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1 **Title:** Winter extratropical cyclones influence seabird survival: variation between and within
2 common eider populations

3 **Running page head:** Winter extratropical cyclones and eider survival

4

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24 **Keywords:** Seabirds; Extreme weather and climatic event; marine vertebrates, multi-event
25 models; hidden states and mixture models; NAO; Arctic; inter and intra-population

26 heterogeneity; migratory tactics; *Somateria mollissima*;

27 **Abstract**

28 Mid-latitude atmospheric variability is mainly driven by extratropical cyclones (ETCs) that
29 play a primary role in determining the variation in local weather and marine conditions. ETCs
30 have a broad range of intensities, from benign to extreme, and their paths, frequency, and
31 intensity may change with global warming. However, how ETCs, and cyclones in general,
32 currently affect marine wildlife is poorly studied and remains substantially unexplored. To
33 understand how extreme winter ETCs affect the inter-annual variability of adult seabird survival
34 within and between populations, we used capture-mark-recapture datasets collected in two arctic
35 (northern Canada and Svalbard) and one subarctic (northern Norway) breeding populations of
36 common eider, *Somateria mollissima*, over periods of 19, 16 and 30 years, respectively. We
37 found significant negative correlations between winter ETC activity and eider survival, but
38 different mechanisms appear to be involved in the different studied populations. The number of
39 winter ETCs, extreme or not, was found to be linked to survival without lags in the Canadian
40 population, whereas amplitude and duration of extreme winter ETCs (with time lags) impacted
41 adult survival in the Svalbard and northern Norway eider breeding populations. We hypothesise
42 that fjords found on the wintering grounds would act as climatic shelters and provide natural
43 protection, and hence could partly explain inter-population heterogeneity in the response to
44 ETCs. We suggest that ETCs represent a likely mechanism behind the frequently reported
45 relationship between North Atlantic Oscillation and seabird survival in the North Atlantic.

46 **Introduction**

47 Understanding how individuals and populations respond to fluctuations in climatic conditions
48 is critical in order to explain and anticipate changes in ecological systems. This requires
49 identifying relevant climatic parameters that affect demographic rates (e.g. survival, recruitment

50 or breeding success; (Jenouvrier 2013), both directly and indirectly (Grosbois & Thompson
51 2005, Harris et al. 2005). In some regions, extreme climatic events such as heat waves, droughts,
52 intense precipitation and storms are predicted to increase in frequency in most future climate
53 scenarios and have been identified as one of the largest threats to wildlife (Easterling et al. 2000)
54 IPCC 2002; (Ummenhofer & Meehl 2017). Adverse weather conditions caused by these events
55 have already been identified as having a direct impact on plants (e.g. (Reyer et al. 2013) and
56 animals (e.g. Jenouvrier et al. (2015) for birds, Tyler (2010) for large mammals).

57 Tropical cyclones, defined as air masses rotating around a centre of low atmospheric pressure
58 originating in the tropics, and their associated strong winds are often reported as examples of
59 extreme events, which can drive wildlife demography (e.g. Dunham et al. (2011) on a lemur
60 species or Pike and Stiner (2007) on sea turtle species). In birds, most studies dealing with the
61 effect of tropical cyclones are based on a single population and a single extreme event
62 (Chambers et al. 2011, Raynor et al. 2013), with much greater mass-mortality occurring during
63 migration periods (Newton 2007). However, studies based on long-term population monitoring
64 and fluctuations of extreme events over time are crucial to properly quantify the effect of such
65 events on bird demography (van de Pol et al. 2017). There are very few examples of such studies
66 in the literature in the context of extreme events (Jenouvrier et al. 2009, Boano et al. 2010,
67 Genovart et al. 2013, Descamps et al. 2015). Moreover, populations of a given species and
68 individuals within a population may respond differently to extreme events. None of the previous
69 studies considered such potential heterogeneity although it may influence species persistence.

70 In addition, the vulnerability of wildlife to cyclones occurring outside the tropics
71 (extratropical cyclones, ETCs; (Wang et al. 2013) has never been investigated although they are
72 a dominant feature of mid-latitude atmospheric variability and play a primary role in determining

73 local weather (Hoskins & Hodges 2002, Ulbrich et al. 2009, Wang et al. 2013). ETCs
74 (extratropics defined as 30–90°N or S) are often associated with extreme winds and precipitation
75 and with changes in temperature (Hoskins & Hodges 2002, Ulbrich et al. 2009, Wang et al.
76 2013). Hence, assessing the potential effects of ETCs and their extremes (i.e., cyclones
77 associated with extremely high wind speeds) on marine bird species breeding, wintering or
78 migrating outside the tropics is important to understand ecological responses to changes in
79 climatic conditions.

80 In this study, we investigated the influence of winter ETCs, extreme or not, on adult survival
81 of a long-lived sea duck, the common eider (*Somateria mollissima*). Increased ETC activity
82 could directly (no time lag) increase their foraging effort and energetic needs required to
83 maintain body temperature (Heath et al. 2006, Heath & Gilchrist 2010) and ultimately may
84 directly decrease common eider survival. In addition, ETCs could negatively and indirectly (with
85 time lag) affect eider survival by influencing oceanographic conditions (Visbeck et al. 2003,
86 Sarafanov 2009) and hence eider food availability and/or food quality (Menge et al. 2008,
87 Descamps et al. 2010). Heavy storms can destroy bivalves beds at shallow depths (Brenko &
88 Calabrese 1969, Reusch & Chapman 1995, Carrington 2002, Carrington et al. 2009) or reduce
89 primary productivity (Fujii & Yamanaka 2008).

90 The effects of ETCs could be modulated by coastal topography and by the presence of fjords
91 on the eider wintering grounds. Fjords, hereafter named “climatic shelters”, are defined as
92 narrow inlets of the sea between cliffs or steep slopes, which can provide natural shelters from
93 the wind (Howe et al. 2010). The climatic shelter effect of fjords has already been suggested for
94 marine wildlife (Boje 2002, Brown 2002, Sanino & Van Waerebeek 2008, Howe et al. 2010,
95 Acevedo et al. 2017). Hence, we expect that the direct effects of ETCs on birds should be

96 strongly reduced for eiders wintering in areas offering climatic shelters. When natural shelters
97 are available, the effects of ETCs, if any, should be mostly indirect (through the food chain). The
98 effects of ETCs may thus vary among and within populations, depending on the presence of
99 climatic shelters and on the frequency and/or intensity of the ETC affecting the specific
100 wintering grounds used by birds. We examined the relationship between winter ETCs and eider
101 survival in three breeding populations with different wintering areas. We predicted intra- and
102 inter-population heterogeneity in the effects of ETCs on survival and hence defined population-
103 specific predictions.

104 Most female eiders breeding in Canada winter in southwest Greenland, where there is
105 access to climatic shelters (fjords), while the rest of the population winter in southern Atlantic
106 Canada, with no access to fjords (Mosbech et al. 2006, Guéry et al. 2017). Winter ETC activity
107 also varies between these two distinct wintering grounds (e.g. more ETCs and a longer duration
108 of extreme ETCs in southern Atlantic Canada; Table 1). We thus expected to observe intra-
109 population heterogeneity in the response of eider survival to ETC activity in this Canadian
110 breeding population, and we predicted that winter ETC activity would have a negative influence
111 with a direct (without time lag) effect only on the survival of eiders wintering in southern
112 Atlantic Canada (Figure 1). For eiders breeding in Svalbard, the majority winter in the northeast
113 fjords of Iceland while the others winter in fjords of northern Norway. Eiders breeding in
114 northern Norway are year-round residents and spend the winter in the fjords close to their
115 breeding grounds. We thus expected no direct effect of winter ETC activity in both the Svalbard
116 and Northern Norway breeding populations (Figure 1).

117 Finally, we expected that the frequency and intensity of winter ETCs would be the main
118 specific driver explaining the reported relationships between the North Atlantic Oscillation

119 (hereafter, NAO; Hurrell *et al.* 2003) and the survival of eider populations wintering in the North
120 Atlantic (Guéry *et al.* 2017). The winter NAO is well-known to be correlated with mean
121 intensity, track density and mean speed of ETCs (Sorteberg *et al.* 2005), especially in winter
122 (Hurrell *et al.* 2003). In accordance with previous results based on NAO (Guéry *et al.* 2017), we
123 predicted that winter ETC activity would have negative and indirect (with time lag) effects on
124 eiders wintering in northern Norway (Figure 1). The specific wintering location of many
125 individuals in our study populations was unknown. To investigate intra-population heterogeneity,
126 we thus used a novel statistical tool (capture-recapture mixture model) to test for a priori
127 expected intra-population heterogeneity. This approach allowed us to examine the relationship
128 between local wintering conditions and the survival response of groups of individuals generated
129 by the mixture model based on capture history. A lack of recapture data in the Svalbard breeding
130 population prevented us from properly testing intra-population heterogeneity in the survival
131 response to ETC activity, so the ETC effect of each wintering ground (either Iceland or northern
132 Norway) was tested on the whole population.

133 **Materials and methods**

134 *Study species and populations*

135 *Common eider (Somateria mollissima)*

136 Common eiders are sea ducks that mostly breed in the Arctic and whose females are typically
137 faithful to their natal colony (Wakeley & Mendall 1976, Swennen 1989). They start breeding
138 between 2 and 5 years old (Hario *et al.* 2009) and can live an average of 15 years (Zammuto
139 1986). Only adult females (>2 years old as they come back to the colony to attempt breeding)
140 were captured on their breeding grounds and included in the study, but their exact age was
141 unknown. Their winter diet can include several marine resource types such as bivalves, marine

142 *polychaete* worms, gastropods, crustaceans and echinoderms (Goudie & Ankney 1986,
143 Guillemette et al. 1992, Merkel et al. 2007).
144
145 *Canadian Arctic, East Bay Island*
146 Data were collected from 1996 to 2014 on East Bay Island (Mitivik Island; 0.19 km²), a small
147 island in the North East of Southampton Island, Nunavut, Canada. An average of 545 female
148 eiders (ranging from 209 in 1997 to 1035 in 2006) were annually seen from observation blinds or
149 physically captured. Blind distribution and the rolling topography of the island induced detection
150 heterogeneity among birds (Guéry *et al.* 2017). The wintering areas of 26 common eider females
151 were determined (see below) using satellite transmitters implanted in 2001 and 2003 (Mosbech
152 *et al.* 2006), and in 2012 and 2013 (Gilchrist unpubl. data; Figure 2). The procedures for
153 capturing, marking and band reading in East Bay are described in detail by both Mosbech *et al.*
154 (2006) and Descamps *et al.* (2010). Female eiders from East Bay winter either in southwest
155 Greenland (78%) or near sea ice edges of southern Atlantic Canada (22%) along southern
156 Labrador, Newfoundland, and south of the Gulf of Saint-Lawrence (Mosbech et al. 2006); Figure
157 2). Sea ice is observed only in the southern Atlantic wintering area
158 (http://nsidc.org/data/seaiice_index/archives/image_select.html). In the Gulf of St. Lawrence,
159 eiders preferably feed on blue mussels that they find near the shore, in kelp beds or in rocky
160 habitat (Guillemette et al. 1992), while they feed on gastropods in Newfoundland (Goudie &
161 Ankney 1986) and on softshell clams *Mya eideri* and marine *polychaete* worms that they find in
162 soft sediments in southwest Greenland (Merkel et al. 2007).
163
164 *Svalbard, Prins Heinrich Island*

165 An average of 65 females (ranging from 8 in 2003 to 136 in 2007, with 0 captured in 2000 and
166 2006) were physically captured every year from 1999 to 2014 on Prins Heinrich Island (78° 55
167 'N, 12°00' E; Figure 2), on the west coast of Svalbard, one of several islands housing an eider
168 colony with 3000 breeding females. This small island (0.06 km²) in Kongsfjorden, covered by
169 rock and tundra, is a flat and homogeneous island. No heterogeneity in detection occurred
170 (Guéry et al. 2017). About 77% of eiders in this breeding population migrated to northeastern
171 Iceland and 23% to northern Norway (Hanssen *et al.* 2016), called zone 1 (Figure 2). Wintering
172 locations were determined from geolocators (Global Location Sensing or GLS logging; Wilson
173 *et al.* 1992), which record sunlight intensity used to calculate visited areas with an accuracy of
174 ca. 200 km around each point (Wilson et al. 1992). Due to the lack of variation in day length
175 with respect to latitude close to equinoxes, latitudes are unreliable for these specific periods.
176 Geolocators were deployed on female common eiders breeding on Storholmen Island, located 5
177 km NE of Prins Heinrich Island. A total of 95 females were equipped in June or July over four
178 years (2009, 2010, 2011 and 2013), while 48 females were recaptured and data was successfully
179 retrieved from 47 geolocators. Details on capture, geocator deployment, and the calibration,
180 smoothing and calculations of the geocator data are described in Hanssen *et al.* (2016).

181

182 *Northern Norway, Grindøya Island*

183 This study was conducted in an eider colony (200-500 pairs) on Grindøya, a 0.65-km² island near
184 Tromsø, northern Norway (69°37'N, 18°51'E, Figure 2). During the breeding seasons of 1985-
185 2014, nesting female eiders were captured (average of 104; ranging from 36 in 2014 to 235 in
186 1995) with a noose pole during the incubation period, i.e. only physical recaptures occurred (no
187 band reading at distance). Females from Grindøya annually breed in habitats including beach,

188 stunted forest or bushes that induced heterogeneity in detection probability (Guéry et al. 2017).
189 They are resident and preferably feed on blue mussels. They thus spend the winter in the vicinity
190 of their breeding location in northern Norway (Bustnes & Erikstad 1993, Anker-Nilssen et al.
191 2000), called zone 2, all exposed to the same winter conditions.

192

193 *Wintering areas definition*

194 Wintering areas were defined using tracking data for the two migrating populations: from
195 satellite transmitters for the Canadian breeding population and geolocators for the Svalbard
196 breeding population. All tracking data were filtered to keep only reliable locations following the
197 procedures described in Mosbech *et al.* (2006) for the Canadian breeding population and in
198 Hanssen *et al.* (2016) for the Svalbard breeding population. Thus, we extracted winter locations
199 from December to March for the Canadian population and from December to February for the
200 Svalbard population. Data were excluded close to the spring equinox (March) for Svalbard eiders
201 (see above). We then calculated kernel densities and kernel contours using the `adehabitatHR`
202 package in R (Calenge 2006). Finally, as female eiders only reside at sea and along shorelines
203 during winter, we subtracted land cover from the density core contours to get the final wintering
204 areas (Figure 3). For eiders from northern Norway, no tracking data were available, but they are
205 known to stay close to the shore in water shallower than 10m (Bustnes & Lønne 1997) in the
206 vicinity of their breeding island (mostly within 50 km, Bustnes and Erikstad unpublished data).
207 As eiders spread along the shoreline, we defined their wintering area as the smallest ellipse that
208 is allowed by the data grid resolution of the data used to identify ETCs and is parallel to the
209 shoreline and centred on the breeding island, i.e. with a major axis of 200 km and a minor axis of
210 160 km. We also subtracted land cover to get the final wintering areas.

211

212 ***Variables considered***

213 *Winter ETC variables*

214 ETCs in the northern hemisphere are weather systems with an anticlockwise circulation,
215 around a centre of low atmospheric pressure. They are much less known to biologists than
216 tropical cyclones but are of paramount importance as they regulate local weather and contribute
217 to the general circulation of the atmosphere through the transportation of energy and momentum
218 polewards (Hoskins & Hodges 2002, Ulbrich et al. 2009, Wang et al. 2013). Also, ETCs are
219 different from tropical cyclones since they primarily get their energy from horizontal temperature
220 contrasts, though diabatic processes can also play an important role in their development,
221 whereas tropical cyclones are dependent on evaporation over warm tropical waters and develop
222 via the release of latent heat. Even if tropical cyclones can undergo extratropical transition (Jones
223 et al. 2003) to become extratropical cyclones, no tropical cyclones reached the latitudes of the
224 eider wintering areas during the study period.

225 Several methods exist to track ETCs, using either minimum pressure or maximum
226 vorticity (in the north hemisphere), which is a measure of the spin of the air. Because these
227 methods have different views on what and when define a cyclone, they often differ on how many
228 cyclones are detected. However, differences mainly occur for the weaker storms, and they
229 generally agree for the strongest ones. Readers are referred to Ulbrich *et al.* (2009) for a
230 comprehensive review of studies using different cyclone tracking methods. In this study, we used
231 the approach described in Roberts *et al.* (2014) and Hoskins and Hodges (2002), i.e. ETCs are
232 identified and tracked using the maximum vorticity approach based on the 850hPa relative
233 vorticity since it represents smaller spatial scales than the pressure and is less influenced by the

234 large-scale background (Hodges 1994, Hoskins & Hodges 2002, Roberts et al. 2014). To remove
235 short-lived and stationary systems, tracks were retained for further analysis only when they
236 lasted longer than 1 day and travelled further than 1000 km. Thus, we considered all synoptic
237 scale (1000-2500 km) ETCs in the northern hemisphere (30-90⁰N), which cover a broad range of
238 intensities, extreme or not. Data used for the cyclone tracking are from the European Centre for
239 Medium-Range Weather Forecasts (ECMWF) Interim reanalysis (ERA-Interim, (Dee et al.
240 2014)) for the December-March period of 1979-2015 at 3-hour time resolution (see Roberts et al.
241 2014).

242 Properties from the eider wintering areas were added to the tracks by defining a spherical
243 cap sampling region of arc radius 6° (~670km) centred on the ETC positions (adequate for
244 capturing the wind extremes for individual ETCs, (Bengtsson et al. 2009); Figure 3). Varying
245 this radius between 5-10 degrees did not change our main conclusions. To calculate the winter
246 ETC activity experienced by eiders, we considered all ETC regions overlapping with the
247 population-specific wintering area defined above (Figure 3). All the wind-related variables added
248 to the vorticity tracks were based on the 10m winds above the sea surface, available from the
249 ERA-Interim data, as eiders generally fly just a few meters above the water. This was achieved
250 by masking the 10m wind data to retain only data within the eider wintering areas.

251 Several classifications of extreme ETCs exist (see review of Catto (2016)), and we used the one
252 based on wind impact, one of the major impacts of ETCs. We defined extreme ETCs as cyclones
253 that reached at least once a wind speed above the 95th percentile threshold of the local wind
254 speed distribution (Table 1). Wind speeds can vary substantially in our study areas. In Greenland
255 for example, winter wind speeds associated with ETCs were an average of $11.7 \pm 0.2 \text{ m s}^{-1}$,
256 while wind speed reached 28.5 m s^{-1} during the strongest ETC (Table 1). To describe ETC activity in each wintering area during the winter (December to
257 March), we considered six variables from mean to extreme ETC activity within the ETC regions
258 overlapping with the population-specific wintering area. The two variables for the mean ETC
259 activity are the total number of ETCs (Number of ETCs), where an ETC is counted if the
260

261 sampling region overlaps a wintering region, and their mean wind speed (Mean wind) . The four
262 other variables measure the number of extreme ETCs, i.e. with wind speeds above the 95th
263 percentile threshold of the local wind speed distribution at least once in the overlap region, the
264 number of days of extreme ETC (Duration extreme ETCs), the duration of the longest ETC
265 (Longest ETC) and the maximum wind speed of the strongest ETC (Max wind), all relative to
266 the overlap. Descriptive statistics of each variable on wintering area are described in

267 Table 1. Correlations (statistical test based on Pearson's correlation coefficient with the
268 function cor.test in the software R) between variables of winter ETC activity and winter NAO
269 are presented in the Supporting Information S2 for each wintering area. The winter NAO was
270 significantly correlated with at least one winter ETC variable and in most cases with the number
271 of winter ETCs.

272

273 *Winter North Atlantic Oscillation*

274 Winter North Atlantic Oscillation (NAO) values are based on the difference in
275 normalized sea level pressure between Lisbon, Portugal and Stykkisholmur/Reykjavik, Iceland.
276 Data from [https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-](https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based)
277 [index-station-based](https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-station-based) were used in the analysis. We defined the winter NAO as monthly NAO
278 values averaged from December to March (Descamps et al. 2010, Guéry et al. 2017), when all
279 the birds were on their wintering grounds.

280

281 *Mark-recapture modelling procedure*

282 We followed the same mark-recapture modelling procedure as the one presented in Guéry
283 *et al.* (2017) including i) goodness-of-fit (GOF) tests to check the fit of our datasets to the single-
284 state Cormack-Jolly-Seber (CJS) reference model (Burnham 1987) and test for individual
285 detection heterogeneity (see Supporting Information S1), ii) CMR mixture models, which
286 classify individuals (hidden classes) based on their encounter history implemented in program E-

287 SURGE, iii) a model selection based on the Akaike's information criterion (Burnham &
288 Anderson 2002) adjusted accordingly (see below) and, iv) analyses of deviance (ANODEV,
289 (Grosbois et al. 2008) in order to test and quantify the influence of environmental covariates on
290 eider survival in each population. We analysed 3954, 553 and 1336 individual encounter
291 histories of female Common eiders respectively from the Canadian Arctic (East Bay), Svalbard
292 (Prins Heinrich) and northern Norway (Grindøya). Avian cholera outbreaks have occurred
293 regularly in the Canadian population, which strongly affected eider survival (Descamps et al.
294 2009, 2012). To remove this cause of mortality from the analysis, we removed the individuals at
295 their last capture/recovery (right-censoring). Models were implemented in program E-SURGE
296 (Choquet et al. 2009b). The implementation in practice of the CMR mixture models in program
297 E-SURGE is given in Appendix S2 of Guéry *et al.* (2017).

298 All the GOF test components were computed using U-CARE (Choquet et al. 2009a), and
299 GOF tests results are presented in Appendix S1 (Table S1).

300 In the model selection, we investigated the effect of winter ETCs on female eider survival
301 with and without taking into account survival heterogeneity among individuals. Although the
302 mark-recapture modelling procedure was the same, the approach proposed in this paper is
303 different from Guéry *et al.* (2017). We started from these winter locations to define wintering
304 areas and used them to extract local covariates (ETCs variables). We then considered whether
305 variations in winter ETC variables on each wintering ground affected just one or both groups of
306 eiders. We expected each wintering ground conditions to only explain survival variation of the
307 right hypothetical group. We studied this influence of ETC activity with and without delayed
308 effect (time lags). Finally, we compared the relationships between female eider survival and
309 winter ETCs to that of survival and winter NAO, with or without time lags accordingly.

310 Concerning the impact of the winter NAO on eider survival, adding year 2014 to the time series
311 used in the previous study (Guéry *et al.* 2017) confirmed their results in all three breeding
312 populations, especially for the Svalbard population: winter NAO marginally explains survival
313 fluctuations ($p = 0.073$; Table 2).

314 We used the Akaike's information criterion (Burnham & Anderson 2002) to rank our
315 models, adjusted for overdispersion (Quasi-Akaike's information criterion, QAIC) for the
316 Canadian population, adjusted for small sample size (Second-Order Akaike's information
317 criterion, AICc) for the Svalbard population and adjusted for both overdispersion and small
318 sample size (QAICc) for the Norwegian population.

319 Finally, we performed analyses of deviance (ANODEV, (Grosbois *et al.* 2008) to test
320 whether or not variations in the covariate were significantly associated with variation in eider
321 survival in each population, and we calculated the proportion of deviance (Dev) explained by a
322 given covariate as:

$$323 \quad R_{Dev}^2 = \frac{Dev(F_{cst}) - Dev(F_{co})}{Dev(F_{cst}) - Dev(F_t)}$$

324 where F_{cst} , F_t and F_{co} refer respectively to models with constant, time and covariate effects
325 (results in Table 2).

326 **Results**

327 ***Relationships between winter ETCs and eider survival***

328 In the Canadian Arctic breeding population (East Bay), the ETC variables that were
329 significantly linked to adult eider survival and described this relation best were: the number of
330 winter ETCs in southern Atlantic Canada with no time lag (model 1_{time} 2_{Number of ETCs of sAC}; Table
331 2; Figure 4) and the duration of the longest ETCs in southwest Greenland with a lag of two years
332 (model 1_{Longest ETC_L2} of G 2_{constant}; Table 2). As predicted, the most parsimonious model detected a

333 significant individual heterogeneity in the survival response to winter ETC activity in this
334 population. In this model, survival variation of the group, which represented 24% of individual
335 capture histories, was negatively related to the number of winter ETCs in southern Atlantic
336 Canada (group H2; slope on logit scale = -1.46 ± 0.38 SE), while survival of the largest one
337 (group H1, 76% of capture-histories) fluctuated over years (model 1_{time} 2_{Number of ETCs of sAC};
338 $R_{Dev}^2 = 0.35$; **Table 2**; Figure 4). Although statistically less supported ($\Delta QAIC = 29.51$; **Table 1**),
339 the duration of the longest ETC in southwest Greenland with a lag of two years was also
340 significantly and negatively correlated to survival of the group H1 (model 1_{Longest ETC_L2 of G}
341 2_{constant}; slope on logit scale = -0.41 ± 0.08 SE; $R_{Dev}^2 = 0.39$; **Table 2**).

342 Survival of eiders breeding in Svalbard and northern Norway was associated with lagged winter
343 ETC activity (**Table 2**). Survival of eiders breeding in Svalbard, for which intra-population
344 heterogeneity could not be tested, was negatively associated with the maximum wind speed of
345 the strongest ETC recorded on the Norwegian wintering ground zone 1 with a lag of two years
346 (model Max wind_L2 of No; $R_{Dev}^2 = 0.30$; slope on logit scale = -0.65 ± 0.26 SE; **Table 2**;
347 **Figure 5**) and the duration of extreme ETCs in Greenland with the same time lag (model
348 Duration extreme ETCs_L2 of I; $R_{Dev}^2 = 0.28$; slope on logit scale = -0.47 ± 0.24 SE; **Table 2**).

349 The main covariates that significantly and negatively explained survival of female eiders
350 breeding (and wintering) in northern Norway, i.e. Grindøya population, were the maximum wind
351 speed of the strongest ETC of northern Norway zone 2 with lags of one and two years (e.g.
352 model Max wind_L1 of Nno; $R_{Dev}^2 = 0.22$; slope on a logit scale = -0.34 ± 0.06 SE; **Table 2**; **Figure**
353 **6**). No significant heterogeneity was detected for this population ($\Delta QAIC_c > 3$; **Table 2**).

354

355 ***Comparison between winter extra tropical cyclones and North Atlantic Oscillation***

356 In East Bay population wintering areas, the winter NAO was highly and significantly
357 linked to the number of winter ETCs on the southern Atlantic Canada wintering ground

358 ($R^2=0.90$; $p<0.0001$; Fig S2.1; Supporting Information S2), whereas it was not linked to winter
359 ETC activity in Greenland with a lag of 2 years (Fig S2.3; Supporting Information S2).
360 Moreover, the number of ETCs in southern Atlantic Canada performed as well as the winter
361 NAO to explain eider survival at a population level (h^* NAO versus h^* Number of ETCs of sAC;
362 $\Delta QAIC = 1.35$; $R_{Dev}^2=0.27$ and 0.26 respectively). However, when we tested the effect of the
363 number of winter ETCs in southern Atlantic Canada and the winter NAO on each group
364 separately, the number of winter ETCs performed better ($\Delta QAIC = 3.81$) and explained ($R_{Dev}^2 =$
365 0.35) survival variation of the smallest group better than the direct winter NAO (models 1_{time}
366 $2_{Number\ of\ ETCs\ of\ sAC}$ versus $1_{time} 2_{NAO}$; **Table 2**).

367 For the Svalbard population, the lagged winter NAO was significantly associated with the
368 total number ETCs in Iceland (e.g. with winter NAO with one-year lag: $R^2 = 0.74$; $p = 0.001$; Fig
369 S2.4; Supporting Information S2) but not significantly in northern Norway zone 1 (e.g. with
370 winter NAO with one-year lag: $R^2 = 0.48$; $p = 0.073$; Fig S2.6; Supporting Information S2).
371 However, the ETC related covariates performed better than the NAO to explain variation in
372 survival of Svalbard eiders. No significant influence of winter NAO (lagged or not) on survival
373 was detected, whereas the maximum wind speed of ETCs in Norwegian wintering grounds (with
374 a 2 years-lag) performed and explained eider survival better than winter NAO regardless of time
375 lag (e.g. $\Delta QAIC = 2.00$ between models Max wind_L2 of No and NAO; **Table 2**).

376 For the Norwegian breeding and wintering population, the winter NAO was significantly
377 associated with the number of extreme winter ETCs (e.g. with winter NAO with one-year time
378 lag: $R^2 = 0.37$; $p = 0.049$; Fig S2.8; Supporting Information S2). Survival of eiders breeding and
379 wintering in northern Norway was better explained by the winter NAO with a lag of two years
380 alone (model NAO_L2, $R_{Dev}^2 = 0.32$; **Table 2**) than by any winter ETC-related covariate. The

381 winter NAO with lags was not significantly associated to wind speed of the strongest ETC with
382 lags (Fig S2.8; Fig S2.9; Supporting Information S2) and including both variables into the same
383 model improved its performance. Models including the effects of both winter NAO and winter
384 ETC activity performed better (Table 2) and explained a larger proportion of variation in survival
385 (Table 2) than a model with winter NAO only. In particular, the winter NAO with a lag of two
386 years combined with the maximum wind speed of ETCs with a lag of one year explained 53% of
387 eider survival variation (model NAO_L2+Max wind_L1 of nNo; Table 2).

388 **Discussion**

389 The marine environment in non-tropical regions is highly influenced by ETCs (Hoskins
390 & Hodges 2002, Ulbrich et al. 2009, Wang et al. 2013). Although several marine species winter
391 in these regions, no study has quantitatively investigated the effect of cyclones occurring outside
392 the tropics on wildlife species. By coupling long-term capture-mark-recapture data with
393 individual tracking information to identify wintering areas, we provide the first quantitative
394 study of the impact of winter extratropical cyclones (ETCs) and their extremes on the annual
395 adult survival of a seabird. The underlying mechanisms involved in the winter ETC effect seem
396 to differ between and within these populations according to their wintering grounds. As
397 predicted, we detected inter- and intra-population heterogeneity in the response to winter ETC
398 activity that could be driven by variation in the birds' wintering areas.

399

400 *Climatic fluctuations affect survival of a long-lived species*

401 The winter ETC activity seems to have negative effects on female eider survival in all
402 three breeding populations studied and explained between ca. 22% and 43% of the inter-annual
403 survival variation. These effects are similar to the effects of tropical hurricanes recorded on
404 Mediterranean Cory's shearwaters migrating to the Central Atlantic and Southern Atlantic

405 (Boano et al. 2010). Eiders are long-lived and their population growth rate is very sensitive to
406 changes in adult survival (Sæther et al. 2000). Detecting a negative influence of local (here
407 winter ETC activity) and/or global (e.g. winter NAO) climatic variables on survival is thus
408 important to better understand the future viability of their populations. Adult survival is expected
409 to be buffered against environmental variability (Gaillard & Yoccoz 2003), but several studies
410 also showed that climatic variation, whether extreme or not, could reduce the adult survival of
411 long-lived species (e.g. (Sandvik et al. 2005).

412

413 *Direct impact of winter ETCs versus indirect impact of their extremes on survival*

414 Winter ETC activity can directly increase seabird mortality through different
415 mechanisms. They can disturb their feeding behaviour, which is sensitive to the occurrence of
416 stormy weather (e.g. (Finney et al. 1999). Common eiders are mostly visual feeders (Frimer
417 1994), so foraging can be affected by water turbidity associated with strong winds or sea-surface
418 conditions that reduce visual acuity (Eriksson 1985, Henkel 2006). Since ETC activity increases
419 winds, waves and current speed, it can also increase foraging costs for eiders. While common
420 eiders employ a variety of tactics to reduce energy costs during diving, descent duration and
421 number of strokes during descent increase exponentially with increasing current velocity,
422 suggesting an increase in the energetic costs of diving (Heath et al. 2006)Heath & Gilchrist
423 2010). During ETCs, fast currents, the strong increase in drag and energetic costs of diving make
424 even foraging unprofitable with net energy gain per dive cycle predicted to reach zero and
425 become unprofitable at 1.21 m s⁻¹ at 11.3 m depth (Hawkins et al. 2000, Heath et al. 2006,
426 Heath & Gilchrist 2010). Common eiders stop foraging and rest well below this threshold (Heath
427 & Gilchrist 2010), which lowers their energetic gains (Dehnhard et al. 2013). Adding to the fact

428 that the winter period reduces the feeding window of these diurnal feeders (Systad et al. 2000,
429 Heath & Gilchrist 2010), winter ETC activity can potentially cause starvation because birds are
430 unable to forage efficiently (Chambers *et al.* 2011).

431 On the other hand, extreme ETCs may impact eider survival through indirect (lagged)
432 effects via the food chain. Different mechanisms can be hypothesized; extreme wind events
433 associated with extreme ETCs are an important natural disturbance in coastal systems
434 (Richardson & LeDrew 2006), decreasing the food availability of common eiders' benthic prey.
435 Winter diet of common eiders includes different marine resources depending on their wintering
436 grounds: preferably small blue mussels of smaller sizes (Bustnes & Erikstad 1990, Varennes et
437 al. 2015) found near the shore, in kelp beds or rocky habitat in the Gulf of St. Lawrence
438 (Guillemette et al. 1992) or in northern Norway (Bustnes & Erikstad 1988), softshell clams *Mya*
439 *eideri* and marine *polychaete* worms found in soft sediments in southwest Greenland (Merkel et
440 al. 2007), gastropods in Newfoundland (Goudie & Ankney 1986), or sometimes crustaceans and
441 echinoderms. They can also include sea urchins found in shallow water near the shore (<10 m;
442 Cottam 1939, Madsen 1954, Bustnes & Lønne 1997). Extreme cyclones can remove large
443 intertidal and subtidal areas rich in fauna and macroalgae (e.g. (Thomsen et al. 2004), destroy
444 bivalve beds at shallow depths (Reusch & Chapman 1995, Carrington 2002, Carrington et al.
445 2009) and directly decimate sea urchins and drive their community structure (Ebeling et al.
446 1985). In addition, winter ETCs can induce strong wave action, which lowers blue mussel
447 growth rates (Sukhotin et al. 2006), reduce primary productivity, lowering mussel growth rates to
448 taking 3-5 years to reach 1-2cm (Bustnes & Erikstad 1990, Varennes et al. 2015) if carried to the
449 extreme (Fujii & Yamanaka 2008), and act on intertidal gastropod populations via size-specific
450 mortality and indirectly affect them by altering their foraging behaviour, growth and life histories

451 (Brown & Quinn 1988). Also, oceanic volume fluxes are positively related to Nordic seas
452 cyclone activity (Sorteberg et al. 2005) providing transportation of blue mussel larvae over long
453 distances (Berge et al. 2005). As larvae settle when they reached a size between 0.026 -
454 0.035mm (Sprung 1984) and current velocity drives the settlement of marine *polychaete* worms
455 (Pawlik & Butman 1993), extreme winter ETC activity could decrease these species' settlement
456 with higher velocity and thus decrease food availability for eiders in subsequent years. Hence,
457 extreme ETCs may have cascading effects on eider survival through a variety of specific
458 mechanisms.

459

460 *Contrasted effect of winter ETC activity between and within eider populations: a “climatic*
461 *shelter” effect?*

462 First, the strongest relation we detected was a direct and negative link (consistent with
463 our predictions) between the total number of all winter ETCs in southern Atlantic Canada and
464 the survival of eiders breeding in Canada. More precisely, this variable was only associated with
465 the survival of one group of birds (H2; 24% of individual capture histories), potentially those
466 migrating to the southern Atlantic Canada area. Secondly, the wind speed of the strongest
467 extreme winter ETCs impacted, with a time lag, the survival of eiders breeding and wintering in
468 northern Norway, and also, although less strongly, those breeding in Svalbard. Indirect effects of
469 the duration of extreme ETC activity in southwest Greenland were also detected on one group of
470 birds from Canada (H1; 76% of individual capture histories), potentially those wintering on the
471 southwest Greenland ground; indirect impacts of the same variable in Iceland was observed on
472 survival of eiders from Svalbard.

473 We propose that the detected inter- and intra-population heterogeneity, i.e. the direct
474 versus indirect impacts of winter ETC activity on survival described above, can be mostly
475 explained by variation in the natural “climatic shelters” on eider wintering grounds. We suggest
476 that direct effects can occur in the absence of shelter, whereas indirect effects likely occur via the
477 impact of ETC activity on prey availability. Shelter against wind can result in microclimate
478 effects and affect eider energetics during incubation (Høyvik Hilde et al. 2016). At a larger
479 spatial scale, areas providing natural shelter may drive the population response to extreme
480 environmental conditions through various mechanisms. The shelter effect of fjords on marine
481 wildlife has been proposed in the literature (see review by Howe et al. (2010)). Howe *et al.*
482 (2010) defined fjords as “inshore sheltered deep-water bodies, which often possess a unique
483 biogeochemistry, fauna, hydrography and sedimentation”. Fjord and channel systems in
484 Scandinavia, Iceland and Greenland form some of the largest estuarine areas in the world. Fjords
485 are used for spawning grounds, nursery, and recruitment areas by many marine fishes with
486 contrasting life histories, varying from mesopelagic (Lopes 1979) and pelagic (Brown 2002) to
487 demersal fishes (Boje 2002). Fjords are also used by marine mammals seeking refuge from
488 severe weather conditions (Sanino & Van Waerebeek 2008, Acevedo et al. 2017).

489 Female eiders wintering in southern Atlantic Canada feed along the sea ice edge (Goudie &
490 Ankney 1986) with potentially few climatic shelter areas. These individuals can thus be directly
491 exposed to harsh weather conditions and hence be directly impacted by winter ETCs (Figure 1).
492 In addition, sea ice formation covers shallow coastal waters, so wintering sea ducks are cut off
493 from their marine resources and lose potential feeding sources that could have compensated
494 losses of energy caused by low air temperature and foraging in deeper and agitated waters
495 (Vaitkus & Bubinas 2001). On the contrary, Canadian breeding eiders that winter in southwest
496 Greenland are likely less vulnerable to direct effects of ETC activity because they have access to
497 fjords extending deep inland (Ravn Merkel et al. 2002), which may provide shelters that are well
498 protected against extreme ETC winds. In addition, eiders from Svalbard or northern Norway
499 wintering along the Norwegian coast, although facing weaker winter ETC activity than in
500 Canada (

501 Table 1), can feed along the shores of the fjords (Bustnes and Erikstad unpublished data),
502 which may also provide good climatic shelters and reduce the direct effects of ETC activity.
503 However, the effect of ETCs on benthic invertebrates in fjords or in exposed coastal areas
504 deserves further investigation to better understand the role of natural climatic shelters on the food
505 chain and on eider survival.

506

507

508 *Effect of winter NAO and ETCs*

509 The potential mechanisms involved in the relationships between eider survival, winter
510 NAO and local ETC activity were found to differ between populations. Winter ETCs appeared to
511 be one of the main drivers explaining the observed NAO effects on eider survival (Guéry et al.
512 2017) but only in the Canadian wintering population. In the Norwegian breeding population, we
513 found evidence that NAO and ETCs can have independent and cumulative influences. For eiders
514 breeding in the Canadian Arctic, the previously detected direct effect of the winter NAO might
515 be due, at least in part, to its relation with the number of ETCs in the southern Atlantic Canada.
516 Conversely, lagged winter NAO and lagged wind speed of the strongest ETC in northern
517 Norway seem to have independent and cumulative influences on survival of eiders breeding and
518 wintering in northern Norway, explaining together ca. 53% of the adult female eider survival.
519 The link between these two variables with oceanographic conditions in the North East Atlantic
520 could explain this cumulative effect. A low winter NAO with a lag of up to 3 years leads to an
521 increase in sea temperature and salinity in the sub-polar North Atlantic (Sarfanov 2009). This
522 increase in sea temperature and salinity may have in turn a negative impact on blue mussel larvae
523 and adult survival (Brenko & Calabrese 1969, Braby & Somero 2006, Menge et al. 2008),

524 adding to the negative effect of ETC activity on them. Further investigation is needed to better
525 understand these effects on annual eider survival.

526 Large-scale climate indices, such as the NAO, are often used as proxies of environmental
527 conditions as they integrate both temporal and spatial components of several weather variables
528 (Stenseth & Mysterud 2005). However, our study showed that local weather variables are
529 essential and complementary to sharpen our hypothesis on mechanisms when they can be
530 difficult to test in the wild.

531

532 *Effect of extreme events on survival*

533 While many studies focused on a single extreme climatic event (ECE), or one
534 characteristic of several ECEs (usually frequency), we have investigated several characteristics
535 of ECEs (frequency, duration and amplitude) over a long-term study. Interestingly, common
536 eider survival was affected by the amplitude and duration of ECEs but not by their frequency;
537 Canadian eider survival was not impacted by the number of extreme ETCs in southern Atlantic
538 Canada but the total number ETCs, whether extreme or not. We detected an effect of the
539 amplitude of ECEs in regions of relatively low ETC activity, while, we found an effect of the
540 duration in areas of intense ETC activity. This pattern probably stood out because the effect of
541 ECEs occurred mostly through the food web in our study systems, where long lasting or large
542 ECEs are more likely affecting the benthic ecosystems. Our results are noteworthy as population
543 models focusing on the impact of ECEs usually focus on their frequency (e.g. (Jenouvrier et al.
544 2015) rather than their duration or amplitude. Frequency, amplitude and duration of extreme
545 weather events are predicted to increase in most future climate scenarios (Rind et al. 1989,
546 Easterling et al. 2000), potentially impacting population persistence.

547

548 *Conclusion*

549 Even if adult survival of long-lived species should be buffered against environmental
550 variability (Gaillard & Yoccoz 2003), extreme weather conditions (such as extreme ETCs)
551 significantly affect adult survival during the wintering period and can have drastic effects on
552 population trends even with minimal reductions in survival. This is especially important in the
553 case of extreme weather events whose frequency, amplitude and duration are predicted to
554 increase in most future climate scenarios (Rind et al. 1989, Easterling et al. 2000), potentially
555 impacting population persistence. Several studies have reported changes in ETC activity at high
556 latitudes in the northern hemisphere (Bengtsson et al. 2009, Ulbrich et al. 2009). In terms of
557 future work, it might be interesting to consider the clustering of cyclones (Mailier et al. 2006),
558 i.e. where cyclones follow one another in a short period of time, to see whether wildlife species
559 are only affected by separate intense cyclones or also by a succession of ETCs.

560 Hence, to predict the effects of global change on wild populations, differences in
561 individual life-history strategies (e.g. migration strategies) must be taken into account as they
562 introduce inter- and intra-population heterogeneities in the response to climatic fluctuations. In
563 our case, an increase in winter ETC severity or frequency could directly affect only a segment of
564 the population depending on where birds winter, for example with or without access to climatic
565 shelter areas. Whatever the exact causes may be (e.g. wintering strategy, age...), intra-population
566 heterogeneities will impact population trajectories and viability, and should thus be incorporated
567 into population models (Coulson et al. 2001, Benton et al. 2006, Kendall et al. 2011).

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584

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586

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823 **Tables**

824 **Table 1: Descriptive statistics of winter (December-March) extratropical cyclones (ETC) activity variables (mean \pm SE**
 825 **(min-max)) on each wintering ground from 1996-2014 for Greenland and Atlantic Canada, 1999-2014 for Iceland and**
 826 **northern Norway zone 1 and 1985-2014 for northern Norway zone 2. The two variables for the mean ETC activity are the**
 827 **total number of ETCs (Number of ETCs) and the mean of their wind speed (Mean wind) within the overlap region. The**
 828 **four other variables measure the number of extreme ETCs, i.e. with wind speed above the 95th percentile threshold of the**
 829 **local wind speed distribution at least once in the overlap region, the number of days of extreme ETC (Extreme ETCs**
 830 **(days per winter)), the duration of the longest ETC and the maximum wind speed of the strongest ETC (Max wind) all**
 831 **relative to the overlap. “95th percentile” is the 95th percentile threshold of local wind speed distribution (m s^{-1}). Wind**
 832 **speeds are at a 10-m height.**

	Greenland	Atlantic Canada	Iceland	northern Norway zone 1	northern Norway zone 2
Number of ETCs	45.55 \pm 2.01 (29-62)	69.33 \pm 1.40 (56-79)	53.27 \pm 3.11 (29-72)	32.87 \pm 1.74 (25-50)	33.79 \pm 1.49 (20-54)
Mean wind (m s^{-1})	11.64 \pm 0.22 (9.97-13.68)	12.77 \pm 0.13 (11.74-14.22)	14.14 \pm 0.14 (13.18-15.16)	9.35 \pm 0.19 (8.09-10.20)	9.63 \pm 0.20 (8.09-12.92)
Number of extreme ETCs	1.78 \pm 0.37 (0-6)	1.78 \pm 0.37 (0-6)	2.27 \pm 0.34 (1-5)	1.33 \pm 0.27 (0-3)	1.79 \pm 0.35 (0-9)
Duration extreme ETCs (days per winter)	0.44 \pm 0.08 (0-1.12)	0.74 \pm 0.13 (0-2.63)	0.5 \pm 0.09 (0.12-1.37)	0.25 \pm 0.06 (0-0.62)	0.44 \pm 0.12 (0-3.25)
Longest ETC (days per winter)	3.67 \pm 0.20 (2.75-5.87)	3.67 \pm 0.17 (2.5-4.62)	4.05 \pm 0.25 (3-6.5)	1.77 \pm 0.20 (0.37-3.25)	2.20 \pm 0.32 (0.12-7.25)
Max wind (m s^{-1})	24.87 \pm 0.37 (21.74-27.61)	25.74 \pm 0.52 (22.27-29.15)	28.68 \pm 0.58 (25.54-32.67)	22.77 \pm 0.70 (18.82-29.26)	22.51 \pm 0.52 (17.68-29.26)
95 th percentile (m s^{-1})	23.30	22.60	25.30	21.68	20.95

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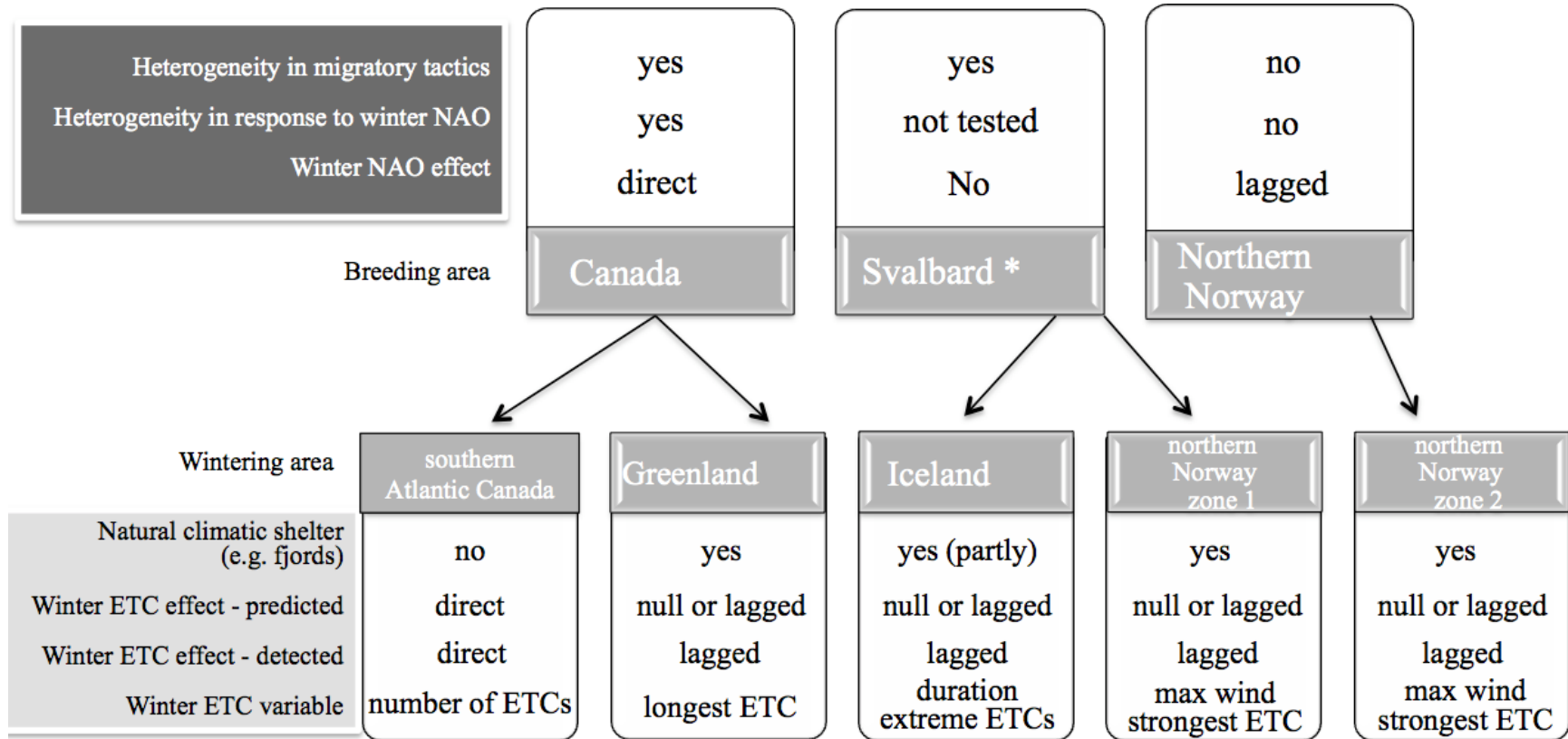
836 Table 2: Effect of winter extratropical cyclones (ETC) activity with or without time lag of one (L1) or two (L2) years on
837 female adult survival of common eider breeding in Canada (East Bay 1996-2014), in Svalbard (Prins Heinrich 1999-2014)
838 and in northern Norway (Grindøya 1985-2014). Results of analysis of deviance (ANODEV) are presented for the first ten
839 models. Variables from each wintering area (G for western Greenland, sAC for southern Atlantic Canada, I for Iceland,
840 No for northern Norway zone 1 and nNo for northern Norway zone 2) were tested either on each class separately (at East
841 Bay: 1 stands for the group H1 wintering potentially in Greenland and 2 for the group H2 potentially in sAC), on both in
842 interaction (h) or without heterogeneity.

Survival	Deviance	Criterion	Δ Criterion	$F_{j-1, n-j}$	p	R_{Dev}^2
Canada (East Bay)		QAIC	Δ QAIC			
1 _{time} 2 Number of ETCs of sAC	22511.14	8126.30	0.00	8.48	0.010	0.35
1 _{time} 2 _{constant}	22525.55	8129.45	3.15	-	-	-
1 _{time} 2 _{NAO}	22521.81	8130.12	3.81	1.58	0.227	0.09
Time (no heterogeneity)	22578.08	8146.23	19.92	-	-	-
h*time	22483.95	8146.58	20.28	-	-	-
1 Longest ETC_L2 of G 2 Number of ETCs of sAC	22657.95	8146.89	20.47	8.19	<0.0001	0.43
1 Longest ETC_L2 of G 2 constant	22688.83	8155.92	29.51	10.07	0.006	0.39
1 Duration extreme ETCs_L2 of G 2 constant	22696.39	8158.52	32.21	8.92	0.009	0.36
1 Number of extreme ETCs_L2 of G 2 constant	22700.09	8159.84	33.54	8.39	0.011	0.34
1 Number of ETCs_L2 of G 2 constant	22710.50	8163.56	37.26	7.02	0.018	0.31
Svalbard (Prins Heinrich)		AICc	Δ AICc			
Max wind_L2 of No	1952.24	1986.99	0.00	5.48	0.036	0.30
Duration extreme ETCs_L2 of I	1952.69	1987.44	0.45	5.08	0.042	0.28
Time	1932.26	1988.14	1.14	-	-	-
Number of ETCs of No	1954.02	1988.77	1.78	3.97	0.068	0.23
Number of ETCs_L1 of No	1954.15	1988.90	1.91	3.87	0.071	0.23
NAO	1954.24	1988.99	2.00	3.80	0.073	0.23
Mean wind_L1 of I	1955.53	1990.28	3.29	2.87	0.114	0.18
Mean wind of No	1956.30	1991.05	4.06	2.36	0.148	0.15
Number of ETCs_L1 of No	1957.20	1991.95	4.95	1.81	0.202	0.12
Constant	1960.67	1993.28	6.28	-	-	-
Northern Norway (Grindøya)		QAICc	Δ QAICc			
NAO_L2+MaxWind_L1 of nNo	8471.13	5882.87	0.00	14.86	<0.0001	0.53
NAO_L2+MaxWind_L2 of nNo	8473.73	5884.65	1.78	13.68	<0.0001	0.51
Time	8412.23	5896.07	13.20	-	-	-
NAO_L2	8498.12	5899.34	16.48	12.68	0.001	0.32
Max wind_L1 of nNo	8510.29	5907.70	24.83	7.76	0.010	0.22
h* Max wind_L1 of nNo	8509.98	5911.57	28.71	4.17	0.010	0.19
Max wind_L2 of nNo	8517.54	5912.67	29.81	5.36	0.028	0.17
h* Max wind_L2 of nNo	8515.84	5915.60	32.73	3.14	0.033	0.15
NAO_L1	8525.57	5918.18	35.32	3.07	0.091	0.10
Constant	8538.47	5924.99	42.13	-	-	-

843 Significant ANODEV results are in bold. n is the number of survival estimates obtained from model Ft (fixed effect model with a time
844 effect, see formula above), j the number of parameters required to describe the relationship between survival and the focal climatic
845 covariate, $F_{j-1, n-j}$ the ANODEV test statistic following a Fisher-Snedecor distribution with j-1 and n-j degrees of freedom, p the p-value of
846 the ANODEV test and R_{Dev}^2 the proportion of survival variation explained by the covariate (see Grosbois *et al.* 2008 for more details).

847 **Figures**

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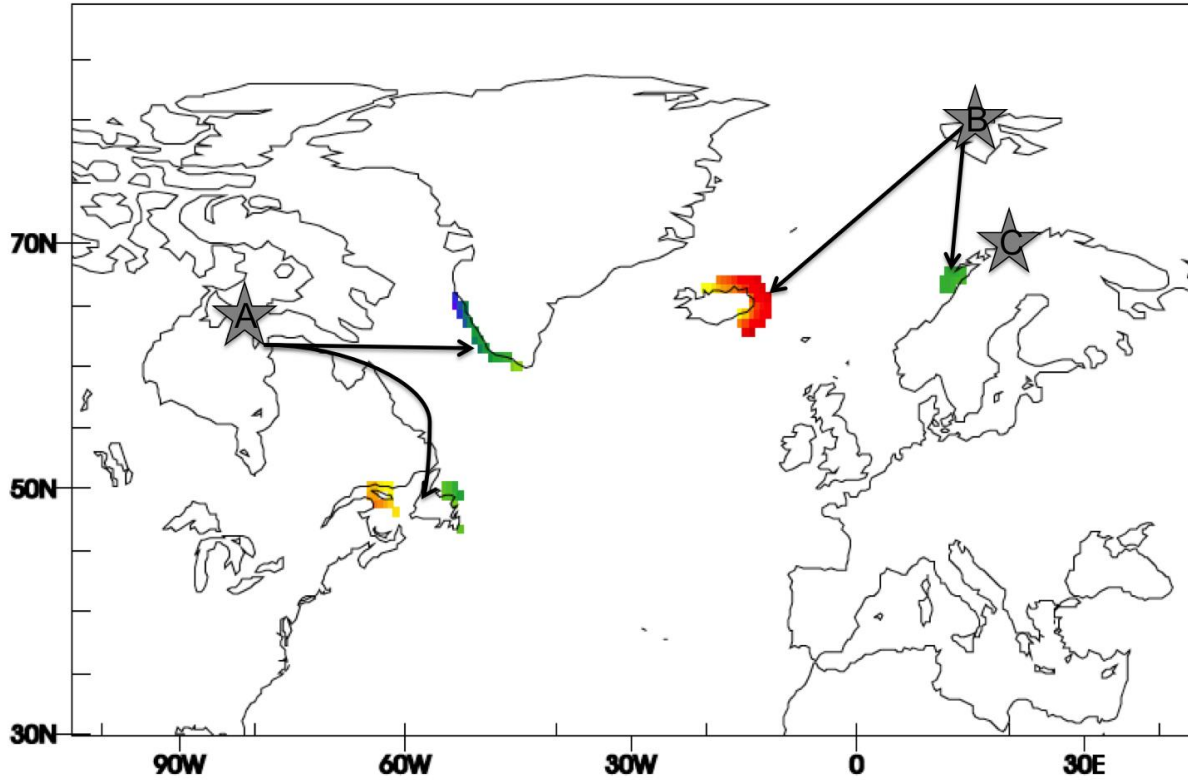
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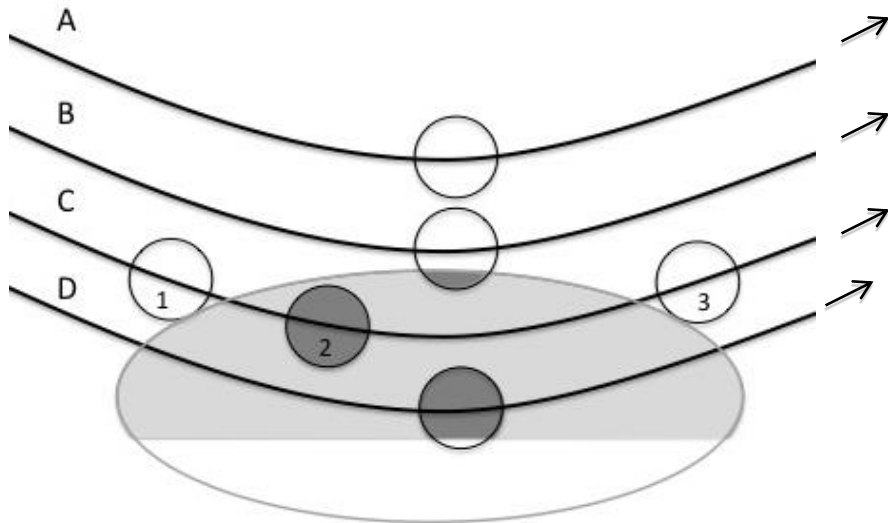
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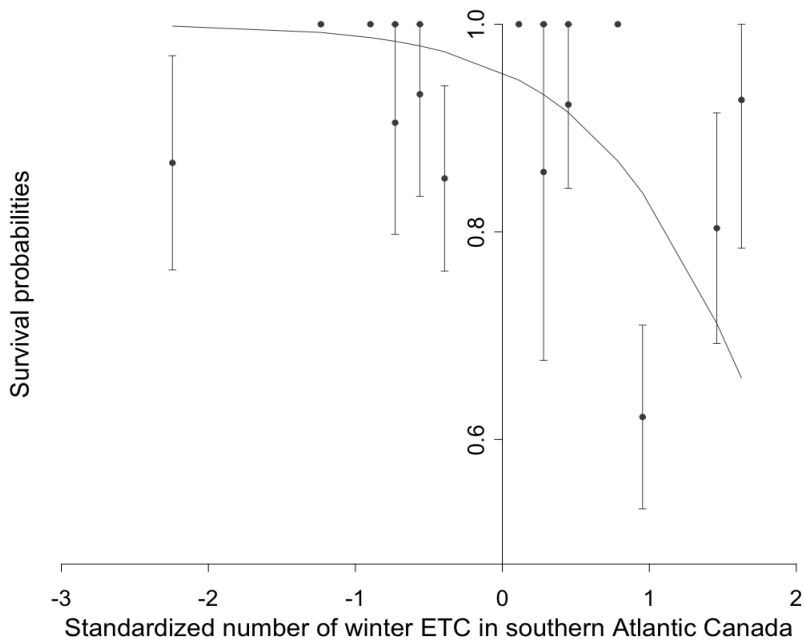
Figure 1: Summary diagram of winter North Atlantic Oscillation (NAO) effect (dark grey box; Guéry *et al.* 2017) and local winter extratropical cyclones (ETC) effect (light grey box) on female eider survival depending on their breeding population and wintering areas. For the Svalbard population, relations between survival and winter variables were given for the whole population (individual heterogeneity was not tested, see methods).



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 855 Figure 2: Grid cells corresponding to the winter (December to March) distribution (home range Kernel core, see
 856 methods) of female common eiders breeding in Canada (A) and wintering either in west Greenland or in southern
 857 Atlantic Canada, breeding in Svalbard (B) and wintering in Iceland and northern Norway. Resident eiders breeding near
 858 Tromsø (C) wintered in the vicinity of the island.



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 860 Figure 3: Schematic of winter extratropical cyclones (ETC) variables extraction. Black lines (A, B, C and D) are examples
 861 of ETC tracks. The light grey ellipse is an example of eider wintering area with the land part masked in white. Black
 862 circles are ETC buffer regions, i.e. a 6-degree geodesic radius cap centred on the ETCs, at different time (e.g. time “1” to
 863 “3” for the ETC track “C”). Parts in dark grey represent the ETC regions overlapping with the wintering area used to
 864 extract the winter ETC variables. For example, ETC corresponding to track B would be included in the number of ETC
 865 and if the numbers 1 to 3 referred to days, the duration of the ETC corresponding to track C is one day.



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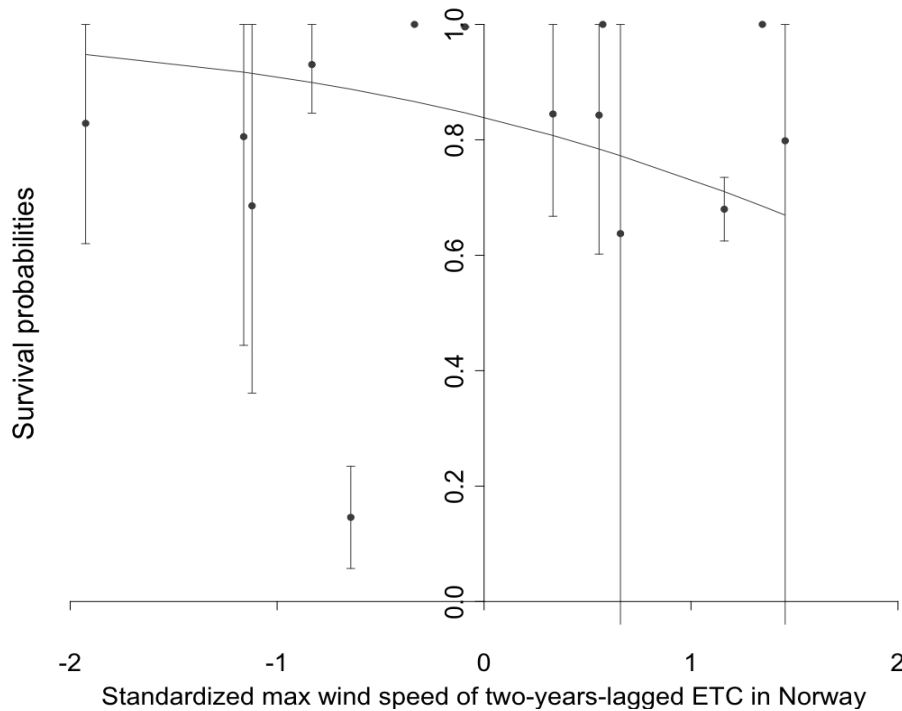
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Figure 4: Influence of the number of winter extratropical cyclones (ETC) without time lag in southern Atlantic Canada (x- axis) on adult survival estimates (\pm SE; y-axis) of female eiders from group H2 and breeding in the Canadian Arctic. Isolated points represent survival estimates from the time dependent model with heterogeneity (model h*time; Table 2). The line represents predicted survival estimates constraint by the number of winter ETCs in southern Atlantic Canada (model with heterogeneity 1_{time} 2_{Number of ETCs of SAC}; Table 2).



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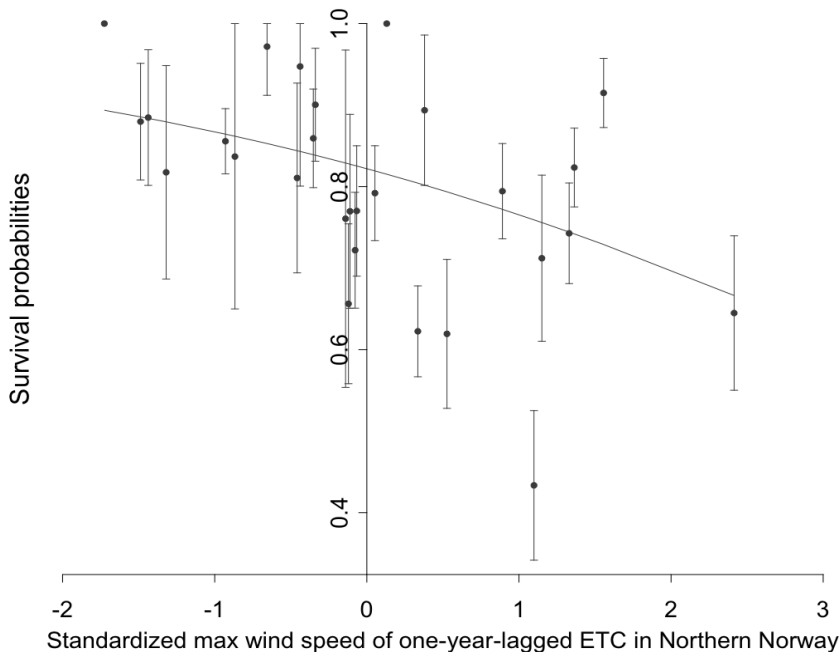
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Figure 5: Influence of the maximum (max) wind speed of winter extratropical cyclones (ETC) with a two-years lag (L2) in northern Norway zone 1 (No; x- axis) on adult survival estimates (\pm SE; y-axis) of females eiders breeding in Svalbard. Isolated points represent survival estimates from the time dependent model with heterogeneity (model Time; Table 2). The line represents predicted survival estimates from the model with survival constraint with the maximum wind speed of the strongest ETCs with a two-year lag (Max wind_L2 of No; Table 2).

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880 **Figure 6: Influence of the maximum (max) wind speed of the strongest winter extratropical cyclones (ETC) with a one-**
 881 **year lag in northern Norway zone 2 (x- axis) on adult survival estimates (\pm SE; y-axis) of female eiders breeding and**
 882 **wintering in northern Norway. Isolated points represent survival estimates from the time dependent model (model time;**
 883 **Table 2). The line represents predicted survival estimates from the model (ϕ (MaxWind_L1_nNo); Table 2) with survival**
 884 **constraint by the covariate.**

885

886 **Supporting Information captions:**

887 **Supporting_Information_S1:**

888 Table S1: Goodness-of-fit (GOF) tests results for the standard time-dependent Cormack-Jolly-Seber
 889 model (CJS-model) and the time-dependent model with individual heterogeneity of detection (IDH-
 890 model) for common Eider at Grindøya (1985-2014), East Bay (1996-2014) and Prins Heinrich (1999-
 891 2014) islands.

892 **Supporting_Information_S2:**

893 Figure S2.1 to S2.9: Correlations between winter NAO and local winter ETCs-related variables with or
 894 without time lags in each wintering areas (Greenland (G), southern Atlantic Canada (sAC), Iceland (I),
 895 northern Norway zone 1 (No) and northern Norway zone 2 (Nno)) for the three populations breeding
 896 either in Canada (1996-2014), in Svalbard (1999-2014) or in northern Norway (1985-2014).

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