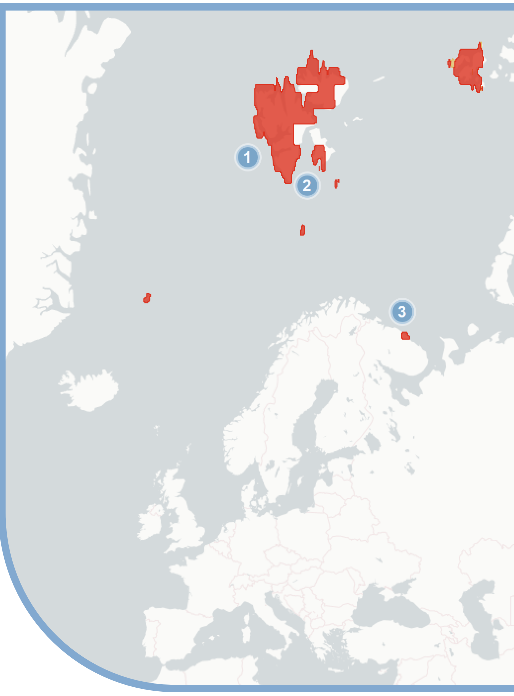
- Razorbills prefer to nest in exposed places, which makes nests particularly vulnerable to storms. Any increase in the frequency or intensity of storms during the breeding season is likely to have severe consequences on razorbill breeding success.
- Razorbill survival in many areas correlates with sea surface temperature, likely due to changes in prey abundance. Projected temperature increases are therefore likely to decrease razorbill survival during the non-breeding season.
- Razorbills are prone to mass-mortality events ("wrecks"), both across Europe and in North America. The exact cause behind them is not certain, but likely related to food availability and winter storms. This makes drastic population reductions more likely, as well long recovery periods.
- Many razorbill populations are heavily reliant on a few prey species, especially during the breeding period. Any change in prey availability, particularly sandeels, is likely to have consequences for razorbill populations.
- Razorbills are vulnerable to mammal predation, and the spread of introduced mammals (favoured by climate change) could threaten more northern populations than previously.
- This species has a long generation length (>10 years), which may slow recovery from severe impacts and increases population extinction risk.

1.3 Adaptive capacity

- Razorbills are pelagic and are easily capable of reaching new potential colony sites. In North America there is some evidence they will colonise new areas to match key prey species ranges. However, there is no observed example of this occurring in Europe.


Razorbill © Seppo Häkkinen

2 Little Auk (*Alle alle*)



1.1 Evidence for exposure

1.1.1 Potential changes in breeding habitat suitability (by 2100):

Current breeding area that is likely to become less suitable (94% of current range).

Current breeding area that is likely to remain suitable (6%).

Current breeding area that is likely to become more suitable (0%).

1.1.2 Current impacts attributed to climate change:

1 **Negative Impact:** Warmer temperatures correlate with longer foraging trips and lower little auk productivity, most likely due to decreased prey availability.

2 **Neutral Impact:** Little auks are breeding earlier in correlation with warmer temperatures, so far no negative consequence has been observed.

3 **Neutral Impact:** Extreme storms during the non-breeding season have led to mass mortality of little auks ('wrecks').

1.1.3 Predicted changes in key prey species:

No key prey assessment was carried out for this species.

1.1.4 Climate change impacts outside of Europe:

- Loss of sea ice and availability of new prey items due to climate change has led to increased little auk breeding success in Greenland.

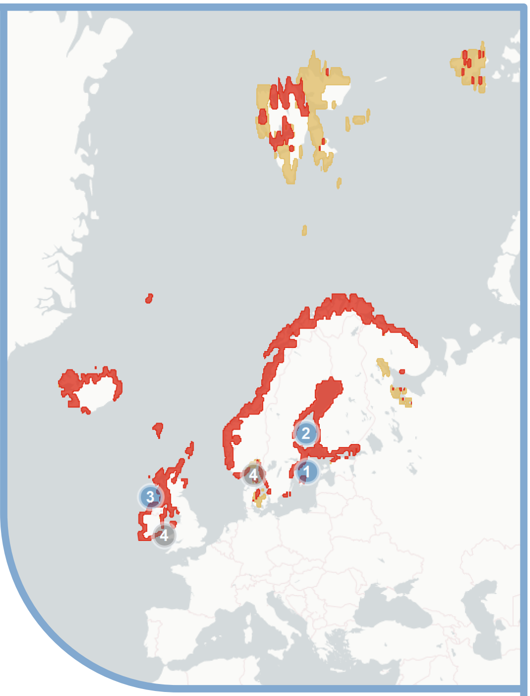
1.2 Sensitivity

- Little auks expend a great deal of energy in flight, and their chicks also have very high energy demands. This means that auks must focus on high-energy prey and are sensitive to even small changes in high-energy prey availability.
- Auk colonies that nest near warmer seas typically have longer and less successful foraging trips for nesting auks, which ultimately lowers chick growth and survival. Populations that therefore nest in areas with projected increases in sea temperature would likely be negatively impacted by climate change.
- Little auks on Svalbard may rely on environmental signals to time breeding events, in particular the timing of snow melt. This theory is not confirmed, but is supported by recent observed changes in phenology. If there is a strong reliance on such environmental cues, it may lead to trophic mismatch with prey species in the future.
- Little auks are dependent on a few species of copepods throughout the year. Any changes in availability or range of these species is likely to have a significant impact on little auks.
- Little auks congregate in large numbers in a relatively small area in the non-breeding season in the Atlantic. Any negative impact in this area is likely to have severe consequences for little auk populations.
- Little auks are known to be sensitive to climate change, and have suffered regional extinctions. They have previously suffered range contractions and local extinctions in the 19th-20th century most likely because of global warming (though historical changes were not primarily anthropogenic). As a result, it has lost much of its previous range in Iceland and Greenland.
- Little auk populations are large, but many are poorly monitored and exposed to multiple potential pressures. Impacts may be difficult to identify and conservation is likely to be difficult to carry out.

1.3 Adaptive capacity

- Little auks in Svalbard and Greenland have plastic foraging behaviour that has helped them compensate for local changes in prey availability and sea ice. However this plasticity likely has a limit and projections suggest they can only compensate to a certain extent.
- Little auks are thought to show strong fidelity to breeding sites. This may reduce the ability of little auks to adapt to changes in local conditions, as they are unlikely to change breeding sites in response to change.

3 Black Guillemot *(Cepphus grylle)*



1.1 Evidence for exposure

1.1.1 Potential changes in breeding habitat suitability (by 2100):

Current breeding area that is likely to become less suitable (76% of current range).

Current breeding area that is likely to remain suitable (24%).

Current breeding area that is likely to become more suitable (0%).

1.1.2 Current impacts attributed to climate change:

1 **Negative Impact:** Heavy rainfall events and high water level has led to flooding of nests and lower hatching success in the Baltic. Such flooding events are becoming more common, and are likely to further increase. Debris left by storms and flooding can also make large areas of shoreline less suitable for breeding.

2 **Negative Impact:** Range expansion of American mink, partly assisted by climate change, has led to increased rates of predation at guillemot colonies.

3 **Neutral Impact:** Guillemots have shifted their laying date, most likely linked to an increase in sea surface temperature and prey availability.

1.1.3 Predicted changes in key prey species:

4 Key prey species are likely to decline in abundance in the Irish Sea and the south-west coast of Sweden.

1.2 Sensitivity

- Black guillemots are particularly vulnerable to predation from mink and rats, due in part to their nesting on the ground in exposed areas. Range expansion of mammalian predators due to climate change (which is already occurring in Scandinavia) may have large impacts on guillemot populations.
- Black guillemots often nest in exposed areas close to water level, which make them vulnerable to flooding either from sea-level rise, extreme precipitation or tidal surges. If climate change results in a higher frequency of any of these events during the summer, it could severely impact black guillemot breeding populations.
- Black guillemots in Europe are declining, though with highly variable severity. There are various underlying causes including marine pollution, predation by invasive species, by-catch, disruption by wind farms and hunting. Any additional pressure from climate change is likely to accelerate these declines.

1.3 Adaptive capacity

- Black guillemots can shift their phenology in response to changes in environmental conditions. They may therefore be able to adjust to changes in conditions and prey availability and therefore mitigate impacts of climate change.
- In recent decades black guillemots have established several colonies in new areas around the Irish Sea and North America, which suggests they may be capable of range shifts in response to climate change.

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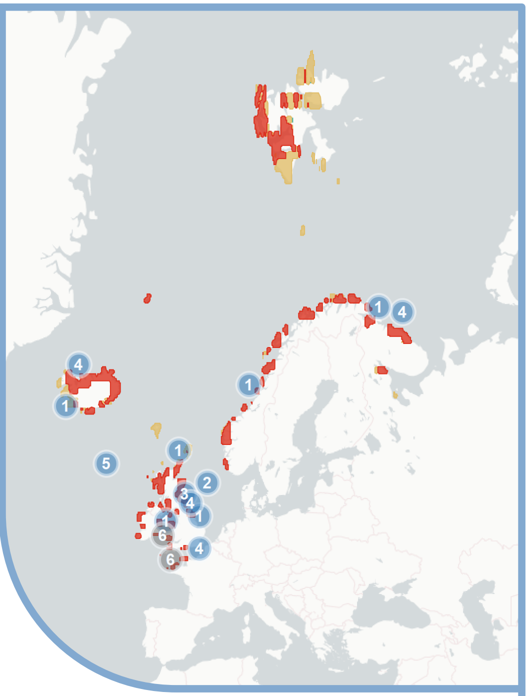
4 Atlantic Puffin (*Fratercula arctica*)



1.1 Evidence for exposure

1.1.1 Potential changes in breeding habitat suitability (by 2100):

Current breeding area that is likely to become less suitable (68% of current range).

Current breeding area that is likely to remain suitable (31%).

Current breeding area that is likely to become more suitable (1%).

1.1.2 Current impacts attributed to climate change:

1 **Negative Impact:** Changes in puffins' prey availability during breeding season has led to decreased breeding success.

2 **Negative Impact:** Changes in puffins' prey availability during non-breeding season has led to increased mortality and population declines.

3 **Negative Impact:** Changes in vegetation has led to fewer suitable puffin nest-sites.

4 **Negative Impact:** Extreme storms during the non-breeding season have led to mass-mortality of puffins ('wrecks').

5 **Neutral Impact:** Puffins have changed their wintering range.

1.1.3 Predicted changes in key prey species:

6 Key prey species are likely to decline in abundance in the Irish Sea and the English Channel.

1.1.4 Climate change impacts outside of Europe

- Some colonies in North America have changed their laying phenology, presumably in response to temperature and/or prey availability.

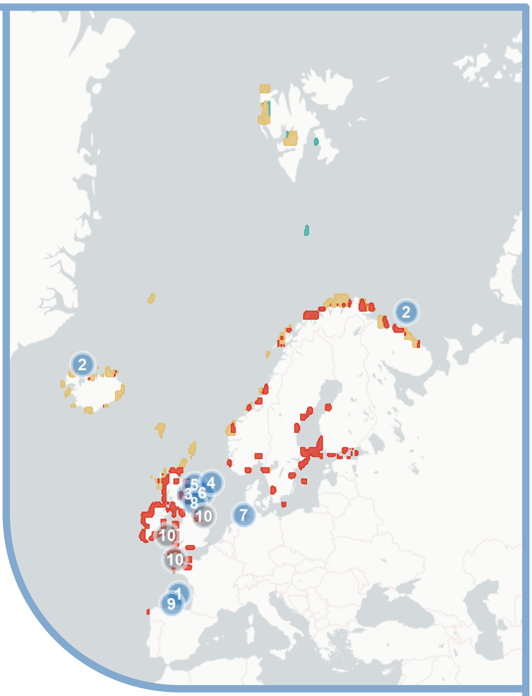
1.2 Sensitivity

- Puffins are prone to population crashes, typically either from lack of prey during the breeding season or the effects of winter storms. This makes drastic populations reductions more likely, as well as long recovery periods.
- Adult puffin survival can drop sharply when there is an increase in the frequency, duration and intensity of winter storms, most likely due to increased foraging difficulty. Note: there is conflicting evidence regarding the effect of storms on puffins. However, puffins in areas most prone to extreme weather are more likely to be severely affected.
- Puffin colony success across Europe is correlated to copepod abundance, as they support many fish populations. In recent decades many areas in the south of the north-east Atlantic have become less suitable for copepods and this trend is likely to continue in the future. A decrease or range shift in copepods will likely have severe impacts on seabird colonies in the north-east Atlantic.
- This species has a long generation length (>10 years), which may slow recovery from severe impacts and increases population extinction risk.
- Puffins are declining rapidly in many parts of Europe, which has most major populations globally. Any additional pressure from climate change is likely to accelerate these declines.

1.3 Adaptive capacity

- Puffins travel long distances and could theoretically reach areas suitable for new colonies. However, while there have been examples of puffins colonising new areas (with or without human assistance), in general they have high site fidelity and rarely colonise new areas.
- Recent observations in Iceland report that puffins have started to swap prey species at some colonies, especially where major prey species have declined. The extent of this switch and the consequences are currently unknown.
- Colonies of puffins on Farne Islands and on Isle of May are breeding later, but not in correlation to changes in sea temperature. This may be due to other environmental changes in breeding or non-breeding areas. While this shift may be adaptive, it may also result in trophic mismatch if breeding cues don’t match prey availability.

5 Common Murre *(Uria aalge)*



1.1 Evidence for exposure

1.1.1 Potential changes in breeding habitat suitability (by 2100):

Current breeding area that is likely to become less suitable (66% of current range).

Current breeding area that is likely to remain suitable (31%).

Current breeding area that is likely to become more suitable (3%).

1.1.2 Current impacts attributed to climate change:

1 **Negative Impact:** High-wind events in the non-breeding season have led to mass mortality of murres in recent years.

2 **Negative Impact:** Extreme storms during the non-breeding season have led to mass mortality of murres ('wrecks').

3 **Negative Impact:** More frequent extreme storms during murres' breeding season has increased foraging difficulty and reduced food fed to chicks.

4 **Negative Impact:** Extreme storms during murres' breeding season have led to wide-spread nest destruction, nesting failure and a net reduction in annual population production.

5 **Negative Impact:** Changes in murres' prey availability during the breeding season has led to decreased breeding success.

6 **Neutral Impact:** Murres are more likely to skip breeding in warmer weather, and this behaviour is becoming more frequent. While this is a cause for concern, it is unclear what effect this will have on the population in the long-term.

7 **Negative Impact:** Heatwaves have resulted in significant murre chick mortality. The frequency and severity of heatwaves is likely to increase.

8 **Neutral Impact:** Common murres have changed their phenology, potentially in response to climate change but the mechanism is unclear.

9 **Positive Impact:** A shift towards warmer, drier and calmer conditions has correlated with higher population abundance. Mechanism unknown, but likely mediated through prey availability and lower energetic costs.

1.1.3 Predicted changes in key prey species:

10 Key prey species are likely to decline in abundance in the Baltic, the Irish Sea and the English Channel.

1.2 Sensitivity

- Murres are prone to sporadic mass-mortality events ("wrecks"), both across Europe and in North America. The likely cause varies between wrecks, ranging from summer heatwaves, to prolonged extreme wind events in winter. Changes in extreme weather are likely to have significant effects on murre mortality.
- Murres in the Baltic are dependent on sprat as a food source and studies suggest they have limited ability to switch to other prey items. Declines in sprat due to climate change would likely have a severe impact on murres.
- Murre colony success across Europe seems to be tied to copepod abundance, as they support many fish species. In recent decades many areas in the south of the north-east Atlantic have become less suitable for copepods and this trend is likely to continue in the future. A decrease or range shift in copepods will likely have severe impacts on seabird colonies in the north-east Atlantic.
- For multiple populations, there is a strong correlation between breeding success and sea temperature in common murres; populations are negatively affected by warmer temperatures, most likely due to changes in marine ecosystems and prey availability. Projected warming is therefore likely to negatively impact many murre populations.
- This species has a long generation length (>10 years), which may slow recovery from severe impacts and increases population extinction risk.
- While most populations in Europe are stable, some are declining rapidly (notably in Iceland). Any additional pressure from climate change is likely to accelerate these declines.

1.3 Adaptive capacity

- There is evidence murres can change their phenology in response to temperature changes. Some populations have shifted their laying date in correlation with temperature changes, others have not. Other populations have changed their arrival date after migration, but not their laying date.
- There appears to be a weak genetic structure across colonies, which could be a result of high dispersal between colonies. This may increase resilience and aid population recovery following wrecks.
- In contrast to murres in the Baltic (see Sensitivity section), studies on populations in the North Sea and eastern Canada have found that murres can switch prey and spend more time at sea to compensate for changes in prey availability.

Common murres © Seppo Häkkinen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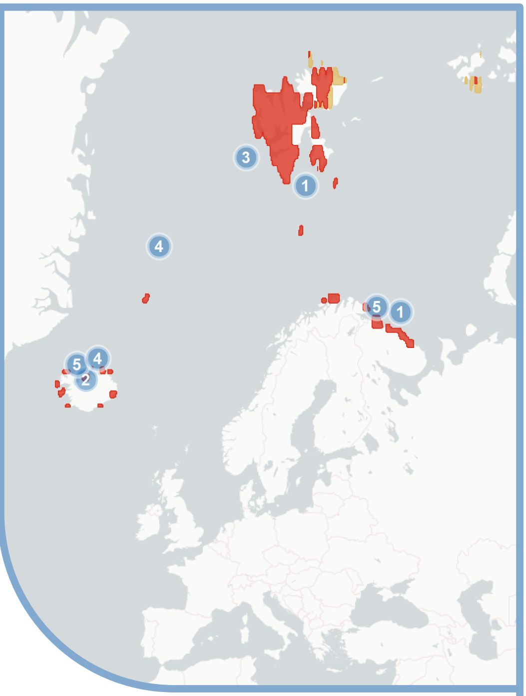
6 Thick-billed Murre (*Uria lomvia*)



1.1 Evidence for exposure

1.1.1 Potential changes in breeding habitat suitability (by 2100):

Current breeding area that is likely to become less suitable (87% of current range).

Current breeding area that is likely to remain suitable (13%).

Current breeding area that is likely to become more suitable (0%).

1.1.2 Current impacts attributed to climate change:

1 **Negative Impact:** Changes in thick-billed murres' prey availability during the non-breeding season has led to increased mortality.

2 **Negative Impact:** Changes in thick-billed murres' prey availability during the breeding season has led to decreased breeding success.

3 **Neutral Impact:** Changes in thick-billed murres' prey availability during the breeding season has led to increased mortality.

4 **Neutral Impact:** Thick-billed murre populations are typically smaller and decline in areas with increasing sea temperatures. Mechanism unclear.

5 **Neutral Impact:** Extreme storms during the non-breeding season have led to mass mortality of murres ('wrecks').

1.1.3 Predicted changes in key prey species:

No key prey species are predicted to decline for this species.

1.1.4 Climate change impacts outside of Europe:

- Thick-billed murres are known to be impacted by climate change outside of Europe. Impacts include increased predation by polar bears, increased parasitism by mosquitoes (leading to breeding failure), and increased mortality caused by algal blooms.
- Changes in the marine ecosystem in the Canadian high Arctic, driven by climate change, has resulted in higher concentrations of mercury bioaccumulated in thick-billed murres. No long-term impact on population health has been observed so far.

1.2 Sensitivity

- This species has a long generation length (>10 years), which may slow recovery from severe impacts and increases population extinction risk.

1.3 Adaptive capacity

- While a wide-roaming pelagic species, thick-billed murres have very high site fidelity. Moreover, juvenile dispersal is also very low. It is unlikely that murres will establish new colonies in response to climate change.

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Potential actions in response to climate change: Auks (Alcidae)

In this section we list and assess possible local conservation actions that could be carried out in response to identified climate change impacts. This section is not grouped by species, but by identified impacts. If an impact or action is specific to one or a few species, this information is included in the action summary or in the footnotes. Effectiveness, relevance, strength and transparency scores are based on the available evidence we collated (see Appendix 2), and therefore all statements regarding limited or a lack of evidence relate to the collated evidence base, and does not infer that no such studies exist.

1 Impact: Increase in mammal predation

Summary:
Invasive mammals are a major threat to many seabird populations, and as such there is a well-established literature on mammal exclusion, management and eradication detailing effective methods and case studies. However, there are more limited options when the mammalian predator in question is itself a conservation target, or is not easily managed. Nevertheless, for many situations there are several, well-researched, actions available that can benefit seabird populations effectively.

Intervention	Evidence of Effectiveness	R	S	T
Manage/ eradicate mammalian predators	There are numerous examples of benefits to seabirds, including auks, following mammal eradication, though this depends on the effectiveness of the methods used and the species in question. Control of rodents and mustelids are particularly well studied.	3	5	3
Physically protect nests with barriers or enclosures	Has been successfully trialled in numerous ground-nesting seabird species. However, we found no studies that look at effectiveness for any auk species.	2	4	4

Reduce predation by translocating predators	Few trials on seabirds, and only one on auks (*Synthliboramphus hypoleucus*). Existing evidence suggests this action can be beneficial and reduce egg/chick predation, and could be a possible action if other forms of predator management are not viable.	2	4	3
Repel predators with acoustic, chemical or visual deterrents	This is a hypothetical action. We found no published studies assessing this action's effectiveness for seabirds.	NA	NA	NA
Use supplementary feeding to reduce predation	Very few trials on seabirds, and none on auks. No studies have shown this action is effective.	1	4	3

Green = Likely to be beneficial. Red = Unlikely to be beneficial, may have negative impact. Orange = contradicting or uncertain evidence. Grey = Limited evidence.
R = relevance rating. **S** = strength rating. **T** = transparency rating. All ratings on a scale of 1 to 5, where 5 is the highest.

Details:

Manage/eradicate mammalian predators
Relevance (R): 6 studies in the evidence base focus on auks, 40 on other seabirds and 3 on other birds. **Strength (S):** The evidence base was comprised of 52 studies. Of these 44 were considered to have a good sample size, and 34 had a clear metric for effectiveness. **Transparency (T):** 52 studies included were published and peer-reviewed, of which 5 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 24 had a published methodology, and 28 justified their rationale.

Physically protect nests with barriers or enclosures
Relevance (R): 0 studies in the evidence base focus on auks, 12 on other seabirds and 6 on other birds. **Strength (S):** The evidence base was comprised of 18 studies. Of these 16 were considered to have a good sample size, and 12 had a

clear metric for effectiveness. **Transparency (T):** 17 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 11 had a published methodology, and 12 justified their rationale.

Reduce predation by translocating predators

Relevance (R): 1 study in the evidence base focusses on auks, 1 on other seabirds and 2 on other birds. **Strength (S):** The evidence base was comprised of 4 studies. Of these 4 were considered to have a good sample size, and 3 had a clear metric for effectiveness. **Transparency (T):** 4 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 2 had a published methodology, and 3 justified their rationale.

Use supplementary feeding to reduce predation

Relevance (R): 0 studies in the evidence base focus on auks, 1 on other seabirds and 3 on other birds. **Strength (S):** The evidence base was comprised of 4 studies. Of these 4 were considered to have a good sample size, and 4 had a clear metric for effectiveness. **Transparency (T):** 4 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 1 had a published methodology, and 4 justified their rationale.

2 Impact: Increased frequency/severity of storms (including wind, rain and wave action) increases foraging difficulty and/or mortality

Summary:

Invasive mammals are a major threat to many seabird populations, and as such there is a well-established literature on mammal exclusion, management and eradication detailing effective methods and case studies. However, there are more limited options when the mammalian predator in question is itself a conservation target, or is not easily managed. Nevertheless, for many situations there are several, well-researched, actions available that can benefit seabird populations effectively.

Intervention	Evidence of Effectiveness	R	S	T
Provide supplementary food during the breeding season	If storms affect foraging during the breeding season, it may be possible to support populations with additional food. Alternatively it may counteract the poor condition of adults after a harsh winter. Trialled on many seabird species. Limited evidence for effectiveness in auks, and all known studies are on *F. arctica*. Typically very labour intensive and difficult given the remote and inaccessible breeding colonies of auks. Likely only plausible for small populations.	3	4	3
Provide supplementary food during the non-breeding season	This is a hypothetical action. We found no published studies assessing this action's effectiveness for seabirds. It is likely to be very difficult or even impossible, especially for pelagic species.	NA	NA	NA
Rehabilitate sick or injured birds	For groups of long-lived, large birds, rehabilitation is known to be an effective way to support populations. However, examples in seabirds are scarce and the overall effectiveness for most species is unknown. Numerous rescue centres report successful rehabilitation of razorbills and murres, and some limited examples in puffins and little auks (survival rates unknown).	1	2	4

Green = Likely to be beneficial. Red = Unlikely to be beneficial, may have negative impact.
Orange = contradicting or uncertain evidence. Grey = Limited evidence.
R = relevance rating. S = strength rating. T = transparency rating. All ratings on a scale of 1 to 5, where 5 is the highest.

Details:

Provide supplementary food during the breeding season

Relevance (R): 5 studies in the evidence base focus on auks, 11 on other seabirds and 0 on other birds. **Strength (S):** The evidence base was comprised of 16 studies. Of these 10 were considered to have a good sample size, and 14 had a clear metric for effectiveness. **Transparency (T):** 16 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 13 had a published methodology, and 4 justified their rationale.

Rehabilitate sick or injured birds
Relevance (R): 0 studies in the evidence base focus on auks, 3 on other seabirds and 4 on other birds. **Strength (S):** The evidence base was comprised of 7 studies. Of these 4 were considered to have a good sample size, and 1 had a clear metric for effectiveness. **Transparency (T)**: 7 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 5 had a published methodology, and 5 justified their rationale.

3 Impact: Increased frequency/severity of storms (including wind, rain and wave action) causes nest destruction

Summary:
While there are several local actions that may prevent or mitigate local nest destruction, they have not been trialled widely, and wide-spread evidence to support their use is currently lacking. If changes in extreme weather threatens the viability of a population, then several actions are available to encourage translocation of populations to safer areas.

Intervention	Evidence of Effectiveness	R	S	T
Alter habitat to encourage birds to leave an area	Few trials on seabirds and none on auks. Several trials of this action have been successful and encouraged terns to shift breeding sites. However, this action is likely more viable for species with lower site fidelity and areas with other available breeding habitat nearby.	2	2	3

Artificially incubate or hand-rear chicks to support population	Known to be effective for some seabirds, though labour intensive and usually only appropriate for small populations. Limited evidence in auks; ex-situ populations of puffins, murres and razorbills have been hand-reared and bred, though with low success rates.	2	2	3
Install barriers to prevent flooding	While likely to prevent flooding there is currently no evidence available on this action's effectiveness in relation to seabird conservation.	NA	NA	NA
Make new colonies more attractive to encourage birds to colonise	Several actions have been trialled across auk (and other seabird) species to encourage colonisation, with variable success, including the use of decoys, acoustic cues, smells and improved habitat. The most notable success has been to use decoys to encourage *F. arctica* to colonise new areas, other actions have had variable success depending on context and species.	2	4	3
Manually relocate nests	This has been reported by practitioners as an effective action to assist seabirds on low-lying beaches in the Baltic, including auks. However, to our knowledge there are no broad-scale studies or reviews of this action's effectiveness.	NA	NA	NA
Provide additional shelter or protection from extreme weather (flooding)	In some seabird species additional protection has reduced flooding, but evidence is limited. We found no published trials on auk species.	1	3	5
Provide artificial nesting sites	Tried extensively on many seabird species with notable success in many cases. Few trials for auk species, but some limited evidence for success in *F. arctica*, *S. antiquus* and *C. monocerata*.	3	5	3

Repair/support nests to support breeding	Very limited evidence for effectiveness, but at least one case study has used this action to increase *U. aalge* breeding success.	3	5	3
Translocate the population to a more suitable breeding area	Known to be beneficial in other seabird groups, but evidence for auks is limited. At least one successful translocation of *F. arctica* has been carried out, but whether it is generally advisable is uncertain.	3	4	4

Green = Likely to be beneficial. Red = Unlikely to be beneficial, may have negative impact.
Orange = contradicting or uncertain evidence. Grey = Limited evidence.
R = relevance rating. **S** = strength rating. **T** = transparency rating. All ratings on a scale of 1 to 5, where 5 is the highest.

Details:

Alter habitat to encourage birds to leave an area
Relevance (R): 0 studies in the evidence base focus on auks, 2 on other seabirds and 0 on other birds. **Strength (S):** The evidence base was comprised of 2 studies. Of these 2 were considered to have a good sample size, and 0 had a clear metric for effectiveness. **Transparency (T):** 2 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 2 had a published methodology, and 1 justified their rationale.

Artificially incubate or hand-rear chicks to support population
Relevance (R): 6 studies in the evidence base focus on auks, 34 on other seabirds and 0 on other birds. **Strength (S):** The evidence base was comprised of 40 studies. Of these 9 were considered to have a good sample size, and 19 had a clear metric for effectiveness. **Transparency (T):** 26 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 17 had a published methodology, and 4 justified their rationale.

Make new colonies more attractive to encourage birds to colonise
Relevance (R): 1 study in the evidence base focusses on auks, 37 on other seabirds and 6 on other birds. **Strength (S):** The evidence base was comprised of 44 studies. Of these 31 were considered to have a good sample size, and 18 had a clear metric for effectiveness. **Transparency (T):** 44 studies included were published and peer-reviewed, of which 1 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 30 had a published methodology, and 22 justified their rationale.

Provide additional shelter or protection from extreme weather (flooding)
Relevance (R): 0 studies in the evidence base focus on auks, 0 on other seabirds and 1 on other birds. **Strength (S):** The evidence base was comprised of 3 studies. Of these 1 was considered to have a good sample size, and 2 had a clear metric for effectiveness. **Transparency (T):** 3 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 3 had a published methodology, and 3 justified their rationale.

Provide artificial nesting sites
Relevance (R): 4 studies in the evidence base focus on auks, 48 on other seabirds and 1 on other birds. **Strength (S):** The evidence base was comprised of 54 studies. Of these 50 were considered to have a good sample size, and 33 had a clear metric for effectiveness. **Transparency (T):** 53 studies included were published and peer-reviewed, of which 2 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 33 had a published methodology, and 27 justified their rationale.

Repair/support nests to support breeding
Relevance (R): 1 study in the evidence base focusses on auks, 1 on other seabirds and 1 on other birds. **Strength (S):** The evidence base was comprised of 3 studies. Of these 1 was considered to have a good sample size, and 1 had a clear metric for effectiveness. **Transparency (T):** 3 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 1 had a published methodology, and 3 justified their rationale.

Translocate the population to a more suitable breeding area
Relevance (R): 1 study in the evidence base focusses on auks, 14 on other seabirds and 0 on other birds. **Strength (S):** The evidence base was comprised of 15 studies. Of these 13 were considered to have a good sample size, and 9 had a clear metric for effectiveness. **Transparency (T):** 14 studies included were published and peer-reviewed, of which 1 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 11 had a published methodology, and 9 justified their rationale.

4 Impact: Increased thermal stress

Summary:
There are currently no well-researched methods to directly assist seabirds with thermal stress, and more information is needed on how thermal stress can impact seabirds and how local conservation action can mitigate these impacts. If thermal stress becomes so common or extreme that it threatens the viability of a population, then several actions are available to encourage translocation of populations to safer areas.

Intervention	Evidence of Effectiveness	R	S	T
Make new colonies more attractive to encourage birds to colonise	Several actions have been trialled across auk (and other seabird) species to encourage colonisation, with variable success, including the use of decoys, acoustic cues, smells and improved habitat. The most notable success has been to use decoys to encourage *F. arctica* to colonise new areas, other actions have had variable success depending on context and species.	3	4	3
Provide additional resources to help seabirds thermoregulate (e.g. artificial pools)	This is a hypothetical action. We found no published studies assessing this action's effectiveness for seabirds.	NA	NA	NA
Provide additional shelter or protection from extreme weather (heatwaves)	Few trials on seabirds and none on auks. Additional shelter has been shown to protect cormorants from heatwaves, but more research is needed before this action can be generally recommended.	2	3	3

Intervention	Evidence of Effectiveness	R	S	T
Translocate the population to a more suitable breeding area	Known to be beneficial in other seabird groups, but evidence for auks is limited. At least one successful translocation of *F. arctica* has been carried out, but whether it is generally advisable is uncertain.	3	4	4

Green = Likely to be beneficial. Red = Unlikely to be beneficial, may have negative impact.
Orange = contradicting or uncertain evidence. Grey = Limited evidence.
R = relevance rating. S = strength rating. T = transparency rating. All ratings on a scale of 1 to 5, where 5 is the highest.

Details:

Make new colonies more attractive to encourage birds to colonise
Relevance (R): 1 study in the evidence base focusses on auks, 37 on other seabirds and 6 on other birds. **Strength (S):** The evidence base was comprised of 44 studies. Of these 31 were considered to have a good sample size, and 18 had a clear metric for effectiveness. **Transparency (T):** 44 studies included were published and peer-reviewed, of which 1 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 30 had a published methodology, and 22 justified their rationale.

Provide additional shelter or protection from extreme weather (heatwaves)
Relevance (R): 0 studies in the evidence base focus on auks, 1 on other seabirds and 0 on other birds. **Strength (S):** The evidence base was comprised of 1 study. Of these 1 was considered to have a good sample size, and 1 had a clear metric for effectiveness. **Transparency (T):** 1 study included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 0 had a published methodology, and 1 justified their rationale.

Translocate the population to a more suitable breeding area
Relevance (R): 1 study in the evidence base focusses on auks, 14 on other seabirds and 0 on other birds. Strength (S): The evidence base was comprised of 15 studies. Of these 13 were considered to have a good sample size, and 9 had a clear metric for effectiveness. **Transparency (T):** 14 studies included were published and peer-reviewed, of which 1 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 11 had a published methodology, and 9 justified their rationale.

5 Impact: Negative changes in vegetation

Summary:
While there are limited trials on seabirds, there are several concrete examples where local management has increased productivity even in relatively large breeding populations.

Intervention	Evidence of Effectiveness	R	S	T
Remove problematic vegetation	Removing vegetation has been shown to benefit several seabird species, but the amount of evidence is limited in auks. Removal of problematic vegetation has resulted in an increase in *F. arctica* breeding success at several sites in Scotland.	2	4	4

Green = Likely to be beneficial. Red = Unlikely to be beneficial, may have negative impact.
Orange = contradicting or uncertain evidence. Grey = Limited evidence.
R = relevance rating. **S** = strength rating. **T** = transparency rating. All ratings on a scale of 1 to 5, where 5 is the highest.

Details:

Remove problematic vegetation
Relevance (R): 2 studies in the evidence base focus on auks, 9 on other seabirds and 5 on other birds. **Strength (S):** The evidence base was comprised of 16 studies. Of these 12 were considered to have a good sample size, and 9 had a clear metric for effectiveness. **Transparency (T):** 16 studies included were published and peer-reviewed, of which 1 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 13 had a published methodology, and 13 justified their rationale.

6 Impact: Reduced prey availability during breeding season

Summary:
Several local actions may assist breeding populations on a small scale, but direct intervention on a large scale is likely to be extremely difficult. General conservation actions to protect fish stocks and local marine areas may be the most effective method. If a population is likely to suffer major losses, even with conservation help, then translocations could be considered.

Intervention	Evidence of Effectiveness	R	S	T
Artificially incubate or hand-rear chicks to support population	Known to be effective for some seabirds, though labour intensive and usually only appropriate for small populations. Limited evidence in auks; ex-situ populations of puffins, murres and razorbills have been hand-reared and bred, though with low success rates.	2	2	3
Make new colonies more attractive to encourage birds to colonise	Several actions have been trialled across auk (and other seabird) species to encourage colonisation, with variable success, including the use of decoys, acoustic cues, smells and improved habitat. The most notable success has been to use decoys to encourage *F. arctica* to colonise new areas, other actions have had variable success depending on context and species.	2	4	3
Provide supplementary food during the breeding season	Trialled on many seabird species. Limited evidence for effectiveness in auks, and all known studies are on *F. arctica*. Typically very labour intensive and difficult given the remote and inaccessible breeding colonies of auks. Likely only plausible for small populations.	3	4	3
Translocate the population to a more suitable breeding area	Known to be beneficial in other seabird groups, but evidence for auks is limited. At least one successful translocation of *F. arctica* has been carried out, but whether it is generally advisable is uncertain.	3	4	4

Green = Likely to be beneficial. Red = Unlikely to be beneficial, may have negative impact.
Orange = contradicting or uncertain evidence. Grey = Limited evidence.
R = relevance rating. S = strength rating. T = transparency rating. All ratings on a scale of 1 to 5, where 5 is the highest.

Details:

Artificially incubate or hand-rear chicks to support population
Relevance (R): 6 studies in the evidence base focus on auks, 34 on other seabirds and 0 on other birds. Strength (S): The evidence base was comprised of 40 studies. Of these 9 were considered to have a good sample size, and 19 had a clear metric for effectiveness. Transparency (T): 26 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 17 had a published methodology, and 4 justified their rationale.

Make new colonies more attractive to encourage birds to colonise
Relevance (R): 1 study in the evidence base focusses on auks, 37 on other seabirds and 6 on other birds. Strength (S): The evidence base was comprised of 44 studies. Of these 31 were considered to have a good sample size, and 18 had a clear metric for effectiveness. Transparency (T): 44 studies included were published and peer-reviewed, of which 1 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 30 had a published methodology, and 22 justified their rationale.

Provide supplementary food during the breeding season
Relevance (R): 5 studies in the evidence base focus on auks, 11 on other seabirds and 0 on other birds. Strength (S): The evidence base was comprised of 16 studies. Of these 10 were considered to have a good sample size, and 14 had a clear metric for effectiveness. Transparency (T): 16 studies included were published and peer-reviewed, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 13 had a published methodology, and 4 justified their rationale.

Translocate the population to a more suitable breeding area
Relevance (R): 1 study in the evidence base focusses on auks, 14 on other seabirds and 0 on other birds. Strength (S): The evidence base was comprised of 15 studies. Of these 13 were considered to have a good sample size, and 9 had a clear metric for effectiveness. Transparency (T): 14 studies included were published and peer-reviewed, of which 1 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 11 had a published methodology, and 9 justified their rationale.

7 Impact: Reduced prey availability during non-breeding season

Summary:
In pelagic species, local intervention to assist populations is likely to be difficult or impossible. General conservation actions to preserve fish stocks and protect marine areas are likely the most effective conservation actions available.

Intervention	Evidence of Effectiveness	R	S	T
Further protections at sea	Additional regulation to protect seabirds at sea can directly and indirectly benefit many seabird species, and limit the impact of climate change.	1	3	3

Green = Likely to be beneficial. Red = Unlikely to be beneficial, may have negative impact. Orange = contradicting or uncertain evidence. Grey = Limited evidence.
R = relevance rating. **S** = strength rating. **T** = transparency rating. All ratings on a scale of 1 to 5, where 5 is the highest.

Details:

Further protections at sea
Relevance (R): 0 studies in the evidence base focus on auks, 1 on other seabirds and 8 on other birds. **Strength (S):** The evidence base was comprised of 9 studies. Of these 7 were considered to have a good sample size, and 3 had a clear metric for effectiveness. **Transparency (T):** 9 studies included were published and peer-reviewed, of which 2 were literature reviews or meta-analyses, 0 were from the grey literature, and 0 were anecdotal. Of the studies included, 3 had a published methodology, and 6 justified their rationale.

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