

Expert Elicitation on demographic consequences of seabird compensatory measures

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27 Abstract

- 28 1. Protected seabirds present a serious constraint to offshore renewable energy expansion due to
29 potential effects of displacement from habitat, barrier effects to movements, and collisions with
30 turbine blades. The process of delivering compensatory measures to offset offshore wind (OW)
31 impacts on seabirds is underway as deployments increase in scale and pace, driving cumulative
32 impacts to become more severe. A range of ornithological compensatory measures have been
33 proposed to offset impacts. However, wide uncertainty remains around the appropriateness of
34 measures for different species, and in the magnitude of potential demographic and population
35 benefits. Available empirical data for quantifying demographic consequences for compensatory
36 measures is often limited to a single population, or lacking completely for some species.
- 37 2. To address this evidence gap we undertook an expert elicitation to estimate potential effectiveness
38 of different compensatory measures for a suite of seabird species representing a significant
39 proportion of UK North Sea breeding populations.
- 40 3. Experts identified 14 compensatory measures with potential for positively affecting seabird
41 population demography in seven species or groups in the UK context: black-legged kittiwake,
42 common guillemot, Atlantic puffin, razorbill, northern gannet, large gulls (herring gull, lesser black-
43 backed, great black-backed) and terns (arctic, common, sandwich).
- 44 4. Experts ranked the 14 measures for each species, extracted a set of highly ranked measures, and
45 elicited potential changes to breeding success and adult survival. We captured experts' uncertainty
46 in potential demographic consequences via eliciting a distribution for each demographic parameter
47 through the quantification of statistical parameters.
- 48 5. Despite recognising considerable uncertainty in their estimates, the experts identified a suite of
49 measures with potential to improve seabird breeding success and adult survival. However, experts
50 also raised important challenges with successful implementation of compensatory measures for
51 seabirds, including both practical, ecological and ethical considerations.

52 **Solution:** We provide species-specific summaries of expert-elicited demographic gains of alternative
53 compensatory measures for seabirds. Our elicitation provides a defensible and transparent base that can
54 be used and updated to inform comparative assessments of different measures. We provide
55 recommendations for the development of statutory guidance for successful selection and implementation
56 of measures for seabirds, highlighting specific challenges and knowledge gaps.

57 **Keywords:** artificial nesting, breeding success, compensation, demography, offshore wind, ornithology,
58 survival

59 **Author contributions:** KS led conception and writing, review and editing. AB and AF led study design, and
60 contributed to conceptualisation and writing. MB, FD, AF, RF, TKR and ES served as experts during the
61 elicitation, and contributed to writing. FD, KS and AB contributed to funding acquisition.

62 **Data availability statement:** data underpinning the expert elicitation is available through the EIDC
63 (Frantsuzova, A.; Butler, A.; Searle, K.; Bogdanova, M.; Daunt, F.; Fayet, A.L.; Furness, R.; Reiertsen, T.K.;
64 Skeate, E. (2026). **Demographic consequences of potential seabird compensatory measures relating to**
65 **protected breeding populations in the North Sea, UK, from an expert elicitation exercise.** NERC EDS
66 Environmental Information Data Centre. <https://doi.org/10.5285/8847e78c-8778-474b-b2a2-3931beeb0e1b>)
67

68 Introduction

69 There is widespread concern that the expansion of offshore wind (OW) developments around the globe will
70 have detrimental effects on protected wildlife (Welcker et al. 2016, Harris et al. 2025, Hooker et al. 2025).
71 These developments have the potential to affect protected wildlife by displacement from important
72 habitat, barrier effects to movements, collisions with turbine blades, noise effects and other factors
73 (Dierschke et al. 2016, Welcker et al. 2016, Thompson et al. 2020, Davies et al. 2024, Thaxter et al. 2024).
74 Different countries have planning and assessment processes aimed at minimising these impacts when
75 delivering their development targets. However, challenges have arisen because potential effects remain in
76 spite of a suite of avoidance and mitigation measures (Perrow 2019, Watson et al. 2025). A solution
77 adopted by a number of countries that allows consenting of offshore wind farms where potential effects
78 remain, while also safeguarding wildlife, is through the delivery of compensatory measures that offset
79 wildlife effects (Croll et al. 2022). However, delivering compensation at the level required to fully offset
80 predicted impacts is proving challenging, in large part because of the lack of empirical evidence of the
81 effectiveness of proposed measures (McGregor et al. 2022).

82 At the forefront of delivering on this challenge is the case of cumulative impacts of OW expansion on
83 seabirds in the North Sea, which have resulted in serious consenting risk, particularly in UK waters. Along
84 with other countries bordering the North Sea, the UK has in place an assessment process whereby
85 developments predicted to have an adverse effect on the integrity of a protected wildlife site may still be
86 approved if compensatory measures can be secured that offset these effects on the site network
87 (specifically, Habitats Regulations and devolved legislation allow for a 'derogation' where there are
88 'imperative reasons of overriding public interest' (IROPI) for the project to proceed (Defra, 2021). The rapid
89 expansion and scale of deployment of OW has resulted in 'real-world difficulties' in identifying and
90 delivering suitable compensatory measures that directly benefit the seabird species impacted by an OW
91 development (Defra 2025; Scottish Gov 2025). As a result, the availability of compensatory measures is one
92 of the key barriers to the OW planning and consenting process (Defra 2025). The length of time taken to
93 agree compensatory measures, which are often difficult to deliver on a project-by-project basis, can
94 therefore delay the progress of OW projects through the planning and consenting process (Defra 2025).
95 New legislation and associated regulations have recently been introduced which explicitly allow flexibility in
96 the design and delivery of environmental compensation, including provision for measures that may operate
97 through wider ecosystem-level gains (Energy Act, 2023; The Environmental Compensatory Measures
98 Reforms Statutory Instrument 2026). This flexibility is intended to enable more strategic and effective
99 compensation where direct replacement of impacted features is not feasible. However, significant
100 challenges in securing and delivering ornithological compensation remain.

101 In response to these challenges, the UK and devolved governments are developing a library of strategic
102 compensatory measures for seabirds¹. At the time of writing, these include predator reduction (UK and
103 devolved government) offshore artificial nesting structures applicable to only a single species (black-legged
104 kittiwakes; UK government), and ending of the Gannet harvest at Sula Sgeir, fishery closure or enhanced
105 management of prey fisheries, bycatch mitigation in longline fisheries and reduction of disturbance at
106 colonies (Scottish government; Tapia-Harris & Evans, 2024). A number of these measures have been taken
107 forward by developments in delivering their compensation needs, but the requirement for a wider library is
108 becoming urgent as cumulative effects of OW developments become more acute. However, the lack of
109 alternative measures is in large part driven by the current paucity of empirical evidence for accrued
110 benefits to seabird demographic rates, either directly or indirectly (Furness, 2021, McGregor et al. 2022,
111 Tapia-Harris and Evans, 2025).

¹ <https://www.gov.uk/guidance/offshore-wind-development-library-of-strategic-compensatory-measures>

112 To address this lack of evidence, we undertook an expert elicitation to determine the likely effectiveness of
 113 different compensatory measures on a range of UK seabird species. Expert elicitation is a process of
 114 obtaining expert knowledge on an uncertain quantity of interest and representing it quantitatively, for
 115 example, as an interval or a probability distribution (Oakley and O’Hagan 2010). The experts quantified
 116 potential demographic impacts of these measures on seabirds, as well as uncertainty about these impacts.
 117 Experts first identified compensatory measures for seabirds with the potential for positively affecting the
 118 population demography (breeding success and adult survival) of seven seabird species/groups: black-legged
 119 kittiwake – *Rissa tridactyla*, common guillemot - *Uria aalge*, Atlantic puffin - *Fratercula arctica*, razorbill -
 120 *Alca torda*, northern gannet - *Morus bassanus*, large gulls (herring gull - *Larus argentatus*, lesser black-
 121 backed - *Larus fuscus*, great back-backed - *Larus marinus*) and terns (arctic - *Sterna paradisaea*, common -
 122 *Sterna hirundo*, sandwich - *Thalasseus sandvicensis*). Each measure was selected by experts as having likely
 123 relevance to at least one of the species under consideration, broadly meaning that they would be likely to
 124 have some positive benefit if applied in an appropriate location in a suitable way. The experts then ranked
 125 the measures for each species and extracted a subset of measures that were highly ranked to provide a
 126 suite of potential compensatory measures most likely to result in a substantive positive benefit. Finally,
 127 experts elicited expected changes to seabird breeding success and adult survival for the suite of
 128 compensatory measures identified as relevant for each species. We captured experts’ uncertainty in
 129 potential demographic consequences via eliciting a distribution for each demographic parameter (breeding
 130 success and adult survival) through the quantification of statistical parameters (median values, inter-
 131 quartiles, and upper and lower limits). These are generally more straightforward for experts to understand
 132 and elicit reliably than parameters such as the mean or standard deviation (O’ Hagan, 2019).

133 We conclude by providing a set of recommendations for the implementation of compensatory measures
 134 for seabirds, and their use in population modelling approaches to estimate the magnitude of potential
 135 offsetting for demographic losses arising from anthropogenic impacts such as offshore renewable energy
 136 developments.

137 **Materials and Methods**

138 We conducted an expert elicitation to identify potential compensatory measures for seabirds affected by
 139 anthropogenic activities that result in a decline in population breeding success or survival. Six experts were
 140 selected on the basis of their recognised scientific contributions to the field of marine ornithology and their
 141 experience in conducting research into seabird demographic responses to a range of environmental and
 142 anthropogenic pressures. The experts were selected to include a range of individuals spanning career
 143 stages, gender, and geographical spread including both UK and non-UK experts; however, all six experts
 144 had experience in seabird research in the North Sea. The expert elicitation, which involved four online
 145 workshops between 2nd and 17th March 2023, aimed to:

- 146 1. identify species-specific lists of potential compensatory measures likely to provide benefit to
 147 seabird populations breeding in the UK that comprise protected populations under national and
 148 international legislation by generating an increase in breeding success and/or adult survival, and
 149 then
- 150 2. elicit quantitative estimates, with uncertainty, for the change in population level average breeding
 151 success or adult survival arising for each species for each of these measures. Exact definitions of the
 152 quantities being elicited were finalised by the experts as part of the elicitation.

153 We used the Sheffield Elicitation Framework (SHELF), an expert elicitation procedure to reach a group
 154 consensus about an unknown quantity of interest, and the uncertainty associated with this, developed by
 155 Oakley and O’Hagan (2010) which incorporates a structured feedback and consolidation routine.

156 *Identification and ranking of compensatory measures by species or species groups*

157 The first workshop focused on the facilitators setting the scene for the experts and ensuring questions
158 about the process were addressed, including the aims of the elicitation process and the wider context in
159 which the results would be placed. The experts then discussed and agreed upon which seabird species and
160 compensatory measures to consider in forthcoming workshops, aggregating species into groupings where
161 they felt that two or more species would respond similarly to an intervention based on their close
162 relatedness. Finally, experts completed a ranking of these measures for each species or species group, and
163 discussed these selections and rankings to produce a shorter list of measures that were collectively
164 regarded as having substantive potential to be successful for each species.

165 *Definitions of quantities of interest*

166 The second workshop focused on discussing and agreeing exact wording for each elicitation question, to
167 ensure all experts shared a common understanding of the biological scope and probabilistic definition of
168 each question. The definitions focused on the potential change in breeding success (number of chicks
169 reared per nest, population level average, %) and adult survival (population level average, %) arising from
170 the application of a specific compensatory measure for a population (hereafter 'colony') of interest. Experts
171 split definitions across measures implemented at existing colonies (e.g., removal of predators) from those
172 implemented via newly created colonies (e.g., creation of new nesting habitat). Elicited quantities for a
173 compensatory measure implemented at an existing colony was defined by the experts, following
174 discussion, as: "*The difference between the demographic rate for a colony at which the measure is*
175 *implemented and the demographic rate at the same colony if this measure were not implemented*". Elicited
176 quantities for a compensatory measure implemented at newly established or occupied colonies was
177 defined by the experts as: "*The difference between the demographic rate for a colony at which the measure*
178 *is implemented and the demographic rate for the natural colony (or colonies) for which it is designed to*
179 *compensate*". In each case, a positive impact implies that the demographic rates are higher with the
180 measure than without it. Similarly, a negative impact implies that the demographic rates are *lower* with the
181 measure than without it.

182 After biological definitions for the quantities of interest had been agreed, the facilitators presented on the
183 definition of probability including examples of probabilistic judgements not related to the quantities of
184 interest, and encouraged discussion amongst the experts in relation to which probabilistic quantities the
185 experts felt would be appropriate to use. Experts decided to elicit the following probabilistic quantities for
186 each of the metrics relating to changes in breeding success and adult survival:

- 187 • Plausible range (L and U): extremely unlikely (but not impossible) to be above/below these limits
- 188 • Median (M): Equally likely the value is below/above M
- 189 • Lower Quartile (Q1): Equally likely the value is between L and Q1 or between Q1 and M
- 190 • Upper Quartile (Q3): Equally likely the value is between M and Q3 or between Q3 and U

191 (Full details of the expert elicitation methodology and workshops is in Supplementary Material S1;
192 summary spreadsheet provided to experts for use in elicitation is provided in Supplementary Material S2).

193 Importantly, the question of 'uncertainty' versus 'variability' was discussed by the experts in relation to
194 their estimation of the above five metrics. Uncertainty was taken to mean an accounting for a lack of
195 precise knowledge regarding the likely true value of metrics for alternative measures. Variability, in
196 contrast, was taken to reflect variation in outcomes from applying a measure in different situational
197 contexts (e.g., at different breeding colonies with different geographical, environmental or ecological
198 characteristics). Experts decided that their estimates for these five metrics should include both their
199 uncertainty in the true value (uncertainty), as well as their assessment for how situational context could
200 alter the effectiveness of measures when applied in different appropriate, but variable locations

(variability). Hereafter, we refer to experts' 'uncertainty' in their estimates as capturing both inherent uncertainty regarding true values for changes in seabird demography arising from alternative measures, and to situational variability in likely responses of seabird demography to application of alternative measures in different suitable, but varying locations. In addition, experts decided that when providing their judgements, they would not consider how easy or difficult the measure would be to put in place (e.g., practical feasibility), but rather provided judgements for its effectiveness, given that it had been implemented. Experts did, however, assume that the measure being considered was utilised in an appropriate location, such that it targeted an element that was known to be currently limiting or regulating the population.

Results

Compensatory measures carried forward to elicitation on demographic gains

Experts identified and ranked 14 compensatory measures for each species (Table A2). The experts decided not to include four of the 14 measures in the subsequent elicitation of potential demographic gains due to either existing or ongoing direct empirical evidence gathering meaning that they felt an expert elicitation for the measures was not appropriate at the time of study (Fisheries management - bycatch, Fisheries management - forage fisheries closures, Altering control measures (gulls), and Cessation of harvesting of the species (gannet)). The remaining ten compensatory measures were then discussed in more detail by the experts to develop final, precise definitions for each species for elicitation of demographic gains in breeding success and adult survival. This resulted in sixteen specific measures across the suite of seabird species for the remaining ten proposed compensatory measures, with some additional variations depending on species context (Table 1). The experts also decided to group some of the original 11 species into species groups based on their close relatedness and therefore likely similar demographic response, so that seven species or species groups were considered within the elicitation: black-legged kittiwake, common guillemot, Atlantic puffin, razorbill, northern gannet, large gulls (herring gull, lesser black-backed, great black-backed) and terns (arctic, common, sandwich). Finally, to limit the elicitation exercise to an achievable set of quantities for estimation, the experts then agreed to only elicit demographic gains in breeding success and adult survival for compensatory measures in which the average rank across all six experts was lower than seven (Table A2), resulting in a total set of 44 compensatory measures by species/species group (Table 1). This was intended to limit the burden on experts and allow sufficient time for careful elicitation of the selected quantities, consistent with recommendations that the number of quantities subjected to full elicitation should be limited (O'Hagan, 2019).

Table 1. Set of definitions for the sixteen compensatory measures agreed upon for elicitation of demographic gains by the experts. 'Colony type' denotes whether the measure is to be applied at an existing, established seabird breeding colony (Existing), or at a newly established or colonised seabird breeding colony. 'Relevant species' lists the species or species groups for which each of the measures was considered to be relevant, and for which demographic gains in breeding success and/or adult survival were be elicited.

Compensatory measure description	Colony type	Relevant species
Removing existing fishing gear, preventing new fishing gear entering marine environment, rescuing chicks from entanglement in nets from all habitat used by the colony	Existing	Gannet
Artificial structure creation - in a new site or next to the existing colony - and attraction to the structure	Newly created or colonised	Terns, kittiwake

Attraction into existing habitat	Newly created or colonised	Terns, puffin
Protection from ground predators at nesting habitat (e.g., wardening, electric fences)	Existing	Terns
Vegetation management of nesting habitat (e.g., removal of bracken)	Existing	Terns, gulls, puffin
Additional conservation designation of protected areas in urban areas	Existing	Gulls
Culling, diversionary feeding and deterrence of aerial predators at the breeding colony	Existing	Puffin, guillemot, gulls, razorbill
Eradication of mammalian predators from breeding colonies (e.g., rats)	Existing	Puffin, guillemot, gulls, razorbill
Minimising human disturbance at the breeding colony (e.g., limiting access of people close to nests: regulate numbers and implement buffer zones)	Existing	Terns, puffin, guillemot, gulls, razorbill, kittiwake
Limiting shipping traffic within year-round foraging areas and in core areas of swimming migration	Existing	Terns, puffin, gannet, razorbill, guillemot
Regulating human activity in the marine environment occurring too close to colonies (e.g., tourist boats, helicopters, drones, jet skis)	Existing	Terns, puffin, gannet, razorbill, guillemot
Delivering food directly to the nest	Existing	Kittiwake, puffin
Delivering food on the ground at the breeding colony	Existing	Gulls
Delivering offal from fishing vessels to within over-wintering areas - offal is a fishing industry product that would otherwise be wasted	Existing	Gannet, kittiwake, gulls
Dropping a zero-discard policy and allowing fishers to discard in areas that birds use in the non-breeding season	Existing	Gannet, kittiwake, gulls
Creating seagrass habitat within the foraging range of a breeding colony – to increase abundance of larval fish or herring	Existing	Terns

238

239 *Elicitation on demographic gains in breeding success and adult survival*

240 Here, we report on the individual expert's results for each of the identified measures for each of the seven
241 species or species groups. These results represent the individual judgements, after discussion of
242 anonymized results. Although all six experts were involved in workshop discussions, only five of the six
243 experts were able to complete the full elicitation of probabilistic judgements for all species by measure by
244 demographic rate combinations. Full details for all 88 species-measures combinations for each of the five
245 experts are available in a published dataset (EIDC dataset: Frantsuzova et al. 2026).

246 ***Species level summaries of main findings***

247 Many impact assessment methodologies focus on individual species. Therefore, we summarise results from
248 the elicitation in relation to each of the seabird species or species groups examined, condensing results to
249 provide a synthesis of the potential effectiveness of the measures considered by experts as those most
250 likely to result in demographic gains. A fuller treatment of all results per compensatory measure and
251 species is provided in Supplementary Material (Section S3).

252 To help illustrate interpretation of the experts' elicited changes in adult survival for subsequent population
253 gains, we have derived simplistic predictions using matrix population algebra for how population size would
254 change over a 30-year period under assumed increases in adult survival. These calculations took species-
255 level breeding success and adult survival rates from a UK review (Horswill and Robinson 2015), and applied
256 these within matrix population calculations (assuming no demographic or environmental stochasticity, and

no density-dependence in demographic rates) to estimate species-level growth rates assuming no change in baseline demography, versus those resulting from a 0.25% (e.g., one quarter of one percent), 0.5% and 1.0% increase in adult survival. These calculations show that over a 30-year period assuming a 0.25% increase in adult survival resulted in population sizes that were approximately 4% greater than those assuming no change to baseline adult survival rate, a corresponding population size increase of around 8-9% for a 0.5% increase in adult survival, and an increase of approximately 16-19% in population size for a 1% increase in adult survival. We use this illustration of potential gains in population size as an aid in interpretation of potential benefits from alternative compensatory measures influencing adult survival, focusing primarily on measures that were estimated by experts to have at least a 1% increase in adult survival. However, we also highlight measures that were predicted to have a 0.25%-0.5% increase in adult survival, as the above illustration suggests that even a seemingly small increase in adult survival may result in potentially non-trivial effects on population size over the lifespan of an offshore wind farm.

Tern species

The experts' rankings of identified measures showed the greatest support for predator management as the measure most likely to result in positive demographic gains, followed by largely equal support for both management of nesting habitat and for forage fisheries closures. The rankings also revealed some support for other measures, including reducing disturbance in the marine habitat around breeding colonies, wider habitat restoration or creation, reducing marine pollution and supplementary feeding direct to the colony (with relative rankings varying across the three species).

The elicitation of potential demographic gains revealed that experts considered that tern breeding success would most positively benefit from protection from ground predators, followed by vegetation management and artificial structure creation or attraction into existing habitat. There was considerable variation across experts in their estimates for how these measures may result in positive changes to tern breeding success, with most experts estimating relatively modest increases of around 0.2-0.3 fledged chicks per nest (median values), although for some measures the experts' medians were as high as 0.5 or 0.6 additional fledged chicks per nest. The experts also exhibited high uncertainty around the likely positive benefits to tern breeding success, reflected in wide quartiles and ranges for all measures. Fewer measures for terns were considered by experts as likely to result in positive gains for adult survival. Only two measures were considered by experts to potentially result in more than a 1% increase in adult survival—protection from ground predators and seagrass habitat creation, with more consensus among experts for protection from predators. The remaining six measures did all include median estimates from at least some experts of around a potential 0.5-1.0% increase in adult survival, suggesting more moderate potential gains to populations. However, notably, all eight of the measures considered for terns were estimated by experts to have the potential for decreases in adult survival, represented by negative lower bounds from at least one of the experts for all measures, by negative lower quartiles from at least one expert for six of the eight measures, and by a negative median estimate by at least one expert for half of the measures considered (Figure 1).

In summary, both the experts' rankings and estimates for potential demographic gains revealed that broadly there were four measures thought most likely to result in positive changes for the three tern species—predator control, vegetation management, artificial structure creation and attraction into existing habitat, with gains most likely derived from increases in breeding success rather than positive changes in adult survival.

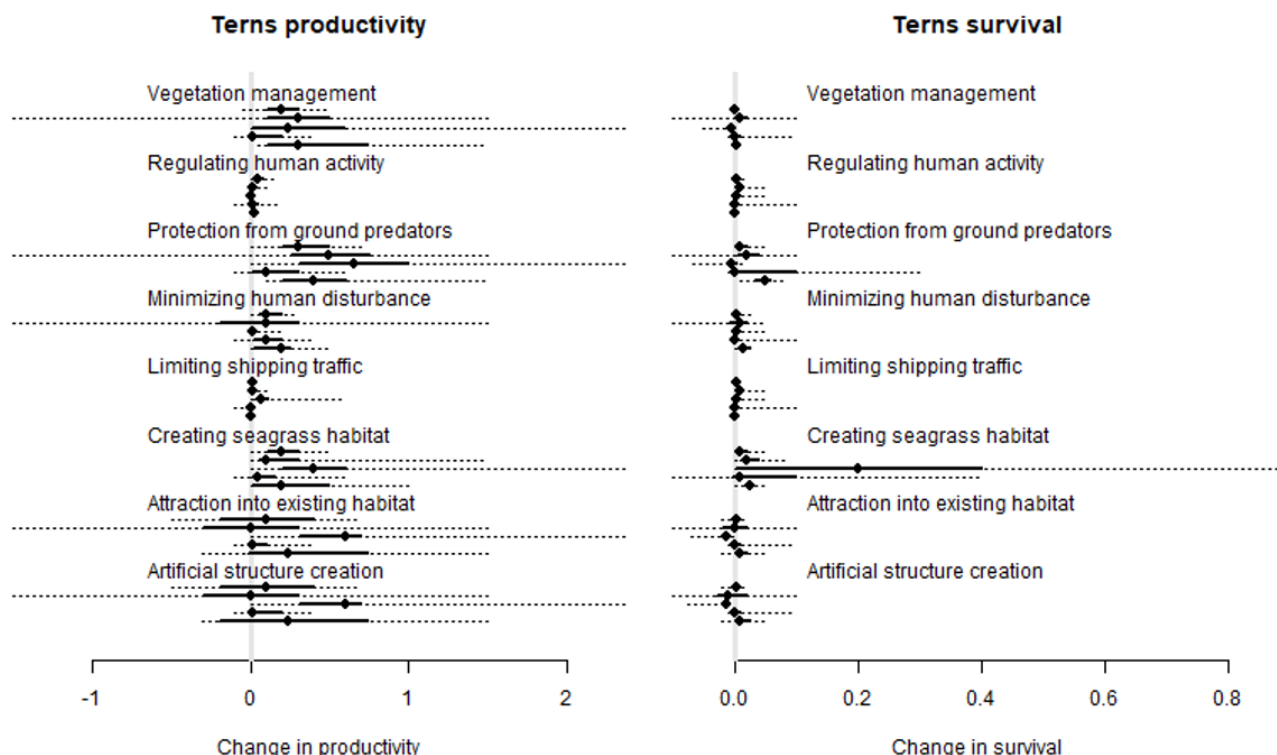


Figure 1. Probabilistic judgements elicited from five experts on the potential demographic gains arising from application of eight alternative compensatory measures for three grouped tern species (common, arctic and sandwich terns). Each probabilistic judgement is depicted by each expert's value for the median (circle), upper and lower quartiles (thick line), and upper and lower limits (thin dotted line).

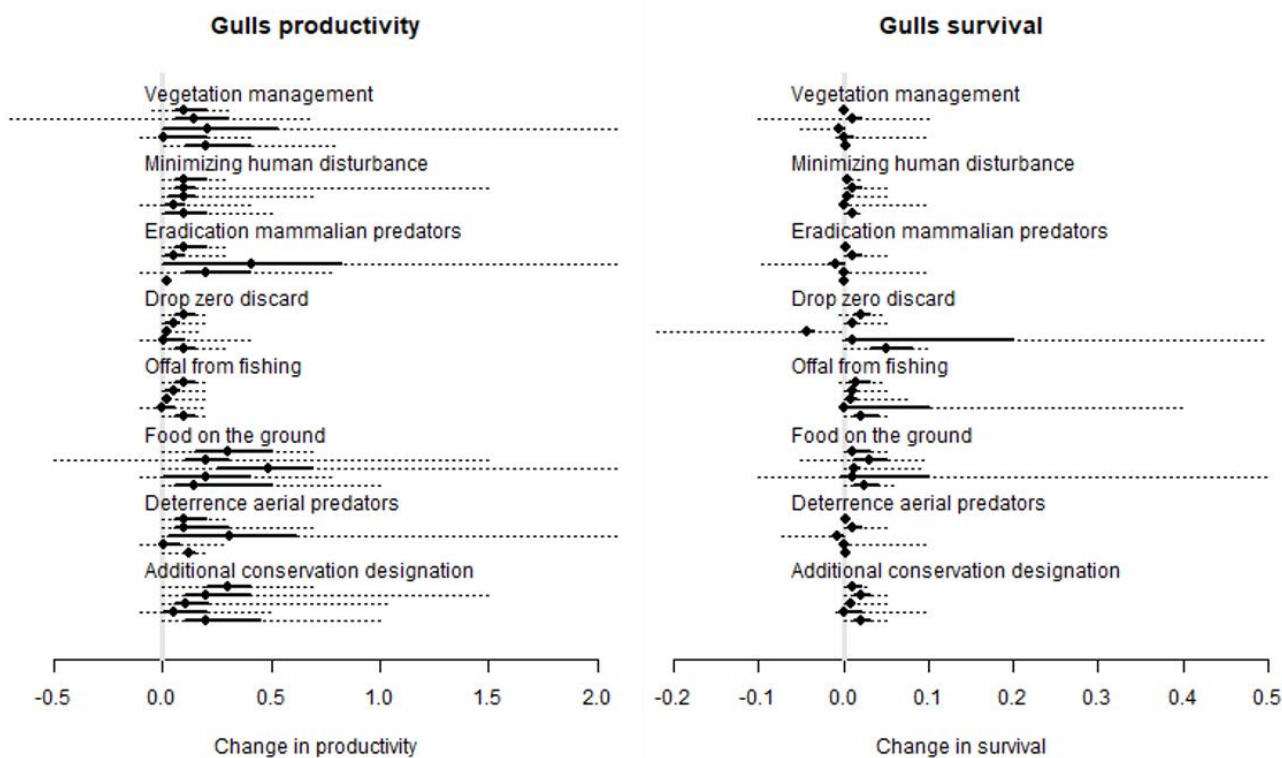
Large gull species

Relative rankings of potential measures varied depending on the large gull species in consideration, however broadly there were three measures ranked consistently highly by the experts—closure of forage fisheries, predator management, and reducing disturbance at colonies. A further three measures also received high rankings across the experts—nesting habitat management, supplementary feeding via discards or offal, and altering control measures (gull control licences). A range of other measures were also ranked relatively highly by the experts, including reduction of bycatch, supplementary feeding direct to the colony, and reducing marine pollution.

Experts generally assigned relatively low potential gains in the number of additional chicks per nest for the measures considered, with the highest potential increases assigned to four measures—supplementary feeding at the colony, deterrence of aerial predators, additional conservation designation, and vegetation management. Potential gains from these measures were estimated to be around 0.1-0.3 additional chicks fledged per nest (median values), with considerable variation across experts in quartiles and ranges suggesting relatively high uncertainty in realised benefits. Additional conservation designation was also identified by experts as having the potential to deliver increases in adult survival of around 0-2% (median values). Three other measures received estimates indicating relatively large positive increases in adult survival, including dropping the zero-discard policy (1-5% increase), delivering offal from fishing (1-2% increase) and providing food on the ground at the colony (1-3% increase). There was, however, strong uncertainty within and among experts in how these measures could result in changes to adult survival, indicated by wide quartile ranges and upper and lower bounds. Additional conservation designation of protected areas in urban areas was also estimated to lead to potential gains in adult survival of 1-2% by at least of the experts, whilst the remaining measures all received at least one expert estimate of a potential gain in adult survival of 1%, but with high variation in median estimates across experts (Figure 2).

327 Importantly, all eight of the measures considered for large gulls were estimated by experts to have the
 328 potential for decreases in adult survival, represented by negative lower bounds from at least one of the
 329 experts for all measures, by negative lower quartiles from at least one expert for six of the eight measures,
 330 and by a negative median estimate by at least one expert for half of the measures considered (Figure 2).

331 In summary, for large gulls, the elicitation revealed that a relatively wide range of measures may be
 332 effective in delivering demographic gains in these species, with different measures resulting in positive
 333 gains for breeding success than for adult survival. Various measures for supplementary feeding and
 334 predator control received generally consistently positive estimates across the experts, as did additional
 335 conservation designation. Notably, measures that were the most contentious across experts such as
 336 altering the zero-discard policy or provisioning of offal from fisheries, were estimated to potentially provide
 337 some of the greatest gains in breeding success or adult survival, adding to the complexity of selecting
 338 appropriate measures in these species.



339
 340 *Figure 2. Probabilistic judgements elicited from five experts on the potential demographic gains arising from*
 341 *application of eight alternative compensatory measures for three grouped gull species (Herring, Lesser black-*
 342 *backed, Great black-backed gull). Each probabilistic judgement is depicted by each expert's value for the median*
 343 *(circle), upper and lower quartiles (thick line), and upper and lower limits (thin dotted line).*

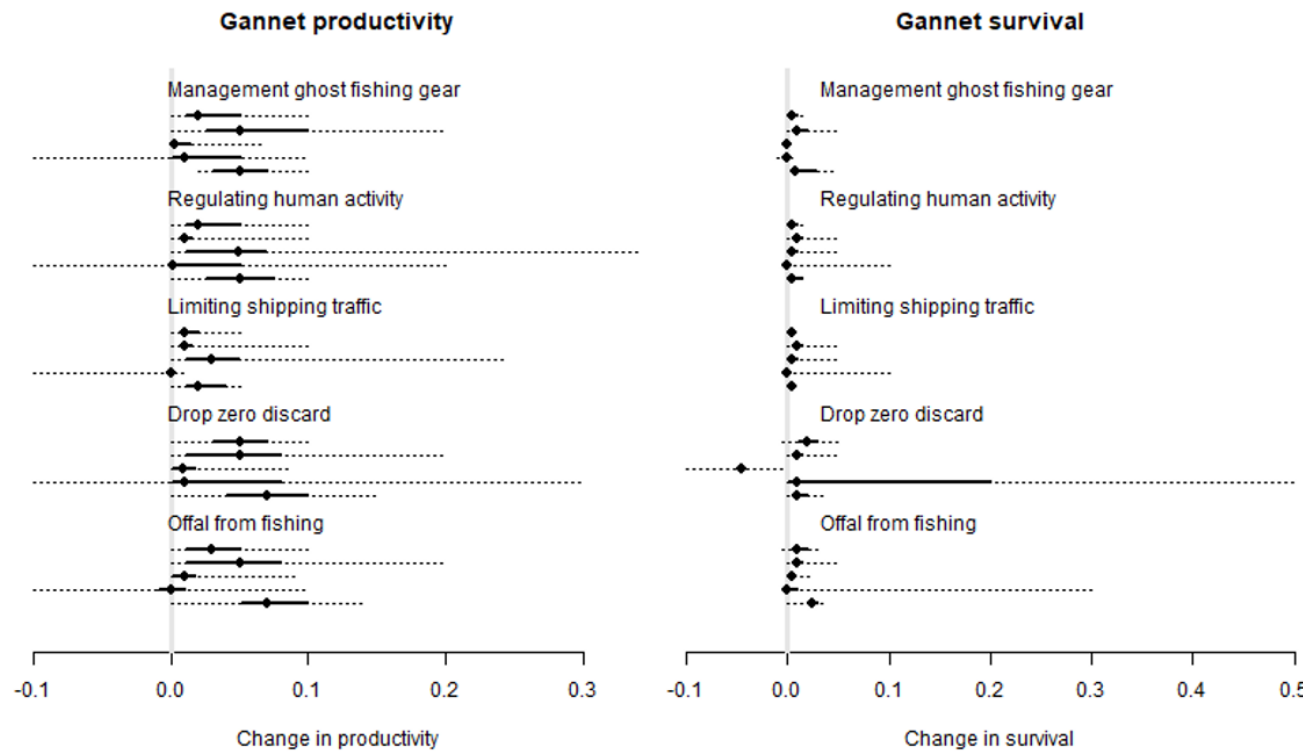
344 **Northern gannet**

345 Experts ranked reducing fisheries bycatch most highly for gannets, followed by cessation in harvesting and
 346 closure of forage fish fisheries. Various other measures were also ranked relatively high, including
 347 supplementary feeding via discards or offal, reducing marine pollution and disturbance at colonies or in the
 348 marine environment, management of predators, and creation of nesting habitat.

349 In terms of measures most likely to result in positive gains in breeding success, experts estimated potential
 350 for increases or around 0.01-0.05 additional fledged chicks per nest for management of ghost fishing gear,
 351 regulating human activity in the marine environment close to colonies, dropping the zero-discard policy,
 352 and provision of offal from fishing in over-wintering areas. Lower increases of 0.01-0.03 additional fledged

353 chicks per nest were also estimated by the experts for limiting shipping traffic in year-round foraging areas.
 354 There was notable uncertainty in the estimates for potential increases in breeding success for all measures
 355 considered by the experts in this species, represented by wide upper and lower bounds and inter-quartile
 356 ranges. Limited potential for increasing adult survival in gannets was identified by the experts, with only the
 357 measures for provision of offal from fishing in overwinter areas and dropping the zero-discard policy
 358 resulting in median estimates of more than a 1% increase in adult survival. However, for both these
 359 measures, experts reported very wide uncertainty in their estimates. The remaining three measures were
 360 estimated to lead to a potential 1% increase in adult survival by at least one of the experts, however there
 361 was wide variation across experts, with many estimating far smaller potential gains in this demographic
 362 rate (Figure 3). As with previous species, all five of the measures considered for gannets were estimated by
 363 experts to have the potential for decreases in adult survival, represented by negative lower bounds from at
 364 least one of the experts for all measures, by negative lower quartiles from at least one expert for two of the
 365 five measures, and by a negative median estimate by at least one expert for one of the measures
 366 considered (Figure 3).

367 Based on the expert estimates of demographic gains, successful measures for gannets tended to involve
 368 changes to fisheries practices, and to a lesser extent better management of potential disturbance from
 369 human activity or shipping in the marine environment. As with large gulls, some of the measures identified
 370 as having the greatest potential for leading to demographic gains in this species were also those that were
 371 found to be most contentious by the experts, such as alterations to the zero-discard policy and the use of
 372 fishing offal.



373
 374 *Figure 3. Probabilistic judgements elicited from five experts on the potential demographic gains arising from*
 375 *application of five alternative compensatory measures for Northern gannet. Each probabilistic judgement is depicted*
 376 *by each expert's value for the median (circle), upper and lower quartiles (thick line), and upper and lower limits (thin*
 377 *dotted line).*

378 *Black-legged kittiwake*

379 Experts' rankings revealed greatest support for three measures thought to be most likely to lead to
380 demographic benefits—closure of forage fisheries, creation of nesting habitat and predator management. A
381 relatively broad range of other measures also received some support, including management of nesting
382 habitat, supplementary feeding via discards or offal from fishing, reducing disturbance at colonies, and
383 addressing marine pollution.

384 Relatively large increases in additional chicks fledged per nest were predicted by experts for two of the
385 measures, ranging from around 0.1-0.8 (median values) for both delivering food directly to the nest and
386 creation of artificial nesting structures. Much more modest gains in breeding success were estimated for
387 other measures, with almost all median estimates falling below 0.1 additional chicks fledged per nest. It
388 was notable that there was very wide uncertainty in experts' estimates for the magnitude of gains in
389 breeding success arising from the two top measures, reflected in very wide quartiles and upper and lower
390 bounds, particularly for estimates around the effect of artificial nesting structures on kittiwake breeding
391 success. Therefore, even though experts generally estimated the potential for relatively large gains in
392 breeding success for these two measures, there was considerable uncertainty within experts for the
393 potential magnitude of such gains, coupled with considerable variation between experts. Experts also
394 identified three measures with strong potential for increasing adult survival, with estimates ranging from
395 around 1-5% increases in adult survival for supplementary feeding (direct to the nest), provision of offal
396 from fishing in overwintering areas, and dropping the zero-discard policy. The remaining two measures
397 were more variable in experts' estimates for potential gains in adult survival, with at least one expert's
398 median estimate reaching a potential 0.5%-1% gain in this demographic rate. As with previous species, all
399 five of the measures considered for kittiwakes were estimated by experts to have the potential for
400 decreases in adult survival, represented by negative lower bounds from at least one of the experts for all
401 measures, by negative lower quartiles from at least one expert for two of the five measures, and by a
402 negative median estimate by at least one expert for one of the measures considered (Figure 4Figure 3).

403 Creation of artificial nesting structures has been proposed as one of the most suitable measures for
404 benefitting black-legged kittiwake, and indeed has been utilised in consenting applications for several
405 offshore windfarms developed in English waters. Whilst experts were consistently supportive of this action
406 as one of the measures most likely to result in positive gains in breeding success, their estimates for how
407 such a measure may affect adult survival were more complex. Two of the five experts estimated a non-
408 trivial decline in adult survival of 1-2% upon application of this measure, one estimated no change, and two
409 estimated gains of 0.5% and 2% (median values). Experts also reported very wide upper and lower bounds
410 for potential changes to adult survival arising from artificial nesting structures, reflecting very wide
411 variation in experts' estimates for expected gains, or indeed, potential reductions. This highlights the
412 urgent need for empirical evidence from artificial nesting structures, particularly in relation to how adult
413 survival of birds utilising such structures for breeding may be affected.

414 In summary, for black-legged kittiwake there was consistent support for the effectiveness of the closure of
415 forage fisheries and predator management, coupled with more mixed support for creation of nesting
416 habitat as measures likely to benefit this species. A range of measures were identified as leading to likely
417 positive gains in breeding success and adult survival, with relatively high potential gains identified for both
418 vital rates. However, as with other species, the measures identified as most likely to lead to potential gains
419 in adult survival were also those considered as most contentious by the experts, including dropping the
420 zero-discard policy and provisioning birds with offal from fishing. Importantly, there was considerable
421 uncertainty around gains arising from the use of artificial nesting structures, including the potential for
422 negative effects on adult survival, which if realised, could offset any potential benefits accruing from gains
423 in breeding success.

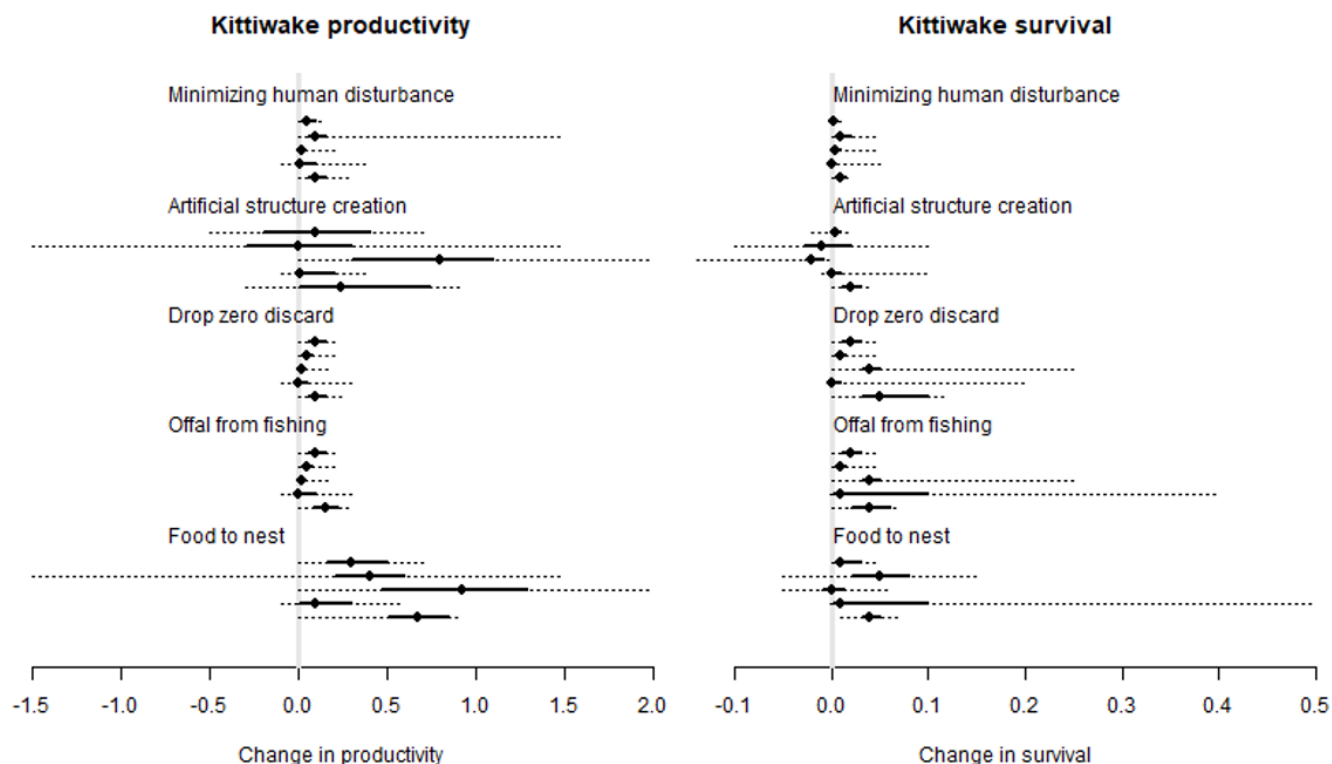


Figure 4. Probabilistic judgements elicited from five experts on the potential demographic gains arising from application of five alternative compensatory measures for Black-legged kittiwake. Each probabilistic judgement is depicted by each expert's value for the median (circle), upper and lower quartiles (thick line), and upper and lower limits (thin dotted line).

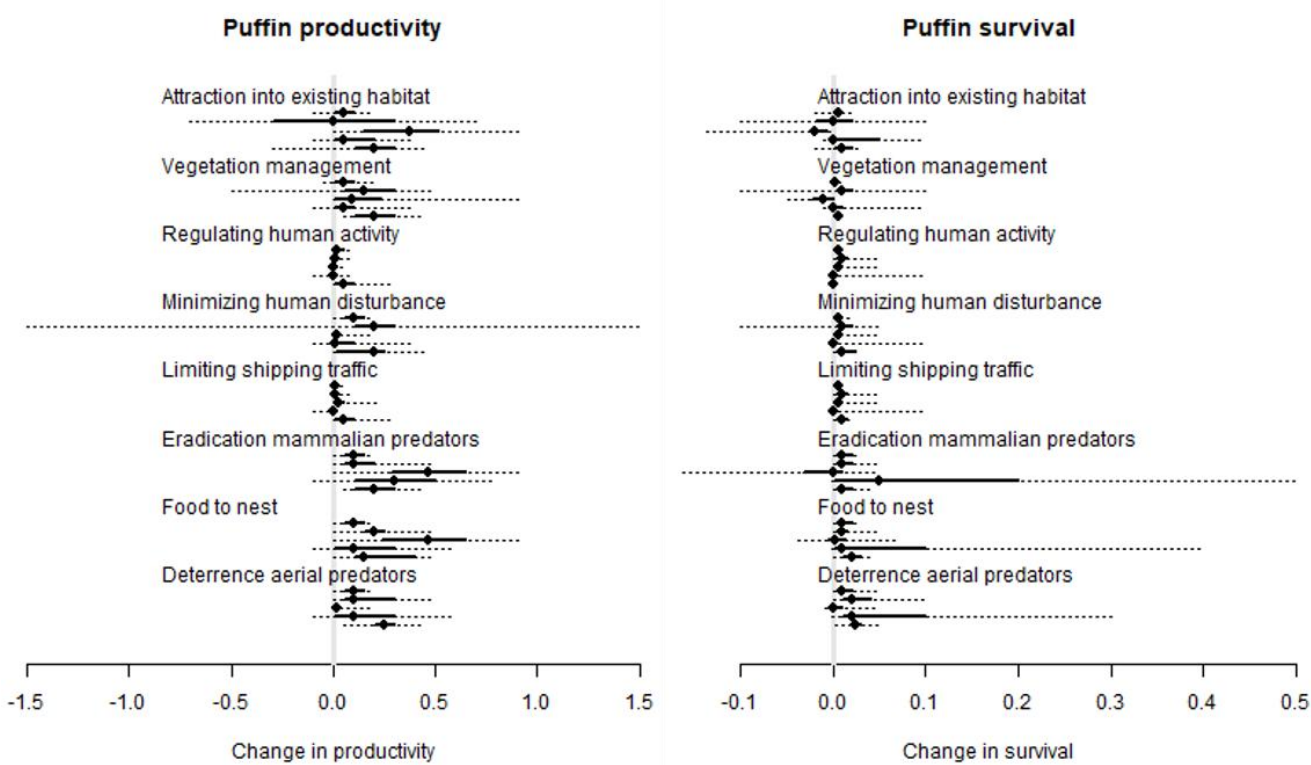
Atlantic puffin

Three measures were ranked highly by the experts, including closure of forage fisheries, predator management and nesting habitat management. A range of other measures were also ranked relatively highly, comprising reducing disturbance at breeding colonies and in the marine environment, rescuing fledglings trapped in human structures, supplementary feeding at the colony, and reducing fisheries bycatch.

Experts considered that several measures could result in relatively high increases in puffin breeding success, broadly over a range of 0.1-0.4 additional chicks fledged per nest (median values), including eradication of predators, deterrence of aerial predators, and supplementary feeding directly to the nest. More moderate increases in breeding success were also predicted for measures such as vegetation management, attraction into existing habitat, and managing visitor disturbance at colonies. In this species, experts exhibited lower uncertainty in their estimates of potential gains in breeding success relative to many of the other species, with inter-quartile and upper and lower ranges relatively narrow, particularly for those with the highest median estimates for potential gains—predator management and supplementary feeding. Significantly, in puffins, the three measures identified by experts as those with the strongest potential for resulting gains in breeding success, were also those identified as most likely to produce gains in adult survival. This consistency in support for measures benefitting both demographic rates suggests that in this species, application of a few measures could result in important synergistic gains in both breeding success and adult survival. Estimates for increases of around 1.0-2.5% percent (median estimates) were given for deterrence of aerial predators and supplementary feeding direct to the nest, and up to 5% for eradication of mammalian predators (Figure 5). All other measures were also estimated by at least one of the experts to potentially result in gains of up to 1% in adult survival (Figure 5). However, all of the measures

451 considered for puffin were estimated by experts to have the potential for decreases in adult survival,
452 represented by negative lower bounds from at least one of the experts for all measures, by negative lower
453 quartiles from at least one expert for five of the eight measures, and by a negative median estimate by at
454 least one expert for two of the measures considered (Figure 5Figure 3).

455 Overall, for puffins, the experts showed one of the most consistent and strong set of estimates for potential
456 gains in both vital rates across all species, identifying three measures focusing on forms of predator control
457 and supplementary feeding direct to the nest as likely to result in positive demographic gains in this
458 species. As with other species, it is important to consider that one of these measures, the use of
459 supplementary feeding, was also one of the most contentious in terms of realised application by the
460 experts.



461
462 *Figure 5. Probabilistic judgements elicited from five experts on the potential demographic gains arising from*
463 *application of eight alternative compensatory measures for Atlantic puffin. Each probabilistic judgement is depicted by*
464 *each expert's value for the median (circle), upper and lower quartiles (thick line), and upper and lower limits (thin*
465 *dotted line).*

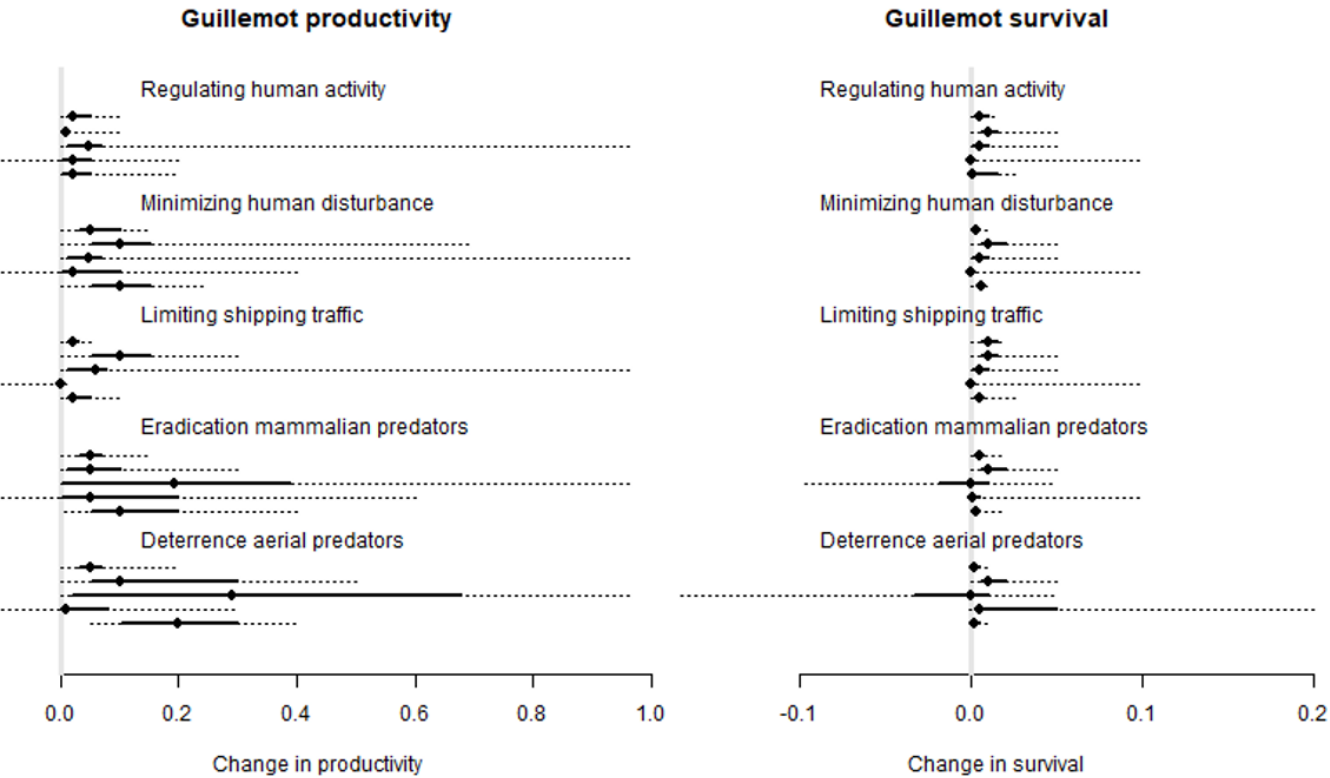
466 *Common guillemot*

467 Experts ranked three measures as the highest potential for success—closure of forage fisheries, reducing
468 bycatch from fisheries, and management of predators. Experts also showed good support for several other
469 measures, including management of nesting habitat, reduction of disturbance at breeding colonies and in
470 the marine habitat, and combating marine pollution.

471 Two of the measures relating to predator management were considered by experts as having relatively
472 good potential for increasing breeding success, with estimates for around 0.1-0.3 additional chicks fledged
473 per nest (median values) for deterrence of aerial predators, and ranging from 0.05-0.2 additional chicks
474 fledged per nest for eradication of mammalian predators. Remaining measures were not estimated to have
475 particularly strong potential gains in guillemot breeding success, with both minimising disturbance at
476 colonies and limiting shipping in year-round foraging ranges receiving estimates of less than 0.1 additional
477 chicks fledged per nest by most of the experts (median values). There was considerable uncertainty within

478 experts' estimates for potential gains in breeding success for all measures in this species, although most
 479 experts did not consider there was much potential for negative effects arising from each measure. In
 480 contrast to some of the other species considered, estimates for gains in adult survival in this species were
 481 relatively low. At least one of the experts estimated a potential gain of up to 1% in adult survival for all five
 482 of the measures considered (based on median values), however there was considerable variation across
 483 experts with some predicting very small potential gains of less than one quarter of one percent (Figure 6). In
 484 addition, all of the measures considered for puffin were estimated by experts to have the potential for
 485 decreases in adult survival, represented by negative lower bounds from at least one of the experts for all
 486 measures, and by negative lower quartiles from at least one expert for two of the five measures. However,
 487 unlike some of the other species considered, no experts estimated a negative value for any of the median
 488 values across all of the measures considered (Figure 6Figure 3).

489 In summary, guillemots were considered most likely to benefit from measures relating to fisheries activity
 490 and to predator management. The elicitation of potential changes in vital rates revealed that experts
 491 considered that measures were most likely to benefit guillemots via changes in breeding success rather
 492 than adult survival, with a focus on those relating to deterrence of aerial predators and eradication of
 493 mammalian predators.



494
 495 *Figure 6. Probabilistic judgements elicited from five experts on the potential demographic gains arising from*
 496 *application of five alternative compensatory measures for Common guillemot. Each probabilistic judgement is depicted*
 497 *by each expert's value for the median (circle), upper and lower quartiles (thick line), and upper and lower limits (thin*
 498 *dotted line).*

499 **Razorbill**

500 In razorbill, experts ranked most highly measures for closure of forage fisheries, predator management,
 501 fisheries bycatch and reducing disturbance in the marine habitat. Three other measures also received
 502 relatively high rankings, including reducing disturbance at breeding colonies, managing nesting habitat and
 503 reducing marine pollution.

As with common guillemots, for razorbills experts considered measures relating to predator management as those with the best potential for gains in breeding success. Experts estimated gains of around 0.1-0.2 additional chicks fledged per nest for deterrence of aerial predators, and of 0.1-0.4 additional chicks fledged per nest for eradication of mammalian predators (median values). Other measures had lower estimates for potential gains, all falling below or equal to just 0.1 additional fledged chicks per nest. There was considerable uncertainty within experts in their estimates, shown by relatively large inter-quartile ranges and upper and lower bounds for all five measures considered. However, there was little expectation for the potential for negative impacts on breeding success arising from any of the measures. In contrast to some of the other species considered, estimates for gains in adult survival in razorbills were relatively low. At least one of the experts estimated a potential gain of up to 1% in adult survival for all five of the measures considered (based on median values), and for some measures the experts' estimates for median values for gains in adult survival were pretty consistent, around 0.5%-1.0% (Limiting shipping traffic within year-round foraging areas, Regulating human activity in the marine environment). However there was considerable variation across experts for this demographic rate, with some predicting very small potential gains of less than one quarter of one percent (Figure 7). In addition, all of the measures considered for puffin were estimated by experts to have the potential for decreases in adult survival, represented by negative lower bounds from at least one of the experts for all measures, and by negative lower quartiles from at least one expert for two of the five measures. However, as for guillemot, unlike some of the other species considered, no experts estimated a negative value for any of the median values across all of the measures considered for razorbill (Figure 7Figure 3).

In summary, for razorbill, measures relating to fisheries management were thought most likely to result in positive gains, alongside measures targeting predator management. Potential for modest gains in razorbill breeding success were thought to be consistent with the two measures targeting aerial and mammalian predators, with more modest but still potentially important potential for a few measures to positively affect adult survival.

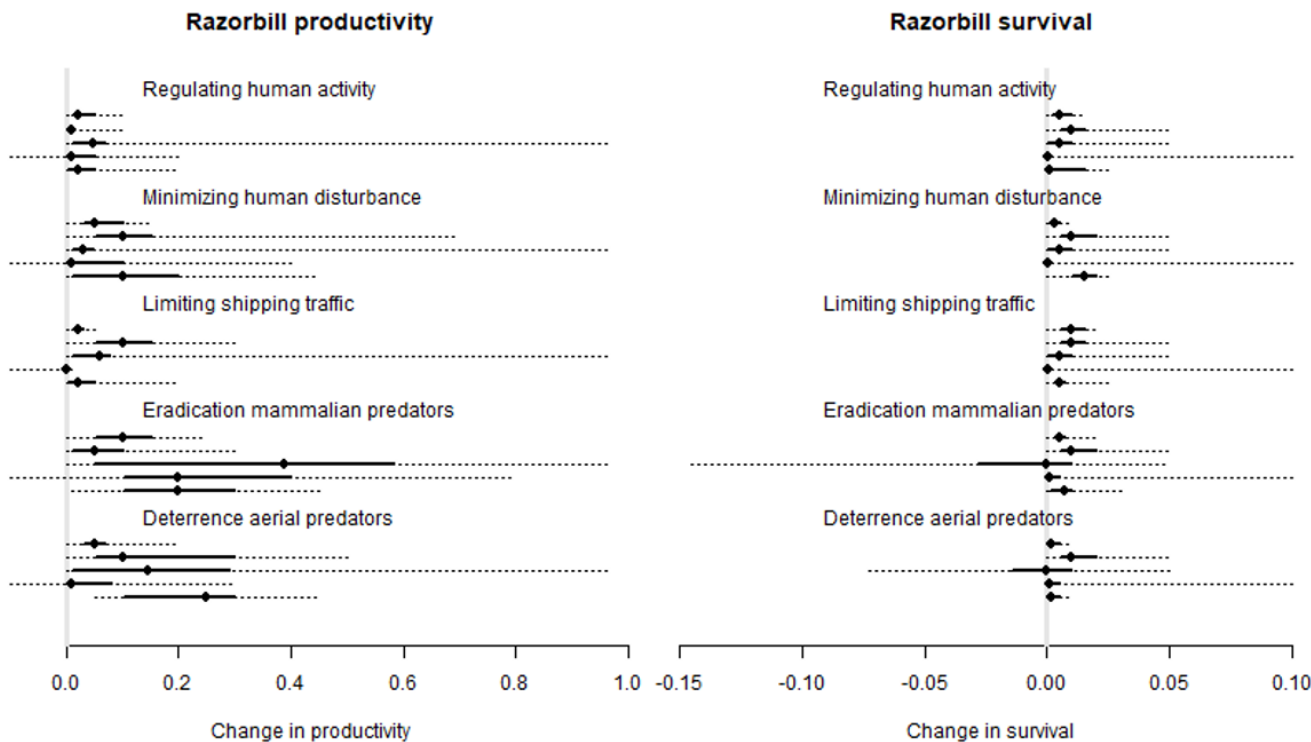


Figure 7. Probabilistic judgements elicited from five experts on the potential demographic gains arising from application of five alternative compensatory measures for Razorbill. Each probabilistic judgement is depicted by each

532 *expert's value for the median (circle), upper and lower quartiles (thick line), and upper and lower limits (thin dotted*
533 *line).*

534 **Discussion**

535 There is an urgent need to identify and secure compensatory measures for seabirds that are capable of
536 delivering substantial gains to populations and species networks. Whilst the evidence base for potential
537 gains from compensatory measures is beginning to grow for some measures (e.g., use of artificial structures
538 for nesting; Christensen-Dalsgaard et al. 2019, Anker-Nilssen et al. 2026), considerable uncertainty remains
539 around their overall effectiveness, hindering the development and implementation of such measures. We
540 conducted an expert elicitation to identify, rank and provide estimates for potential demographic gains
541 arising from a wide range of potential compensatory measures across a suite of seabird species. Although
542 experts included considerable uncertainty in their estimates of potential gains, the elicitation identified a
543 suite of measures with the potential to improve seabird breeding success or adult survival across a wide
544 range of species, in addition to some measures for which estimates of gain were not included due to
545 existing or ongoing empirical evidence collection (fisheries management to reduce bycatch, fisheries
546 management through forage fisheries closures, altering control measures for some gull species, and
547 cessation of harvesting of the species such as gannet). However, experts also identified significant
548 challenges with successful implementation of compensatory measures for seabirds, including both
549 practical, ecological and ethical considerations.

550 ***Use of expert elicitation results in population modelling***

551 Any quantitative evaluation of potential population-level benefits relies upon translating the expert
552 elicitation results into use within population models. This translation relies upon an assumption that the
553 elicited values are relevant to the population(s) of interest: not all measures may be effective in all
554 populations or situations, and the narrative associated with the expert elicitation indicated that part of the
555 uncertainty elicited by the experts related to variability in effectiveness between different populations and
556 situations. There is also an assumption that the knowledge of the group of experts encapsulated through
557 their judgements captures all of the information needed to use their knowledge within population
558 modelling – this assumes for example, that all of the caveats associated with their knowledge are captured
559 within the uncertainty ranges provided.

560 It was notable that all of the compensatory measures considered resulted in experts estimating potential
561 declines in at least one of the demographic rates for their lower bound or lower quartile values. This was
562 particularly true for measures aimed at terns, large gulls, gannets, kittiwakes and puffin, where at least one
563 expert included a potential negative effect on adult survival in their estimated median value. These
564 negative values were discussed by the experts, and arose from a number of considerations. For some of the
565 grouped species, such as terns and gulls, these negative estimates partially represented variation across
566 individual species, with experts considering that not all of the proposed measures would benefit all species
567 with the grouping. In other cases, these negative values represented a genuine belief from experts that the
568 situational context in which certain measures were applied could in some instances lead to unintended
569 declines in demographic rates. For example, management of human disturbance at breeding colonies was
570 thought to have the potential to result in declines in demographic rates in some situations, for example
571 where human presence may serve to deter predators. Where distributions (within or between experts)
572 contain both negative and positive values this indicates that there is a potential for measures to have either
573 a positive or negative impact on demography. This uncertainty, both within and between experts, can be
574 propagated through into population modelling, and implies that the measure may either increase or reduce
575 abundance. The relative probabilities of these outcomes can be evaluated, and will be important when
576 interpreting the results.

577 The principal context that this arises in is in evaluating the population for a specific measure to achieve a
578 specified level of improvement in an outcome such as annual growth rate or quasi-extinction risk within a
579 particular population. Under the assumption that each of the measures has been implemented
580 successfully, the expert elicitation results can be regarded as changes in annual demographic rates within a
581 population model, and the outputs of this model with and without the implementation of the measure can
582 be derived and compared. This is essentially the same process as that used to evaluate the impacts of
583 offshore renewables, or other anthropogenic impacts. Crucially, it relies upon specifying the baseline
584 demographic rates, as well the impacts of the measure. It is important to account for uncertainty in the
585 expert elicitation results, and this is most natural to account for within the context of a stochastic, rather
586 than deterministic, population model, in which other sources of uncertainty and variability (e.g.,
587 environmental stochasticity relating to variations in baseline demography, and demographic stochasticity)
588 are also considered. When considering uncertainty in the expert elicitation results, it is important to
589 distinguish between variation within an expert's estimates (represented by the elicited ranges) and
590 variation between experts (differences in the estimates provided by different experts). In this assessment,
591 all experts were assigned equal weight, such that no individual expert's judgement was given greater
592 influence than another's. The elicited median values were used as the central estimates, while the
593 associated ranges were used to represent uncertainty around these estimates. The judgements on
594 summary statistics (median, quartiles, ranges) provided by experts will typically need to be converted into
595 probability distributions to provide the impacts on demographic rates, with uncertainty, that are needed as
596 inputs to population models. Discussion among experts indicated that, of the range of possible parametric
597 distributions produced by the SHELF software, the beta distribution was the most effective in capturing
598 their knowledge. However, this discussion also indicated that none of the distributions, including the beta
599 distribution, fully captured the judgements of the experts.

600 It may be that a suite of measures will provide a more effective approach than any single measure,
601 particularly when populations are being adversely affected by multiple pressures. Previous research has
602 suggested that coordinated delivery of multiple measures could augment the effectiveness of individual
603 measures, increasing the likelihood of achieving the desired compensatory effect (Tapia-Harris & Evans
604 2024). The simplest way to consider the effectiveness of combinations of measures is to sum together the
605 impacts of different measures, allowing for uncertainty. This can be achieved within a simulation-based
606 approach, by repeatedly simulating the impact of each measure, and then, within each simulation, adding
607 the impacts of different measures together. The challenge in doing this, however, is that the approach
608 assumes independence between measures, which is unlikely to be a realistic assumption in many situations
609 (e.g., because some of the measures target the same underlying processes, so that the effectiveness of one
610 measure is likely to depend on the effectiveness of another). Dependence between measures could be
611 accounted for, but depends upon estimates for the direction and magnitude of dependence (correlation)
612 being available. A further expert elicitation exercise could potentially be used to quantify the levels of
613 dependence between the effectiveness of different measures (Holzhauer et al., 2022). In the absence of
614 such an exercise the most feasible approach may be to explore sensitivity of outputs (e.g., overall
615 effectiveness of a suite of measures) to assumptions regarding the magnitude and direction of dependence
616 between the effectiveness of individual measures (Oakley & O'Hagan, 2004).

617 ***Wider considerations for implementation of measures***

618 During the elicitation, experts engaged in wide-ranging discussions around their reasons for associating
619 alternative measures with potential gains in seabird vital rates. Species-level expertise varied across the
620 experts, meaning that some were more confident in their estimates for gains in breeding success or adult
621 survival for certain species, which they reflected in their inter-quartile ranges and upper and lower bounds.
622 As a consequence, it is critical that the full breadth of their estimated judgements is considered when
623 interpreting the elicitation results to identify measures most likely to be successful. Experts generally stated
624 that they were more confident in their estimates for median values, followed by their estimates for upper

625 and lower bounds, and were least confident in their estimates for quartiles. This was in part because
626 experts found median values as a statistical concept relatively easier to work with than quartiles and
627 ranges. However, it was also due to experts tending to find it easier to provide an estimate for their median
628 expectation for a change in vital rates given their often strong uncertainty in the linkage between
629 application of a measure and any subsequent population-level change in demography. Several of the
630 experts also noted that they found it most easy to first consider the potential range of their estimates with
631 a reasonable level of confidence (e.g., upper and lower bounds), and to then assign a median value within
632 this.

633 Importantly, experts were asked to include both their uncertainty in the overall value of their estimates—
634 that is their confidence in the specific values they estimated—as well as a measure of potential variability in
635 the gains arising from measures due to other factors, such as the local ecological and environmental
636 context of the population to which the measure was being applied. This means, for example, that for
637 measures involving occupation of new nesting habitat, experts included in their values for quartiles and
638 ranges their expectations for potentially differing demographic rates arising from immatures that are newly
639 colonising habitat compared to rates for already established adult breeders. Importantly, the experts did
640 not include any consideration of practical feasibility of implementation of measures, such that their
641 estimates assume that each measure was able to be implemented at an appropriate colony. An additional
642 consideration when interpreting these findings in relation to which measures might be most successful is
643 that where there is more relevant data for estimating potential gains there is likely to be inherently less
644 uncertainty in experts' judgements. Therefore, this uncertainty should not be taken to imply potentially
645 lower levels of success, rather that potential success is highly uncertain due to measures being unstudied or
646 very difficult to study.

647 Critically, the experts felt strongly that the estimates for effectiveness of measures arising from the
648 elicitation should not be considered as conferring their preferences for application. The estimates should
649 be seen as an indicator for the types of compensatory measures likely to lead to some benefit for seabirds,
650 but do not reflect experts' judgement as to overall preference or value. Similarly, because the evidence
651 base for effectiveness of alternative measures is continually evolving, outcomes from the elicitation, if
652 conducted again, will change over time, including potential expansion to include measures not considered
653 here. In relation to this, the experts discussed a range of other issues linked to successful delivery of
654 ornithological compensation throughout the elicitation, identifying additional considerations that should
655 shape development of guidance and subsequent implementation plans (Table 2).

656 Firstly, several of the measures were considered as overly 'artificial', primarily those relating to fisheries
657 measures such as dropping the zero-discard policy, provision of offal from fisheries, and supplementary
658 feeding at colonies. Experts expressed concern that such measures, if applied over the long-term (such as
659 the lifespan of an offshore windfarm), could result in unintended alterations to bird behaviour that could
660 compromise natural populations when measures are halted. For example, some seabird species have been
661 shown to shift diet or other behaviours and traits in response to variation in anthropogenic food resources
662 or to fisheries discarding and offal activity (Votier et al. 2008, Bicknell et al. 2013, Real et al. 2017, Calado et
663 al. 2020). Should such diet shifts result in altered preferences, or in other unintended behavioural changes
664 linked to foraging behaviour and subsequent provisioning to offspring, practices such as supplementary
665 feeding could lead to unintended consequences over the longer term. Experts also discussed the
666 importance of wider policy considerations and potential impacts on other sectors in relation to some of the
667 measures considered. For example, for measures relating to fisheries management—particularly the
668 cessation of the zero-discard policy—experts felt this should be viewed primarily as a policy decision, not an
669 ecological one, due to its interactions with other sectors.

670 In addition, experts had wide-ranging discussions around the importance of considering the wider context
671 of any location or population in which a measure may be implemented (Table 2). Various measures such as

672 those involving other species (e.g., predators) or habitats (e.g., nesting habitat) were highlighted as having
673 strong potential for unintended consequences on both the target species, and others, if implemented
674 without consideration of the wider ecological setting (Russell 2015, Bicknell et al. 2013, Travers et al. 2021,
675 Pearson et al. 2022). An understanding of current constraints and limitations on populations were also
676 emphasised by the experts as critical to successful implementation of a measure (Table 2). For example,
677 where availability of prey is a key limiting factor for population growth, a measure aimed at increasing
678 availability of nest sites is unlikely to result in demographic benefits.

679 Experts also raised the importance of considering both the subset of the population likely to benefit from a
680 measure (e.g., chicks, immatures, adults) when considering its effectiveness, as well as the need to
681 understand how the timing of demographic gains arising from any implementation will affect subsequent
682 population change (Table 2). Furthermore, experts emphasized the importance of considering the location
683 and spatial context for implementation of measures, including the current status and trends in the focal
684 and neighbouring populations, and the likely acceptance of measures from local human communities.
685 Finally, in relation to implementation, experts highlighted the need to consider how climate-driven changes
686 in marine ecosystems may serve to undermine effectiveness of measures over coming decades (Table 2).
687 Marine ecosystems are predicted to undergo potentially significant climate-driven change over coming
688 decades (Mitchell et al. 2020, Olin et al. 2022, Searle et al. 2022, Davies et al. 2023, Tyldesley et al. 2024),
689 therefore whilst some measures may be effective under current conditions, their effectiveness may be
690 undermined in the future (Tapia-Harris & Evans, 2024). Developing compensatory measures that are
691 resilient to predicted future climate change is critical to long-term delivery of gains.

692 The use of multiple measures in a single location was also raised as an important consideration. Experts
693 considered that some measures may provide additional benefit if used simultaneously, but that measures
694 targeting the same demographic rate (e.g., breeding success) may have lower success if applied together in
695 the same location due to other constraints limiting overall potential for gains in population productivity.
696 Similarly, the temporal implementation of different measures targeting the same population should be
697 considered, such that any gains are accrued at the population scale as quickly and effectively as possible
698 (Table 2).

699 Experts also raised challenges with monitoring of compensatory measures. These included difficulties in
700 monitoring effectiveness of measures when likely gains are expected to be small, requiring long-term
701 monitoring to improve demonstration of tangible benefits. This in turn raised concerns around defining
702 triggers for adaptive management, whereby a measure is identified as failing to deliver the required
703 compensation causing alternative approaches to be required (Table 2). Experts also raised concerns around
704 the use of a 'like for like' hierarchy when implementing compensation, whereby the measure is aimed at
705 benefitting the affected species at the same location, with a more strategic, potentially ecosystem-based
706 approach advocated (Table 2). Recent legislation in the UK has relaxed this constraint of a strict like-for-like
707 hierarchy, partly in recognition that sufficient compensation is unlikely to be achievable via entirely local,
708 direct measures (Defra 2026).

Table 2. Summary of additional considerations discussed by experts during the elicitation in relation to ornithological compensation.

General discussion points	Issue
Artificiality of some measures	Some measures, such as supplementary feeding, provision of offal, and dropping zero-discard policy, have the potential for longer-term, unintended behavioural changes in birds. There is a need to consider wider ecological context – supplementary feeding may only be appropriate in locations where predators will not be attracted (e.g., burrow nesting species or artificial nesting towers with access to nests). Dropping the zero-discard policy and provision of offal from fishing are policy decisions, not biological. There was considerable discussion between experts as to whether values for these measures should be elicited at all. More ‘natural’ solutions should be prioritised, and this should be reflected in any hierarchy of measures.
Wider context	Predator and habitat management have the potential for unintended consequences beyond the target species. For example, there may be potential conflict when the predator is itself a protected species (e.g., white-tailed eagles and large gulls), or if vegetation management alters habitat for predators. If unintended consequences occur, other measures need to be ready, for example diversionary feeding of predators. For all measures, local context is key, requiring consideration of limiting factors, accessibility for interventions and other factors. Therefore, all measures need to be considered on a case-by-case basis due to local context and variation in conditions. For example, rats and Manx shearwater on Rum are able to coexist due to the high altitude nest sites, important to identify these exceptions so measures are not applied in places that will result in little gains.
Component of the population targeted by measures	There is the potential for gains to occur in parts of the population for which demographic benefits are not immediately realised, such as immatures not yet breeding. If measures target overwintering populations, knowledge of the provenance of affected birds is needed to apportion gains back to protected populations and the relevant species network.
Temporal aspects	Some measures will produce gains more quickly than others, which needs to be factored in to implementation and monitoring plans.
Location of measures	Consideration should be given to the baseline demographic rates in the target population, i.e. when breeding success and/or adult survival are already very high there is little scope for improvement and gains to be made by application of compensatory measures. There is very wide spatial variation in demographic rates across UK colonies for most species. Climate resilience of measures should be considered, by avoiding areas where climate change is having the strongest effects on populations, as any gains may be undermined by ‘baked in’ climate change over coming decades.

	Acceptance by local human communities should be considered, for example siting artificial colonies in more natural settings to avoid potential conflict with humans.
<i>Benefits of multiple measures applied at one location</i>	Multiple measures are likely to be additive or to act to strengthen one another, especially when one measure is colony-based and a second measure is based offshore: for example use of artificial nesting towers could be coupled with supplementary feeding, and creation of nesting platforms for terns could be coupled with reducing visitor disturbance. Similarly, measures such as supplementary feeding may result in individuals achieving better condition so they are then more receptive to other measures such as accessing resources offshore. Some sets of measures cannot be used in the same location at the same time due to potential for an undermining of benefits accrued from one by implementation of the other. There may also be overlap as to which pressures different measures are trying to alleviate, making them less likely to be additive, for example if two measures are both aimed at improving the same resource. The order of implementation of different measures in the same location should be considered, including the potential differing contribution of gains over time. The demographic rates targeted by each measure should be considered, for example two measures may be additive for productivity, but not for adult survival.
<i>Hierarchy of measures</i>	There is a need for guidance to consider when it is better to move away to a new location as available measures at the directly impacted location become increasingly artificial. The experts felt that for instance more ecosystem-based measures in a different location or broader geographical area may be better than a very artificial measure applied directly to the affected location. Strategic planning should be used here to deliver areas for OW development and areas for seabird protection – some areas should be reserved for birds. There should be more focus on non-SPA birds for application of measures, because SPA birds already have a degree of protection. Further, non-SPA colonies are usually smaller, and adding 100 net individuals to a smaller population will have a greater contribution to population resilience and persistence than adding 100 net individuals at a larger SPA colony. However, it is important to recognise that gains from smaller colonies may not match the potential requirement to deliver many hundreds or thousands of individuals across the species network for cumulative impacts. Small, non-SPA colonies may also be potentially limited in growth due to other factors such as breeding site availability.
<i>Monitoring of effectiveness</i>	Anticipated effects from some measures may be very small, albeit positive, and detecting and demonstrating these gains at the population level could be very challenging.

1 **Addressing knowledge gaps**

2 Throughout the elicitation, experts identified key knowledge gaps, and crystallised their discussions into a
3 series of recommendations. The need for an expert elicitation approach already serves to highlight the lack
4 of available empirical evidence on which to base decisions around effectiveness and successful
5 implementation of compensatory measures for seabirds. However, experts identified some priority areas
6 for more focused research. A particular need is for more empirical evidence on the relative contributions of
7 gains in different vital rates to population growth in different seabird species, potential trade-offs between
8 vital rates, and in methods to robustly estimate population trajectories under alternative scenarios of vital
9 rate combinations under the influence of extrinsic pressures (Jenouvrier et al. 2005, Taylor et al. 2012,
10 Hinke et al. 2017, Genovart et al. 2018, Landsem et al. 2023). A further knowledge gap that requires urgent
11 attention is identifying proximate causes of population regulation, to more firmly establish which processes
12 compensatory measures must target to most benefit a target population. With respect to effectiveness of
13 the measures themselves, the experts identified three for which empirical evidence is currently severely
14 lacking—diversionary feeding of predators, human disturbance at colonies and in marine foraging grounds,
15 and ghost fishing. More practical data-related measures were also identified around knowledge gaps,
16 including an urgent need for the collation of available information key to successful implementation of
17 measures in appropriate locations, such as a register of seabird populations currently affected by predators
18 such as rats (e.g., as has been developed for the east coast of Scotland in Pizzolla et al. 2024). Experts also
19 recommended that guidance should be developed to establish what empirical evidence is required to
20 address current knowledge gaps, including information relating to feasibility of evidence generation, such
21 as expense and time-heavy research needed to estimate gains from measures targeting adult survival in
22 long-lived species.

23 **Recommendations**

24 The experts set out a series of recommendations, arising from their discussions during the elicitation. These
25 broadly revolved around two broad themes; clarity around choice of appropriate measures, and
26 development of guidance for successful implementation. With regards to choosing appropriate measures,
27 experts made the following recommendations:

- 28 – *Application of combinations of measures and potential for co-location:*
 - 29 ○ Advocating the use of more than one measure to ‘de-risk’ the process of compensating for
30 predicted impacts
 - 31 ○ Development of a matrix of measures to show those measures that are potentially additive
32 to one another, and those that should not be applied in the same location due to a
33 likelihood of unintended consequences of undermining of gains
- 34 – *Choice of measures:*
 - 35 ○ Measures should aim to minimise deviation from the natural ecological processes already
36 occurring in populations. Less artificial measures should generally be considered as
37 preferable, even if they are anticipated to be less effective than more artificial measures.
38 For example, more ecosystem-based approaches with plausible links to higher trophic
39 levels are generally more preferable even though there may be a lack of current direct
40 empirical evidence to support gains
 - 41 ○ Consideration is needed as to what happens at the end of the lifespan of the measure. For
42 example, supplementary feeding a colony for 40+ years may have longer lasting effects due
43 to changes in seabird behaviour, which lead to negative consequences when the measure is
44 halted. This has the potential to undermine any gains from the measure itself.

45 Finally, in relation to improving guidance on implementation, experts recommended:

- Guidance should include recognition of the varying ability to monitor and assess potential gains from alternative measures. For example, available evidence may exist for how seabird behaviour may change upon application of a measure (e.g., reducing disturbance at colonies could improve chick provisioning rates during visitor hours). Yet, evidence may not extend to a demonstration of the energetic consequences of behavioural changes (e.g., improved chick condition), or to resulting demographic impacts (e.g., population productivity and growth). Guidance should, therefore, set out where the different levels of current evidence lie for different measures, outlining available evidence for 1. Positive behavioural changes, 2. Positive changes to energetics or condition, and 3. Positive gains in demographic rates.
- Monitoring guidance should recognise the mismatch in timescales between a measure's actions and the gains in adult survival, which are typically lagged, including the possibility that unequivocal demonstration of gains may require monitoring beyond the lifespan of an offshore development
- Advice should be developed to set out 'case studies' for each measure to capture the different considerations involved in their application, and to avoid formulaic use of potential gains without proper, contextual information including assessment of practicality and delivery
- The concept of measures requiring 'additionality' – a requirement under legislation in many countries - could potentially push the use of more extreme measures, beyond those that are already occurring at the SPA for conservation reasons.

Conclusions

This expert elicitation has identified, ranked and estimated the potential for demographic gains arising from a broad range of ornithological compensatory measures on a set of North Atlantic seabird species. We provide species-specific summaries to facilitate implementation of alternative measures, highlighting challenges associated with their effective use in realising robust demographic gains. Experts have revealed considerable uncertainty arising from a lack of empirical evidence for accurately estimating the potential for currently considered measures to result in gains via improved breeding success or adult survival. However, despite this uncertainty, the elicitation provides a considered base upon which guidance for successful implementation of measures for seabirds can be developed, highlighting specific issues and knowledge gaps, and providing important recommendations for development and implementation of guidance. Delivery of this guidance, and a strategic focus on upscaling the current evidence base, must be a critical priority for all governments aiming to safeguard energy security through offshore renewable energy, whilst fulfilling obligations to protected wildlife. There is a pressing need for evidence summaries for the likely effectiveness of ornithological compensatory measures to provide a central repository of evidence for regulators and marine users to inform current and future decision-making. This elicitation can form an important component of such a repository, providing an interim assessment of the potential for demographic gains across a broad suite of measures and species, serving to highlight critical knowledge gaps for research, and setting out important recommendations for robust guidance.

Acknowledgements

This research was funded by the NERC ECOWIND programme, through the ECOWINGS project (NERC Awards NE/X009068/1 and NE/X008916/1). We thank the following for their contributions to note-taking and summaries of elicitation workshops -- Charlotte Regan, Oliver Leedham (UKCEH) and Ana Couto (BioSS). All authors declare no conflict of interest relating to this manuscript.

Supplementary material

- S1. Full detail on methodology during elicitation*
- S2. Example excel forms used to collect experts estimates for changes to demographic rates*
- S3. Rankings of compensatory by experts per species*
- S4. Detailed summary of probabilistic judgements for each species and measure*

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254 **Supplementary Material S1. Full detail on methodology during elicitation**

255 We used the Sheffield Elicitation Framework (SHELF), an expert elicitation procedure to reach a group
256 consensus about an unknown quantity of interest, and the uncertainty associated with this, developed by
257 Oakley and O'Hagan (2010) which incorporates a structured feedback and consolidation routine. This
258 consensus-seeking approach is also referred to as behavioural aggregation (Wilson, K.J., Farrow, M., 2018),
259 because it relies on group discussion to reach consensus judgement, in place of mathematical averaging of
260 several independent judgements. A SHELF exercise starts with specification of the scientific research
261 question and selection of the experts (number and background), which is primarily driven by stakeholder
262 aims. Within the elicitation exercise group meeting, the experts are introduced and trained in probabilistic
263 judgements (which capture uncertainty) by the facilitator. Following information-sharing between the
264 experts, they provide individual judgements about the unknown quantity of interest. Although
265 anonymisation of experts is not a requirement of the SHELF framework, individual probability estimates
266 were anonymised in this exercise before being shared back to the group. This was done to minimise
267 potential status-related influences on participants' judgements and to ensure that estimates were
268 considered on their evidence, rather than attribution to individual expert. The facilitator then fits
269 appropriate probability distributions using individuals' judgements and returns aggregated distribution fits
270 to the experts often in the form of summary statistics or graphs (in our case, the latter was chosen).
271 Thereafter follows a process of feedback on the distribution fits given by the experts. If satisfactory
272 consensus is agreed, the elicitation exercise is completed. Otherwise, the experts may revise their
273 individual judgements, the facilitator refits the distributions about the unknown quantity of interest and
274 returns them again to the experts for their feedback. This process is iterated until consensus is reached, or
275 the experts agree that consensus is not possible given their provided evidence. SHELF has proven to be
276 widely used and reasonably robust given an experienced facilitator, with over 450 scientific works
277 implementing this approach. In comparison to another elicitation framework like Delphi (Dalkey N, Helmer
278 O (1963)), SHELF does not assume expert identity is anonymous (while the expert judgements themselves
279 can be) and relies on the facilitator to be effective at handling various group dynamics and to ensure a
280 balanced discussion with contribution from all experts.

281 *Initial elicitation of quantitative changes to demographic rates*

282 Following identification of appropriate species and compensatory measures, the experts provided
283 individual judgements (with discussion of evidence) for the demographic gains on seabird breeding success
284 and adult survival. In total, there were 44 combinations of species-measures for each potential gain in
285 breeding success and adult survival, totalling 88 combinations. For each of these, the experts were asked to
286 give a quantitative judgement for the plausible range and quartiles (L, Q1, M, Q3, U) of the effect of the
287 compensatory measure on breeding success and adult survival. The values for the plausible range (L and U)
288 were fixed for the first iteration (initial judgements) to be -1 and 1 for all combinations of species and
289 compensatory measures, in the absence of other information. Following the first round of expert
290 judgements and feedback it was decided by the experts, however, that a fixed range of (-1,1) was not well
291 suited to reflecting their judgement, so for subsequent iterations of judgements these values were
292 specified by the experts separately for each species, measure and variable of interest.

293 After the second workshop, experts were tasked with providing individual judgements (and any caveats or
294 evidence) for the probabilistic values defined above for each of the species-measure combinations. The
295 facilitators then fitted probability distribution curves to the judgements for each individual expert using a
296 least squares procedure through the SHELF R package and presented anonymised curves to the experts at
297 the third workshop. SHELF provides options to either directly specify the probability distribution model to
298 use for the production of curves, or to use a 'best fit' distribution in which several candidate probability
299 distributions are fitted and the model chosen that minimises the least squares error for a given set of
300 expert judgements. A 'best fit' approach was initially used but not all of the distributions considered by this

301 approach make use of the lower and upper limits provided by the experts, so a truncated Beta probability
302 distribution was ultimately used because it best reflects the nature of the quantity defining change in the
303 seabird demographic measures, and can be constrained to the interval of the expert plausible range. The
304 experts discussed these probability curves, and identified biological nuances that may be driving
305 differences between experts' values.

306 *Revised judgements and discussion of wider issues*

307 Following this discussion, experts provided a second set of judgements, and during the final fourth
308 workshop, facilitators presented this revised set of judgements to the experts, again in the form of
309 probability curves for each species-measure scenario. The experts then discussed the elicited distributions
310 and wider issues about assumptions behind the entire research question, as well as gaps in data and
311 literature. The final stage of the elicitation allowed experts to adjust their elicited quantities upon
312 conclusion of the fourth workshop, thereby providing the final set of probabilistic judgements for each
313 species-measure combination. One expert was unable to complete the final stage of the elicitation,
314 therefore although the selection and ranking of compensatory measures was completed by all six experts,
315 the elicitation of probabilistic judgements for the demographic responses of each species to proposed
316 measures was completed by five experts.

317 After time to discuss and reflect on the anonymised expert judgements, the facilitators and experts brought
318 to discussion any of the 88 combinations where they felt further discussion was necessary. This was often
319 the case where probability distribution curves varied substantially between the experts. Following the
320 second iteration of expert judgement and feedback process during the final fourth workshop, in cases
321 where consensus still could not be reached, the experts discussed wider assumptions and implications
322 behind the research question, as well as their views and those from current literature. Once all of the
323 individual judgements were deemed final by their respective experts, the resulting individual probabilistic
324 judgements and fitted curves were collated by the facilitators to form the final, comprehensive assessment
325 of potential demographic gains for each of the 88 combinations of compensatory measures by species
326 (EIDC dataset: Frantsuzova et al. 2026).

327 *Probability distribution curves*

328 During the feedback stage of the elicitation exercise (workshops 2-4), the experts were provided with
329 anonymised probability distribution curves for each of the 88 combinations, which were fitted using a least
330 squares procedure through the SHELF web application (Oakley and O'Hagan, 2026) and corresponded to
331 the judgements given by individual experts. Initially, for fitting the curves, a 'best fit' distribution was used,
332 which meant that out of several candidate probability distributions one was chosen that minimised the
333 least squares error for a given set of expert judgements. However, this was judged by the facilitators to not
334 be the most physically appropriate approach, because in some instances a high probability could be
335 modelled outside of the expert plausible range (e.g., because not all of the distributions considered make
336 use of the lower and upper limits provided by the experts). Therefore, it was decided that the most
337 appropriate distribution to fit to expert judgements was the truncated Beta probability distribution,
338 because it best reflects the nature of the quantity defining change in the seabird demographic measures,
339 and can be constrained to the interval of the expert plausible range. This ensured that the fitted
340 distributions remained within the range considered plausible by the experts, while retaining flexibility to
341 represent different shapes of uncertainty in the elicited judgements. The fitted distributions were
342 subsequently used during the feedback stage to allow experts to review the representation of their
343 judgements.

344

345

346 **Supplementary Material S3**

347 **A. Ranking of compensatory measures**

348 *Ranking of compensatory measures by species*

349 Fourteen compensatory measures for seabirds were identified by the six experts in the first stage of the
 350 expert elicitation (Table A1.). These measures were chosen as having the potential for positively affecting
 351 the population demography (breeding success and adult survival) of eleven seabird species in the UK
 352 context: black-legged kittiwake, common guillemot, Atlantic puffin, razorbill, northern gannet, herring gull,
 353 lesser black-backed gull, great black-backed gull, arctic tern, common tern and sandwich tern. The fourteen
 354 measures were selected by the experts as having some likely relevance to at least one of the eleven species
 355 under consideration, broadly meaning that they would be likely to have some positive benefit if applied in
 356 an appropriate location in a suitable way. The fourteen measures fell within eight broad categories: two
 357 relating to fisheries management (reduction of bycatch and forage fisheries closures; two relating to
 358 nesting habitat (creation of new nesting habitat and protection and environmental management to
 359 improve quality of existing nesting habitat); two relating to reducing disturbance (reducing human
 360 disturbance at breeding colonies and reducing human disturbance in the marine habitat around breeding
 361 colonies); two relating to artificial feeding of birds (provision of supplementary feed direct to the breeding
 362 colony and provision of supplementary food indirectly via use of discards or offal from the fishing industry);
 363 three relating to control or management measures (altering licensing around removal of gull nests,
 364 cessation of species harvesting and rescuing fledglings trapped by anthropogenic structures at breeding
 365 colonies); predator management through a variety of mechanisms depending on species; reduction of
 366 marine pollution; and finally wider habitat creation or improvement related to lower trophic levels
 367 providing prey for seabird species (Table A1.).

368 *Table A1. Set of fourteen compensatory measures for seabirds identified during expert elicitation.*

Measure	Description
Fisheries management: Bycatch	Reducing bycatch from fisheries
Fisheries management: Forage fisheries closures	Closure of forage fish fisheries in seabird foraging areas (sandeel, sprat)
Marine pollution	Removing existing fishing gear, preventing new fishing gear entering marine environment, rescuing chicks from entanglement in nets at the colony
Nesting habitat creation	In a new site or at/adjacent to an existing colony - including attraction to the new habitat
	Attraction into existing habitat
Nesting habitat management – protection and environmental management	Protection from ground predators at nesting habitat - e.g., wardening, electric fences
	Vegetation management of nesting habitat - e.g., Removal of bracken/other vegetation
	Additional conservation designation of protected areas in urban areas
Predator management	Culling, diversionary feeding and deterrence of aerial predators at the breeding colony
	Eradication of mammalian predators from breeding colonies e.g., rats
Reducing human disturbance at colonies	Minimising human disturbance at the breeding colony - e.g., limiting access of people close to nests: regulate numbers and have buffer zones

Reducing disturbance in marine habitat near colonies	Limiting shipping traffic within year-round foraging areas Regulating human activity in the marine environment occurring too close to colonies - e.g., tourist boats, helicopters, drones, jet skis etc
Supplementary feeding: Direct to colony	Delivering food directly to the nest Delivering food away from nests at the breeding colony
Supplementary feeding: Indirectly through discards/offal from fishing industry	Delivering offal from fishing vessels to over-wintering areas - offal is a fishing industry product that would otherwise be wasted Dropping a zero-discard policy and allowing fishers to discard in areas that birds use in the nonbreeding season
Altering control measures	Adjust current licensing around removing gull nests from inconvenient/unsafe locations. The eggs removed under licence could be hatched artificially with fledglings subsequently released, and/or reduction in the number of licences issued
Cessation of harvesting of the species	Harvesting of species reduced or stopped (e.g., gannets)
Wider habitat restoration or creation	Creating seagrass habitat (for herring) within the foraging range of a breeding colony
Rescuing fledglings	Releasing fledglings that have been trapped in human structures or disorientated by light/noise – at colonies or grounded fledglings elsewhere (mainland)

369

370 These fourteen measures were then ranked by experts for each of the eleven species, according to those
371 most likely to result in positive benefits to seabird demographic rates (breeding success or adult survival),
372 with a score of 1 indicating the highest likelihood of success, and a score of 14 representing the lowest
373 likelihood of success. Rankings were done individually for each of the 11 seabird species (Table A2).

374 When rankings were averaged across experts over all species considered, the joint top ranked measures
375 were closure of forage fisheries and management of predators. Management of nesting habitat and
376 reduction of disturbance at breeding colonies were ranked joint second across all species. Finally, the joint
377 third ranking measures over all species considered were reducing fisheries bycatch and creation of nesting
378 habitat.

379 *Tern species*

380 When averaged across the six experts, management of predators was ranked as the measure with the
381 greatest potential for positive benefit for the three tern species (Table A2). Management of nesting habitat
382 was ranked on average as the second most positive measure for all three species, closely followed by
383 forage fisheries closures (Table A2). Creation of nesting habitat was ranked on average as the fourth best
384 measure for arctic and common terns, with reducing disturbance at colonies ranked on average as the
385 fourth best measure for sandwich tern, and the fifth best measure for both arctic and common terns (Table
386 A2). Other measures for terns that were on average ranked relatively highly (mean rank across experts less
387 than eight; i.e. included in the top half of all ranked measures on average across the six experts) included
388 nesting habitat creation for sandwich tern, reducing disturbance in the marine habitat around breeding
389 colonies (all three species), wider habitat restoration or creation (all three species), reducing marine
390 pollution (arctic tern), and supplementary feeding direct to the colony (arctic tern) (Table A2).

391 *Large gull species*

392 Averaged across experts, closure of forage fisheries ranked highest for both great black-backed gull and
393 lesser black-backed gull, whilst ranking sixth for herring gull. Management of nesting habitat was on
394 average ranked highest for herring gull, and fourth for lesser black-backed gull. Reducing disturbance at
395 colonies was on average ranked highest for herring gull, ranked third for great black-backed gull, and joint
396 second for lesser black-backed gull alongside predator management. For both great black-backed gull and
397 herring gull, management of predators was on average ranked second, joint with supplemental feeding via
398 discards or offal from fishing for herring gull. Altering control measures (gull control licenses) was ranked as
399 the fifth best measure for both herring gull and lesser black-backed gull. Other measures for large gulls that
400 were on average ranked relatively high (mean rank across experts less than eight; i.e. included in the top
401 half of all ranked measures on average across the six experts) included reduction of bycatch, altering of
402 control measures (gull control licenses) and nesting habitat management for great black-backed gull,
403 supplementary feeding direct to the breeding colony for both herring gull and lesser black-backed gull, and
404 via discards or offal from fishing for both great black-backed gull and lesser black-backed gull. Finally,
405 reducing marine pollution was also ranked in the top half of measures for great black-backed gull and
406 herring gull (Table A2).

407 *Northern gannet*

408 The highest ranked averaged measure on for northern gannet was reducing fisheries bycatch, followed by a
409 cessation in harvesting and closure of forage fisheries. Other measures for this species that were on
410 average ranked relatively high (mean rank across experts less than eight; i.e. included in the top half of all
411 ranked measures on average across the six experts) included supplementary feeding via discards or offal
412 from fishing, reducing marine pollution, reducing disturbance at colonies and in the marine environment,
413 management of predators and creation of nesting habitat (Table A2).

414 *Black-legged kittiwake*

415 The top ranked measure for all six experts for black-legged kittiwake was the closure of forage fisheries.
416 Creation of nesting habitat was on average ranked second, followed by management of predators. Other
417 measures for this species that were on average ranked relatively high (mean rank across experts less than
418 eight; i.e. included in the top half of all ranked measures on average across the six experts) included
419 management of nesting habitat, supplementary feeding via discards or offal from fishing and via direct
420 application at the breeding colony, reducing disturbance at breeding colonies, and lowering marine
421 pollution (Table A2).

422 *Atlantic puffin*

423 On average, the top ranked measure for Atlantic puffin was the closure of forage fisheries, followed by
424 management of predators, and management of nesting habitat. Other measures for this species that were
425 on average ranked relatively high (mean rank across experts less than eight; i.e. included in the top half of
426 all ranked measures on average across the six experts) included reducing disturbance at breeding colonies,
427 rescuing fledglings trapped in human structures, supplementary feeding direct to the breeding colony,
428 reducing disturbance in the marine habitat, and lowering of fisheries bycatch (Table A2).

429 *Common guillemot*

430 The top ranked measure on average across the six experts for common guillemot was the closure of forage
431 fisheries, followed by a reduction in fisheries bycatch, and management of predators. Four other measures
432 were on average ranked in the top half of measures (mean ranking across experts less than eight), including
433 management of nesting habitat, reduction of disturbance at breeding colonies, reducing disturbance in the
434 marine habitat, and lowering marine pollution (Table A2).

435 *Razorbill*

436 Averaged across the experts, the top ranked measure for razorbill was the closure of forage fisheries,
437 followed by management of predators, reduction of fisheries bycatch, and reducing disturbance in the
438 marine habitat. Three other measures ranked on average in the top half of potential actions (mean ranking
439 across experts less than eight), including reducing disturbance at breeding colonies, management of nesting
440 habitat, and a reduction in marine pollution (Table A2).

441

Table A2. Summary of individual and mean expert rankings for each compensatory measure by species combination.

Species	Arctic tern							Common tern							Northern gannet						
Measure	Expert Mean	Expert 1	2	3	4	5	6	Mean	1	2	3	4	5	6	Mean	1	2	3	4	5	6
Bycatch	10.7	8	11	12	10	11	12	10.8	8	11	12	11	11	12	1.5	1	1	2	1	2	2
Forage fisheries closures	2.7	1	4	1	1	4	5	2.8	2	4	1	1	4	5	3.3	7	3	1	2	4	3
Marine pollution	7.5	6	8	10	5	8	8	8.0	6	8	10	8	8	8	6.7	6	9	8	5	5	7
Nesting habitat creation	4.3	3	3	4	11	3	2	3.2	1	3	4	6	3	2	7.3	10	8	9	9	3	5
Nesting habitat management	2.7	5	1	3	2	1	4	2.7	5	1	3	2	1	4	9.0	9	7	5	12	11	10
Predator management	2.0	2	2	2	3	2	1	2.2	3	2	2	3	2	1	7.3	8	6	6	10	8	6
Reducing disturbance at colonies	4.8	4	5	5	6	6	3	4.7	4	5	5	5	6	3	7.2	4	5	7	8	7	12
Reducing disturbance in marine habitat	7.2	7	6	6	8	10	6	7.0	7	6	6	7	10	6	7.3	5	4	11	6	9	9
Supp feed: Direct to colony	7.8	9	7	8	7	9	7	8.2	9	7	8	9	9	7	11.0	11	10	13	11	10	11
Supp feed: discards/offal from fishing	9.2	10	10	9	9	7	10	9.3	10	10	9	10	7	10	6.5	2	11	12	4	6	4
Altering control measures	13.2	11	14	14	13	13	14	13.0	11	14	14	12	13	14	13.5	12	13	14	14	14	14
Cessation of harvesting of the species	13.2	12	13	13	14	14	13	13.2	12	13	13	14	14	13	2.3	3	2	4	3	1	1
Wider habitat restoration or creation	7.8	13	9	7	4	5	9	7.8	13	9	7	4	5	9	10.3	13	12	10	7	12	8
Rescuing fledglings	12.0	14	12	11	12	12	11	12.2	14	12	11	13	12	11	11.7	14	14	3	13	13	13

	Great black-backed gull							Common guillemot							Herring gull						
Measure	Mean	1	2	3	4	5	6	Mean	1	2	3	4	5	6	Mean	1	2	3	4	5	6
Bycatch	5.0	1	7	7	3	11	1	1.7	2	1	2	2	1	2	8.2	4	7	7	10	11	10
Forage fisheries closures	3.7	4	1	6	1	5	5	1.3	1	2	1	1	2	1	4.8	10	1	6	1	5	6
Marine pollution	7.8	7	6	10	8	6	10	6.2	7	9	4	5	5	7	7.7	8	6	10	7	6	9
Nesting habitat creation	9.2	8	5	8	12	13	9	9.2	8	8	11	11	9	8	8.8	7	5	8	12	13	8
Nesting habitat management	5.3	10	4	1	4	7	6	5.3	5	4	3	6	8	6	4.2	6	4	1	3	7	4
Predator management	4.0	3	2	4	11	1	3	3.3	3	3	5	3	3	3	4.3	5	2	4	11	1	3
Reducing disturbance at colonies	4.7	6	3	3	6	3	7	5.3	4	5	6	8	4	5	3.7	3	3	3	5	3	5
Reducing disturbance in marine habitat	10.5	11	8	12	10	10	12	5.5	6	6	7	4	6	4	10.3	11	8	12	9	10	12
Supp feed: Direct to colony	8.0	9	9	13	5	4	8	10.2	9	10	10	9	11	12	7.7	9	9	13	4	4	7
Supp feed: discards/offal from fishing	5.3	5	11	2	2	8	4	10.2	10	12	12	10	7	10	4.3	2	11	2	2	8	1
Altering control measures	5.0	2	12	5	7	2	2	12.8	11	13	14	12	13	14	4.7	1	12	5	6	2	2
Cessation of harvesting of the species	13.5	12	14	14	14	14	13	13.3	12	14	13	14	14	13	13.5	12	14	14	14	14	13
Wider habitat restoration or creation	10.2	13	10	9	9	9	11	9.2	13	7	9	7	10	9	10.0	13	10	9	8	9	11
Rescuing fledglings	12.8	14	13	11	13	12	14	11.5	14	11	8	13	12	11	12.8	14	13	11	13	12	14

	Black-legged kittiwake							Lesser black-backed gull							Atlantic puffin						
	Mean	1	2	3	4	5	6	Mean	1	2	3	4	5	6	Mean	1	2	3	4	5	6
Bycatch	8.7	7	5	7	11	11	11	9.0	4	7	12	10	11	10	7.2	5	4	11	6	4	13
Forage fisheries closures	1.0	1	1	1	1	1	1	3.5	2	1	6	1	5	6	1.3	1	1	1	1	3	1
Marine pollution	7.8	8	7	8	9	8	7	8.0	9	6	11	7	6	9	8.5	8	11	10	7	7	8
Nesting habitat creation	2.5	2	2	4	2	3	2	9.2	10	5	7	12	13	8	8.7	10	10	5	9	12	6
Nesting habitat management	5.0	9	4	3	3	7	4	4.5	8	4	1	3	7	4	4.5	4	3	3	3	9	5
Predator management	3.8	4	6	2	6	2	3	4.0	3	2	4	11	1	3	2.0	2	2	2	2	1	3
Reducing disturbance at colonies	7.5	5	9	12	7	6	6	4.0	5	3	3	5	3	5	5.7	3	7	6	10	6	2
Reducing disturbance in marine habitat	9.3	10	10	11	8	9	8	10.3	11	8	12	9	10	12	7.0	6	6	9	4	10	7
Supp feed: Direct to colony	6.5	6	3	10	5	5	10	7.3	7	9	13	4	4	7	6.8	7	9	8	11	2	4
Supp feed: discards/offal from fishing	5.5	3	11	6	4	4	5	5.0	6	11	2	2	8	1	11.0	11	12	12	12	8	11
Altering control measures	13.0	11	13	14	13	13	14	4.7	1	12	5	6	2	2	13.2	12	13	14	13	13	14
Cessation of harvesting of the species	13.3	12	14	13	14	14	13	13.5	12	14	14	14	14	13	13.3	13	14	13	14	14	12
Wider habitat restoration or creation	9.2	13	8	5	10	10	9	10.0	13	10	9	8	9	11	9.7	14	8	7	8	11	10
Rescuing fledglings	11.8	14	12	9	12	12	12	12.7	14	13	10	13	12	14	6.2	9	5	4	5	5	9

	Razorbill							Sandwich tern							Mean over all species	Mean over large gulls	Mean over terns	Mean over auks
	Mean	1	2	3	4	5	6	Mean	1	2	3	4	5	6	Mean	Mean	Mean	Mean
Bycatch	3.0	3	4	2	5	2	2	10.7	8	11	12	10	11	12	7	7	11	4
Forage fisheries closures	1.2	2	1	1	1	1	1	2.5	3	4	1	1	3	3	3	4	3	1
Marine pollution	6.5	7	10	4	6	5	7	8.3	9	8	10	7	8	8	8	8	8	7
Nesting habitat creation	9.3	8	9	11	11	9	8	5.2	4	3	4	11	5	4	7	9	4	9
Nesting habitat management	5.7	6	3	3	8	8	6	2.3	5	1	3	2	1	2	5	5	3	5
Predator management	2.7	1	2	5	2	3	3	1.8	1	2	2	3	2	1	3	4	2	3
Reducing disturbance at colonies	5.5	4	6	7	7	4	5	4.5	2	5	5	4	6	5	5	4	5	6
Reducing disturbance in marine habitat	4.8	5	5	6	3	6	4	6.7	6	6	6	6	10	6	8	10	7	6
Supp feed: Direct to colony	9.7	9	8	10	9	11	11	8.2	10	7	8	8	9	7	8	8	8	9
Supp feed: discards/offal from fishing	10.2	10	12	12	10	7	10	9.3	11	10	9	9	7	10	8	5	9	10
Altering control measures	13.0	11	13	14	13	13	14	13.2	12	14	14	12	13	14	11	5	13	13
Cessation of harvesting of the species	13.3	12	14	13	14	14	13	13.3	13	13	13	14	14	13	12	14	13	13
Wider habitat restoration or creation	8.7	13	7	9	4	10	9	6.8	7	9	7	5	4	9	9	10	8	9
Rescuing fledglings	11.5	14	11	8	12	12	12	12.2	14	12	11	13	12	11	12	13	12	10

Supplementary Material S4. Detailed summary of probabilistic judgements for each species and measure

Tern species

In terms of median values, experts broadly estimated the greatest potential gains in breeding success from protection from ground predators (median increase in breeding success for L, Q1, M, Q3, U, hereafter termed “from low to high”: 0.1, 0.3, 0.4, 0.5, 0.65), vegetation management (median increase in breeding success from low to high: 0.01, 0.2, 0.24, 0.3, 0.3), artificial structure creation (median increase in breeding success from low to high: 0, 0.01, 0.1, 0.24, 0.6) and attraction into existing habitat (median increase in breeding success from low to high: 0, 0.01, 0.1, 0.24, 0.6), with the strongest consensus across experts for median values in vegetation management, and considerable variation amongst experts’ median values for protection from ground predators, artificial structure creation and attraction into existing habitat (Figure 1). For the four other measures, regulating human activity and limiting shipping traffic were estimated to have negligible potential benefits to breeding success according to experts’ median values with strong consensus across the five experts (all median values very close to zero, Figure 1), and for minimising human disturbance and creating seagrass habitat experts’ median values suggested some potential improvement to breeding success, particularly for the seagrass measure where medians were up to 0.2 to 0.4 for three experts (Figure 1).

Quartile ranges were narrowest around those measures estimated to have negligible benefits to breeding success (regulating human activity and limiting shipping traffic), reflecting a strong consensus across experts that these two measures are unlikely to produce gains in breeding success in tern species. Quartile ranges were also relatively narrow for both minimising human disturbance and creating seagrass habitat (Figure 1), reflecting a degree of consensus across experts in the likely effectiveness of these measures, albeit associated with only marginal increases in breeding success (Figure 1). Quartile ranges for artificial structure creation were the greatest across all eight measures, with three experts’ lower quartiles estimating that breeding success could be lower at newly created colonies when compared to existing colonies (Figure 1). These wide values for quartile ranges likely partly reflect that experts’ were estimating gains across a range of tern species, with some known species-specific differences in propensity to use newly created habitats for breeding. Finally, quartile ranges for vegetation management, protection from ground predators and attraction into existing habitat were all relatively wide, again with two experts’ lower quartiles suggesting that breeding success could be lower in newly recolonised habitat when compared to existing colonies (Figure 1).

For demographic gains via increases in adult survival, two of the measures had median values from some of the experts with a greater than 1% increase in adult survival upon implementation of the measure -- seagrass habitat creation (median increase in adult survival from low to high: 0.01, 0.01, 0.02, 0.025, 0.2) and protection from ground predators (median increase in adult survival from low to high: -0.04, 0, 0.01, 0.02, 0.05; Figure 1). Quartile ranges for these two measures indicated relatively more consensus amongst experts in their estimates for potential benefits arising from protection from ground predators, with wider inter-quartile ranges reported for creation of seagrass habitat, however lower bound estimates included more negative values for protection from ground predators (3 out of 5 estimates) than for creation of seagrass habitat (1 out of 5 estimates) (Figure 1). The other six other measures all included a median value for increases in adult survival of up to 1% from at least one of the experts, with several measures also receiving estimates of one half of one percent from a few of the other experts, including minimising human disturbance at the colony and regulating human activity in the marine environment (Figure 1). Notably, several of the measures received negative estimates for lower bounds from all five experts (artificial structure creation, attraction into existing habitat – noting that both of these measures required experts to estimate the change in adult survival between an existing colony versus a newly created one), or for 4 of the 5 experts (vegetation management of nesting habitat), suggesting experts considered these measures to potentially result in declines in adult survival in some situations.

Large gull species

Three of the measures had median estimates from experts indicating low expectations of gains in breeding success, including providing offal from fishing (median increase in breeding success from low to high: 0, 0.02, 0.05, 0.1, 0.1), dropping the zero-discard policy (median increase in breeding success from low to high: 0.01, 0.02, 0.05, 0.1, 0.1) and minimising human disturbance (median increase in breeding success from low to high: 0.05, 0.1, 0.1, 0.1, 0.1; Figure 2). Consensus across experts for the measures for providing offal from fishing and dropping the zero-discard policy was strong, reflected by narrow inter-quartile ranges and upper and lower bounds (Figure 2). This was also generally the case for the measure of minimising human disturbance, although in this case whilst inter-quartile ranges were narrow, ranges from lower to upper bounds were wide (Figure 2). Eradication of mammalian predators indicated some potential gains in breeding success across the experts' median values (low to high: 0.02, 0.05, 0.1, 0.2, 0.41), but with considerable variation amongst experts in their inter-quartile ranges and upper and lower bounds (Figure 2). The four remaining measures also suggested a potential for demographic gains via increased breeding success; vegetation management (low to high: 0.01, 0.1, 0.15, 0.2, 0.21), delivering food on the ground at the colony (low to high: 0.15, 0.2, 0.2, 0.3, 0.5), deterrence of aerial predators (low to high: 0.01, 0.1, 0.1, 0.13, 0.31), and additional conservation designation (low to high: 0.05, 0.11, 0.2, 0.2, 0.3) (Figure 2). Again, all of these four measures had considerable variation across experts in upper and lower quartiles, and in upper and lower bounds, particularly in the case of vegetation management and delivering food on the ground at the colony which both included some relatively strong negative estimates for lower bounds (Figure 2).

For potential gains in adult survival, three of the measures (vegetation management, eradication of mammalian predators and deterrence of aerial predators) had median values across the experts that did include at least one estimate for potential gains in adult survival of 1%, but also included median estimates for zero or slightly negative median values, with lower bounds and lower quartiles also including negative values, including one expert who estimated a lower bound of a potential decrease in adult survival of around 10% for vegetation management (Figure 2). The measure aimed at minimising human disturbance also resulted in median estimate for potential gains in adult survival of 1% from two experts and for one half of one percent for another 2 experts, coupled with no negative values in either medians or quartile ranges and only one negative estimate for lower bounds (Figure 2). This measure does, therefore, appear to represent relative consensus across experts for potentially delivering positive changes to adult survival in gull species. The four remaining measures all also indicated potential adult survival benefits according to the experts' median values. Dropping the zero-discard policy had median values of around 1% to 5% increases in adult survival across experts (noting one exception indicating a 4% decrease in adult survival; Figure 2). Delivering offal from fishing resulted in median values of <1% for 2 experts and 1-2% for 3 experts (Figure 2). Providing food on the ground at the colony resulted in median values indicating a 1% to 3% increase in adult survival with strong consensus in median values across all five experts (Figure 2). And finally, additional conservation designations had median values of 0 to 2% increase in adult survival, again with good consensus in median values across the five experts (Figure 2). The estimates for upper and lower bounds for changes to adult survival were widest for dropping the zero-discard policy, providing offal from fishing, and providing food on the ground at the colony indicating strong uncertainty and variability in experts' estimates for these measures (Figure 2).

Northern gannet

Median estimates for potential gains in breeding success arising from the five compensatory measures considered for gannets were broadly similar across four of the measures, with a tendency to be lower for the measure involving limiting shipping traffic within year-round foraging areas (median increase in breeding success from low to high: 0.0001, 0.01, 0.01, 0.02, 0.03; Figure 3). Median values for the alternative four measures were variable across experts, reflected in the relatively wide quartile ranges for each measure (Figure 3), but did suggest the potential for some gains in breeding success likely to arise from application of management of ghost fishing gear (median increase in breeding success from low to high:

0.003, 0.01, 0.02, 0.05, 0.05; Figure 3), regulating human activity in the marine environment close to breeding colonies (median increase in breeding success from low to high: 0.002, 0.01, 0.02, 0.05, 0.05; Figure 3), dropping the zero-discard policy (median increase in breeding success from low to high: 0.009, 0.01, 0.05, 0.05, 0.07; Figure 3), and provision of offal from fishing in over-wintering areas (median increase in breeding success from low to high: 0, 0.01, 0.03, 0.05, 0.07; Figure 3). There was strong uncertainty associated with the estimates of potential gains in breeding success for all five measures considered for this species, with wide ranges reported, especially for regulating human activity and dropping the zero-discard policy (Figure 3). Notably, all five measures included relatively strong negative estimates for lower bounds from one of the five experts, indicating a potential for measures to result in negligible gains or even losses in breeding success (Figure 3).

Two measures included potential increases in adult survival of 1%-2.5% for median values from several experts (provision of offal from fishing in over-wintering areas, and dropping the zero-discard policy; Figure 3), although one of these, relating to the zero discard policy, also included one negative estimate for the median, and 3 of the 5 experts estimate negative values for lower bounds for this measure (Figure 3). Most consistently, the median estimates for increases in adult survival arising from these two measures tended to include gains of 1-2% (provision of offal from fishing: 3 out of 5 experts; dropping zero-discard: 4 out of 5 experts; Figure 3). The remaining three measures were all estimated to have a 1% increase in adult survival by at least one of the experts (based on median values), and with 2 to 3 experts estimating potential gains of one half of one percent for both limiting shipping traffic and regulating human activity in the marine environment (Figure 3). The estimates for upper and lower bounds for changes to adult survival were widest for dropping the zero-discard policy and for providing offal from fishing, indicating strong uncertainty and variability in experts' estimates for these measures (Figure 3). Notably, one expert estimated a median decrease in adult survival arising from dropping of the zero-discard policy for gannets, and indeed their estimates for quartiles and lower and upper bounds were all also negative (upper bound equalled zero), indicating a strong belief in potential negative consequences for adult survival arising from this measure (Figure 3).

Black-legged kittiwake

Median estimates for potential gains in breeding success arising from the five compensatory measures considered for black-legged kittiwake indicated stronger support for expected gains for two of the measures -- delivering food directly to the nest (median increase in breeding success from low to high: 0.1, 0.3, 0.4, 0.67, 0.9207; Figure 4), and artificial structure creation (median increase in breeding success from low to high: 0, 0.01, 0.1, 0.24, 0.8; Figure 4). The remaining three measures had broadly similar estimates for median potential gains in breeding success, all below gains of 0.15: minimising human disturbance at the breeding colony (median increase in breeding success from low to high: 0.01, 0.02, 0.05, 0.1, 0.1; Figure 4), dropping the zero-discard policy (median increase in breeding success from low to high: 0.001, 0.019404, 0.05, 0.1, 0.1; Figure 4), and delivering offal from fishing vessels to over-wintering areas (median increase in breeding success from low to high: 0, 0.019, 0.05, 0.1, 0.15; Figure 4).

Quartile ranges for potential increases in breeding success arising from the five measures were widest for the two measures with greater estimated potential for gains (delivering food directly to the nest, and creation of artificial structures; Figure 4). This suggests that whilst experts generally expected both of these measures to deliver gains in breeding success, there was considerable uncertainty within experts in relation to the potential magnitude of such gains (Figure 4), as well as between experts – particularly for the creation of artificial structures where two of the five experts estimated the potential for lower quartile ranges to include negative changes in breeding success upon application of this measure (Figure 4). Quartile ranges for the remaining three measures were narrower, reflecting the much lower estimated median gains in comparison to the most successful measures (Figure 4). The same pattern was reported for the upper and lower ranges of potential gains in breeding success, with the widest ranges for delivering food directly to

the nest and for creation of artificial nesting structures, with the widest variability in ranges reported for artificial structures, where four of the five experts reported a negative lower bound for their estimates indicating the potential for a reduction in breeding success should this measure be applied (Figure 4).

Three of the measures were estimated to have relatively high potential for gains in adult survival with median values indicating up to a 4% or 5% potential increase in this vital rate for delivering food directly to the nest (median increase in adult survival from low to high: 0, 0.01, 0.01, 0.04, 0.05; Figure 4), provision of offal from fishing in over-wintering areas (median increase in adult survival from low to high: 0.01, 0.01, 0.02, 0.04, 0.04; Figure 4), and dropping the zero-discard policy (median increase in adult survival from low to high: 0.001, 0.01, 0.02, 0.04, 0.05; Figure 4). However, three experts estimated negative values for their lower bounds for delivering food directly to the nest, including a potential reduction in adult survival of 5% from 2 of the experts, revealing a strong potential for application of this measure resulting in decreases in adult survival in some situations. Two experts estimated potential gains of 1% for minimising human disturbance at the breeding colony for their median values, with a 3rd expert estimating potential gains of one half of one percent (Figure 4). Only one potential negative value was estimated for this measure for the lower bound, suggesting relative consensus across experts in the likelihood of potential positive gains in adult survival arising from this measure. However, for the creation of artificial nesting structures, two of the experts considered a non-trivial negative, reduction in adult survival of 1% or 2% to be plausible for this measure (based on median values), one expert expected no change in adult survival, and two estimated median values for a 0.5% and 2% potential gain in adult survival (Figure 4). Estimates for upper and lower bounds were again widest for the three measures with the highest estimated median values for potential gains in adult survival (delivering food directly to the nest, provision of offal to over-wintering areas, and dropping the zero-discard policy; Figure 4). However, for the creation of artificial nesting structures, experts' also reported wide upper and lower bounds, reflecting high variation in experts' estimates for the expected gains, or losses, arising from application of this measure to black-legged kittiwake adult survival (Figure 4). Notably, 4 of the 5 experts estimated negative values for their lower bounds, and 3 of the 5 experts estimated negative values for their lower quartiles for this measure, indicating a strong potential for declines in adult survival in some situations for implementation of artificial structures.

Atlantic puffin

For puffin, median potential gains in breeding success arising from the eight compensatory measures considered by the experts revealed relatively strong support for expected positive gains for several methods. Notably, eradication of mammalian predators (median increase in breeding success from low to high: 0.1, 0.1, 0.2, 0.3, 0.465), delivering food directly to the nest (median increase in breeding success from low to high: 0.1, 0.1, 0.15, 0.2, 0.465), and deterrence of aerial predators (median increase in breeding success from low to high: 0.0186, 0.1, 0.1, 0.1, 0.25), all resulted in median estimates for relatively large, positive gains in puffin breeding success with none of the inter-quartile ranges including negative values (Figure 5). Vegetation management also resulted in median gains in breeding success that were relatively well supported by experts' estimates (median increase in breeding success from low to high: 0.05, 0.05, 0.093, 0.15, 0.2; Figure 5), again with none of the lower quartile estimates for the five experts including any negative values. Attraction into existing habitat also resulted in experts' median estimates suggesting largely positive gains in puffin breeding success (median increase in breeding success from low to high: 0, 0.05, 0.05, 0.2, 0.372; Figure 5), although here, one of the experts estimated a potentially negative change in breeding success as their lower quartile value (Figure 5). Experts also estimated median values for gains in breeding success arising from minimising human disturbance that were positive, albeit slightly smaller than for some of the other measures (median increase in breeding success from low to high: 0.01, 0.0186, 0.1, 0.2, 0.2; Figure 5), but again, none of the experts included a negative value for their lower quartile estimate for this measure suggesting a relatively strong level of support for a small, but positive response in puffin breeding success upon application of the measure. Finally, the remaining two measures had median estimates from experts that were close to zero, with regulating human activity in the marine environment near the colony receiving estimates of less than 0.05 from all but one expert (median increase in breeding

success from low to high: 0.002, 0.00465, 0.01, 0.02, 0.05; Figure 5), and limiting shipping traffic within year-round foraging areas receiving similarly low median values for potential gains (median increase in breeding success from low to high: 0.0001, 0.01, 0.01, 0.0279, 0.05; Figure 5).

Inter-quartile and upper and lower bounds for potential gains in puffin breeding success arising from those measures with the largest estimated medians were relatively narrow, suggesting low uncertainty and variability associated with experts' estimates for the potential for positive gains arising from the two predation measures and delivery of food direct to the nest (Figure 5). Uncertainty and variability, as captured by experts' estimates for upper and lower bounds, were relatively greater for two of the other measures in which experts' median suggested potential for gains in breeding success. Both vegetation management and attraction into existing habitat had several negative estimates for lower bounds, suggesting that experts anticipated some potential for declines in breeding success should these measures be applied (Figure 5).

Experts' median estimates for gains in adult survival identified the same three measures likely to have the best gains as those indicated for breeding success, with deterrence of aerial predators (median increase in adult survival from low to high: 0, 0.01, 0.025, 0.02, 0.02) and eradication of mammalian predators (median increase in adult survival from low to high: 0, 0.01, 0.01, 0.01, 0.05), as well as delivery of food directly to the burrow (median increase in adult survival from low to high: 0.00175, 0.01, 0.01, 0.01, 0.02) all having relatively high positive median values, with only one expert estimating a negative value for the lower bound in each measure (Figure 5). Estimated lower bounds for these three measures also indicted experts believed negative effects on adult survival arising from these measures were unlikely, with most lower bounds for these three measures very close to zero (Figure 5). The remaining five measures also included relatively consistent support for potential gains in adult survival, with 4 experts estimating potential gains in adult survival of one half of one percent to 1% for limiting shipping traffic and minimising human disturbance at the colony (Figure 5). The remaining three measures (regulating human activity in the marine environment, vegetation management, and attraction into existing habitat) all received an estimate from 2 of the 5 experts of a potential one half of one percent or a 1% increase in adult survival, but importantly, two of these measures (vegetation management and attraction into existing habitat) included negative lower bound estimates from 4, or all 5 of the experts, as well as one negative estimate for the median value (Figure 5).

Common guillemot

Deterrence of aerial predators was the measure with the greatest reported median values for potential gains in guillemot breeding success (median increase in breeding success from low to high: 0.01, 0.05, 0.1, 0.2, 0.291), along with the widest inter-quartile ranges, although no experts estimate a lower inter-quartile value that included the potential for negative changes to breeding success upon application of this measure (Figure 6). Similarly, eradication of mammalian predators showed good potential for positive gains in guillemot breeding success, with experts reporting relatively high median values (median increase in breeding success from low to high: 0.05, 0.05, 0.05, 0.1, 0.194), and no experts estimating negative values for lower inter-quartiles (Figure 6). Minimising human disturbance at colonies was also estimated by experts as having relatively high median values (median increase in breeding success from low to high: 0.02, 0.0485, 0.05, 0.1, 0.1), again with no experts estimating negative values for lower inter-quartile range values (Figure 6). The final two measures also reported modest potential gains in guillemot breeding success, limiting shipping within year-round foraging areas (median increase in breeding success from low to high: 0.001, 0.02, 0.02, 0.0582, 0.1) and regulating human activity in the marine environment close to colonies (median increase in breeding success from low to high: 0.01, 0.02, 0.02, 0.02, 0.0485), again with no experts estimating negative values for lower inter-quartile ranges for these two measures (Figure 6).

In contrast to some of the other species considered, estimates for gains in adult survival in this species were relatively low. At least one of the experts estimated a potential gain of up to 1% in adult survival for

all five of the measures considered (based on median values), however there was considerable variation across experts with some predicting very small potential gains of less than one quarter of one percent (Figure 6). Limiting shipping traffic was estimated by 4 of the 5 experts to have the potential for a one half of one percent to a 1% increase in adult survival (Figure 6), with the same true for 3 of the 5 experts for an additional two measures – minimising human disturbance at the breeding colony and regulating human activity in the marine environment (Figure 6). Importantly, all of the measures considered for puffin were estimated by experts to have the potential for decreases in adult survival, represented by negative lower bounds from at least one of the experts for all measures, and by negative lower quartiles from at least one expert for two of the five measures (deterrence of aerial predators, and eradication of mammalian predators). However, unlike some of the other species considered, no experts estimated a negative value for any of the median values across all of the measures considered, and in general estimates showed relative consistency across experts (Figure 6Figure 3).

Razorbill

Similar to guillemot, the predation-related measures indicated the best potential for gains in breeding success across the five experts' estimates. Deterrence of aerial predators was the measure with the greatest reported median values for potential gains in razorbill breeding success (median increase in breeding success from low to high: 0.01, 0.05, 0.1, 0.1455, 0.25), with no experts estimating a lower inter-quartile value that included the potential for negative changes to breeding success upon application of this measure (Figure 7). Likewise, eradication of mammalian predators showed good potential for positive gains in razorbill breeding success, with experts reporting relatively high median values (median increase in breeding success from low to high: 0.05, 0.1, 0.2, 0.2, 0.388), and no experts estimating negative values for lower inter-quartiles (Figure 7). Minimising human disturbance at colonies was also estimated by experts as having relatively high median values (median increase in breeding success from low to high: 0.01, 0.0291, 0.05, 0.1, 0.1), again with no experts estimating negative values for lower inter-quartile range values (Figure 7). The final two measures also reported modest potential gains in razorbill breeding success, limiting shipping within year-round foraging areas (median increase in breeding success from low to high: 0.0001, 0.02, 0.02, 0.0582, 0.1) and regulating human activity in the marine environment close to colonies (median increase in breeding success from low to high: 0.01, 0.01, 0.0485, 0.02, 0.02), again with no experts estimating negative values for lower inter-quartile ranges for these two measures (Figure 7).

In contrast to some of the other species considered, estimates for gains in adult survival in razorbills were relatively low. At least one of the experts estimated a potential gain of up to 1% in adult survival for all five of the measures considered (based on median values), and for some measures the experts' estimates for median values for gains in adult survival were pretty consistent, around 0.5%-1.0% (Figure 7). One measure, limiting shipping traffic, resulted in 4 of the 5 experts estimating potential gains in adult survival of one half of one percent to 1% (based on median values), and two additional measures (minimising human disturbance at the colony, and regulating human activity in the marine environment) also received similar estimates for gains of one half of one percent to 1% from 2 of the 5 experts (Figure 7). In addition, all of the measures considered for puffin were estimated by experts to have the potential for decreases in adult survival, represented by negative lower bounds from at least one of the experts for all measures, and by negative lower quartiles from at least one expert for two of the five measures (deterrence of avian predators, and eradication of mammalian predators). However, as for guillemot, unlike some of the other species considered, no experts estimated a negative value for any of the median values across all of the measures considered for razorbill, and in general estimates showed relative consistency across experts for this species (Figure 7Figure 3).