The version of record of this manuscript has been published and is available in Bird Study 11 December 2023 https://www.tandfonline.com/doi/full/10.1080/00063657.2023.2286297

Identifying targets for conservation: the arrival and loss of Common Eider *Somateria mollissima* ducklings in an estuarine nursery

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Short Title: Eider ducklings in an estuary

Key words: Eider ducklings, estuary, nursery, conservation, predation, crèche , attendant females

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SUMMARY

Capsule The arrival of Common Eider *Somateria mollissima mollissima* ducklings into a reception and nursery area is a measure of breeding success and phenology but reveals gaps in knowledge for effective conservation.

Aims Estuarine habitats are important wildlife areas but continually under threat from human activities. Common Eiders *Somateria mollissima mollissima* (hereafter Eider) may be an indicator species for monitoring impacts of development in estuaries used by them as nursery areas. The aim of this study was to understand the arrival and distribution of ducklings in a commercial and recreational estuarine environment.

Methods Coquet Island is a breeding site for Eider at the southern limit of their range on the east coast of the UK. Numbers of Eider ducklings arriving in the adjacent Coquet Estuary nursery area were monitored daily during the breeding season over a 27-year period from 1995 to 2021 inclusive.

Results Counts of ducklings were higher overall in less disturbed parts of the estuary, but there were no consistent patterns of habitat use. First-arrival dates varied annually by up to 23 days. Daily arrival counts were affected by tide, and, to a lesser extent, rain and wind direction. Observed arrivals each season correlated with counts of breeding females on Coquet Island. There was evidence for links between broader-scale weather conditions (North Atlantic Oscillation indices) and yearly variation in rates of duckling arrival. Arrivals were more synchronous in years when ducklings were late in arriving and support theoretical predictions from modelling studies. There were high daily rates of duckling loss from the estuary which may have been a consequence of brood movements out of the estuary and loss to predation. There was a positive correlation between counts of ducklings and attendant females.

Conclusions Annual duckling counts show the value of estuaries for monitoring phenological variation of Eider breeding. A better understanding of environmental factors influencing duckling retention or loss in estuaries is needed. Enabling human and wildlife activities to exist together within estuarine environments may promote effective Eider conservation.

INTRODUCTION

The intertidal habitats of estuaries are key areas supporting wildlife and bird diversity, but have been under continual threat from human commercial and recreational activities (Kennish 2002). Changes in patterns of recreational use of marine habitats as a consequence of the covid-19 pandemic demonstrate negative effects of human activities on the presence of shorebirds (Lewis *et al.* 2022). Conversely, in breeding contexts, the presence of people can have positive impacts by reducing predation (Leighton *et al.* 2010, Fox *et al.* 2015, Hentati-Sundberg *et al.* 2021). Future climate change is likely to affect estuarine habitats as a result of sea-level rise, temperature fluctuations, and variation in salinity as a result of changes in tidal flushing and freshwater input (Robins *et al.* 2016). The consequences for individual estuaries are hard to predict and will require long-term monitoring for assessment (Robins *et al.* 2016), an approach also badly needed to understand how to mitigate the increasing impacts of human activities on the wildlife dependant on estuarine and intertidal habitats for their existence.

Estuaries and intertidal habitats are also important nursery areas for Common Eider *Somateria mollissima mollissima* (hereafter Eider) ducklings but, as with shorebirds (Lewis *et al.* 2022), are susceptible to disturbance from recreational and commercial use which can increase predation on ducklings (Åhlund & Götmark 1989, Keller 1991, Hamilton 2001). As ducklings are flightless, they may be an indicator for monitoring the wildlife diversity of some estuarine habitats during the breeding season. The Common Eider (hereafter Eider) has a circumpolar distribution, but has declined in parts of the range, particularly in Europe (Ekroos *et al.* 2012, Öst *et al.* 2016). Such declines may be attributable to population-specific effects on adult survival and/or fecundity (Öst *et al.* 2016). Nature tourism (Fox *et al.* 2015) and commercial interests with respect to the sustainable harvesting of eider down from some populations can facilitate research, monitoring and conservation (CAFF 1997, Kristjánsson & Jónsson 2011), but, elsewhere, more effort is needed to monitor, identify and mitigate decline.

The Eider is of moderate conservation concern in the UK (Stanbury *et al.* 2021). The Northumberland coast is an important breeding area where approximately 1,600 nesting females, 4% of the UK population, are concentrated mainly on the Farne Islands and Coquet Island and only a few nest on the adjacent mainland (Dean *et al.* 2015). Coquet Island, a 6-ha grassy plateau (Coulson 2010) situated 2 km east of the mouth of the River Coquet Estuary, is a Bird Sanctuary managed by the Royal Society for the Protection of Birds (RSPB); the Eiders there are at the southerly limit of their regular breeding distribution on the east coast of the UK (Dean *et al.* 2015). The Eider population on Coquet Island, a key attribute that led to the designation of the island as a Site of

Special Scientific Interest (SSSI; Natural England 1983), has declined by more than 50% from around 500 pairs in the early-mid 1980s, possibly as a result of reductions in food availability (Coulson 2010). From 1995 to 2021, Coquet Island supported a mean of 291 pairs (range 184 - 391) and was in unfavourable condition as an SSSI at the last assessment (Natural England 2013). Few Eiders use the intertidal rocky habitat around the island as duckling foraging areas and crèches are moved by their attendant females to the Coquet Estuary within a few days of hatching.

The Coquet Estuary, running approximately west to east and hosting the port of Amble, appears to be a nursery area for Eider ducklings from Coquet Island, and contains a variety of habitats, including intertidal mudflats, sand spits and saltmarsh on the northern side, with port and recreational structures to the south. Despite the apparent importance of this estuarine habitat for the sustainability of the Coquet Island population, there is little information on the distribution and numbers of ducklings using the estuary. Furthermore, pressures for increasing recreational and commercial development of coastal areas raise substantial concern for the impact of changes to the estuarine environment on the future viability of the breeding Eider population of Coquet Island.

The threats to Eider ducklings in estuarine and intertidal habitats can be difficult to quantify. The narrow and sheltered Coquet Estuary, some 5 km long with a maximum depth of 3.5 m at the lowest spring tides with good visibility from the port and recreational infrastructures, makes this potential Eider nursery area amenable for monitoring annual variation in duckling numbers and identifying priorities for conservation action. This study originally had the short-term aim of establishing what areas within the estuary were mainly used by Eider broods or crèches. However, Eider duckling counts during the breeding season were continued without interruption for 27 years. As well as revealing how Eider ducklings are distributed within the estuary system, these data have been analysed to ask whether the count data reflect breeding phenology and success on the offshore Coquet Island colony and the influence of environmental factors.

METHODS

Study site and survey methods

Despite its small size (approximately 8 ha), Coquet Island (longitude -1.54°, latitude 55.33°) is an SSSI, a Special Protection Area (SPA) for its assemblage of breeding seabirds and is included within the Northumberland Marine SPA protecting seabird foraging areas. The tidal range is relatively large, 4.2 m and 2.0 m on spring and neap tides, respectively, and tidal streams off the Northumberland coast flood in a southerly direction and ebb in a northerly direction.

An initial survey was carried out in 1994 to monitor duckling numbers on a daily basis in the Coquet Estuary and the shoreline outside, from the date of the first arrivals of ducklings in the Coquet estuary until ducklings were difficult to distinguish from adults at a distance. The length of the annual monitoring season was, therefore, determined by annual variation in Eider breeding phenology. The dates on which surveys ended each year varied from 26 July to 14 August. From 1995, the Coquet Estuary was divided into monitoring areas with boundaries based on geographical features or habitat types (Figure 1). Only one monitoring area (area **j**) was located outside the estuary, and this was unbounded offshore. Although the coastline southwards from **j** to Wellhaugh Point (Figure 1), consisting of exposed rock platform at low tide, was monitored in 1994 and 1995, Eider duckling numbers were low and sporadic; therefore, this section of coast was excluded from the survey. The coastline to the north of the estuary breakwater is sand, subject to greater human disturbance and was not routinely monitored. Survey areas were assigned to categories of use as commercial, recreational and/or wildlife (Table 1).

All survey areas were walked by one of the authors (HBC) at low tide from approximately a week before the expected first sighting date. In particular, the Northside area, which appeared to be favoured by Eider broods or crèches, was checked daily at low tide from the beginning of May. Duckling numbers were then recorded from the date of first duckling sighting each year. The survey start dates each year were also guided by the first observations of ducklings on Coquet Island. Thereafter, survey counts were standardised to start at 06:00 h each day where possible; overall, 99.94% of area counts were between 05:00 and 07:00 h and surveys took up to about an hour to complete each day.

Birds were counted using 12 x 50 (Swift Super Tecnar, for the first 4 years) or 10 x 42 (Viking multi coated, the remaining study years) binoculars from ‘count stations’ at elevations providing a clear view over the water even in rough weather (Figure 1). Although Eider broods frequently amalgamate into crèches guarded by parental or non-parental attendant females, single broods can also attract non-parental attendant females (Waltho & Coulson 2015); for convenience, we refer to all groups of ducklings with attendant females as a ‘crèche’. The number of ducklings sighted in each crèche and the number of accompanying attendant females were recorded; ducklings were not assigned to age categories. In poor weather, crèches were counted three times at each location, and the average count recorded. All the adult females counted in each survey were females behaving as ‘attendant females’ (‘Broody’ and ‘Associate’ categories described by (Munro & Bédard 1977)) and were amongst or in very close proximity to the crèche.

Data sources

All data were processed and analysed using R version 3.6.1 (R Development Core Team, 2016). The data comprised counts of ducklings and attendant females by survey area. Duckling 'arrivals' observed in the Coquet Estuary were the positive differences of each daily count minus the count for the previous day; the sum of these values was used as an estimate of total arrivals in the estuary each season. These observed arrivals do not take into account unobserved losses in the estuary between daily surveys. Additional field data were collected by RSPB staff and were the number of Herring Gulls *Larus argentatus* and Lesser Black-backed Gulls *L. fuscus* (referred to as 'large gulls') nesting on Coquet Island each year (Booth & Morrison 2010), the number of female Eiders nesting on Coquet Island each year, and the 'first nest' dates which were available for years 2001 to 2021 inclusive. 'First-nest' dates were determined from the presence of incubating females, found during routine conservation and maintenance work or from targeted searches around the expected time. The number of nesting female Eiders was determined from two census visits, the first ~26 days after the first-nest date and the second ~26 days later (Coulson 2010). Counts were by two to five people searching marked grid squares for incubating Eiders; predated and failed nests were recorded for the first census only and included in the total population. Only females on the nest were recorded in the second census to prevent double counting of single sites.

Meteorological data were used in the analysis to investigate the contribution of environmental factors to the numbers of nesting Eiders or breeding success, and to test the role of wind, rain and sea conditions on the arrival of ducklings in the Coquet Estuary. Principal-components-based North Atlantic Oscillation (NAO) indices (Hurrell *et al.* 2003) were obtained from https://climatedataguide.ucar.edu/climate-data/hurrell-north-atlantic-oscillation-nao-index-pc-based. Indices for December-January-February-March, December-January-February, March-April-May, and March were compared in exploratory analyses (see Supplementary Information, Text 1), and separate monthly indices for March to July were used for further analysis. NAO indices reflect atmospheric pressure differences across the North Atlantic (Hurrell *et al.* 2003) and are associated with broad-scale variability in weather patterns (Hall & Hanna 2018). In the North Atlantic, positive NAO indices are linked to less extreme weather and cooler, drier conditions in spring (Zhang *et al.* 2022).

Local weather data for the Boulmer meteorological station (9 km north of the Coquet Estuary) were from the UK Meteorological Office Integrated Data Archive System (MIDAS). Hourly wind data were processed to daily mean wind speed and mean maximum gust speed. Because these were significantly correlated, we used their orthogonal principal components, pcaW1 and pcaW2. Daily mean wind direction was calculated using circular statistics (R package *circular*) and converted into

90° quadrants centred on East, North, South and West, respectively. Rain was expressed as daily totals (mm precipitation). These data as daily values for the day before each survey were used to investigate the effects of weather on duckling arrivals. Minimum temperature measurements were daytime measurements for the day before the survey day (09:00 to 21:00) and night-time measurements from 21:00 the day before survey day to 09:00 on the survey day; the mean of these daytime and night time values were used but were strongly correlated with seasonal progression (day in the year); therefore, residuals from a linear model of minimum temperature predicted by day in the year were used in generalised linear mixed models (GLMM). The environmental parameter of wind, rain, wave height and sea surface temperature (SST) were also processed to monthly mean values for March to July inclusive to investigate effects on duckling arrival parameters at a broader scale.

Tidal states at each survey were retrospectively assigned using sea-level data at 15 min intervals from the UK Tide Gauge Network for North Shields (longitude -1.439778, latitude 55.007444; 24 years) and Whitby (longitude -0.614694, latitude 54.49; 3 years), obtained from the British Oceanographic Data Centre. Peaks (high tide) and valleys (low tides) were identified from the tide gauge data using the *findPeaks* and *findValleys* functions of R-package *quantmod*. Successive times for low and high tide were checked for consistency, errors corrected and adjusted to Amble using high and low tide differences in timing between current tide tables for Amble and North Shields, and converted to BST. For three years (2002, 2016 and 2019), North Shields data could not be used and tide-gauge data for Whitby, applying the appropriate corrections for Amble, were used instead. The time for each survey used for tide state allocation was the time that the last survey area was counted. Tidal states were assigned to approximate tidal cycle quadrants as High (H), Falling (F), Low (L) or Rising (R) with quadrant boundaries at H ± 1.5 h and L ± 1.5 h.

Data for sea surface wave significant height, the average height in metres of the highest one third of the waves (where height is the vertical distance from a wave trough to the following wave crest), in a 1.5 km latitude and approximately 1.5 km longitude cell containing Coquet Island (Supplementary Information, Figure S1) were from the Atlantic- European North West Shelf- Wave Physics Reanalysis Copernicus Marine at https://resources.marine.copernicus.eu/product-detail/NWSHELF_REANALYSIS_WAV_004_015/INFORMATION. For analysis of the effects of wave height on duckling arrivals, mean wave heights from 09:00 h the day before to 00:00 h on the days of duckling arrivals were calculated.

Daily files of Level 4 processed satellite data at 0.05° latitude and longitude resolution for sea surface temperature (SST) at 20 cm depth were obtained from https://cds.climate.copernicus.eu/cdsapp#!/dataset/satellite-sea-surface-temperature?tab=form and used to calculate the mean March SST for the coordinate range -1.6° to -1.5° longitude and 55.3° to 55.5° latitude.

Statistical methods

Observed rates of duckling loss per day (reported as rate constants or proportionality constants) were estimated by fitting exponential decay curves from peak counts to the next trough using function *nlsLM* from the R package *minpack.lm* (Elzhov *et al.* 2023). Counts of arrivals each day (0 or positive integers) were tested against predictor variables using zero-inflated GLMMs using *glmmTMB* with the quadratic parameterisation of the negative binomial distribution and year as a random effect. Continuous predictors were standardised to mean = 0 and sd = 1 and models checked for autocorrelation with the Durbin-Watson test (*lmtest* R-package). Predictor variables were day-in-the-year (as a second-order polynomial), tide state, wave height, precipitation, wind direction (quadrant), and wind speed principal components pcaW1 (speed) and pcaW2 (orthogonal gust component), and daily minimum temperatures corrected for seasonal effects (Supplementary Information, Text 2). Models were ranked by AICc and the top models selected by ΔAICc < 2; these were significantly different (Analysis of Deviance; $P \ll 0.0001$) from the null model (ΔAICc = 123.8). Multicollinearity was checked using the R-package '*performance*' (Lüdecke *et al.* 2021). For the top models, predictors which made significant contributions to the models were uncorrelated (Variance Inflation Factors [VIF] 1 to 1.2). Otherwise, for precipitation and the interaction of precipitation with tide there was low correlation (VIF 3.6 and ≤ 4, respectively).

As a means to compare arrival-count profiles between years, we fitted simple three-parameter (upper asymptote, midpoint, and a scale parameter) logistic curves by non-linear least squares to the cumulative proportion of duckling arrivals across each season. These curves were not intended to be the best statistical non-linear curve fit to the data for each year, but provided an adequate fit using a mathematical function common to all years. The logistic curve parameters *midpoint* (the time at which half the duckling totals have arrived) and *scale* (a measure of spread or the time from the midpoint to approximately 0.63 of the upper asymptote) provided two simple measures to compare arrival profiles. However, *midpoint* and *scale* were significantly correlated and the principal components (PC) were used: *midpoint* was the main contributor to the major axis, PC1, and is referred to as Duckling Arrival Parameter 1 (DAP1), and *scale* to the minor axis, PC2, and is referred to as DAP2.

Averaging correlation coefficients (*rho*) across years was done by calculating means, weighted by sample size, after Fisher's z transformation and then back transformation to *rho* for calculation of confidence intervals (Corey *et al.* 1998). The relationship between ducklings and attendant females in each year was estimated using a full ordinary linear regression model of duckling numbers (dependent variable) by female numbers and year (independent predictors), zero intercept and weighted by residuals to account for increasing variance as duckling numbers increased.

To explore potential environmental influences on duckling count arrival parameters DAP1 and DAP2, mean monthly values for the environmental variables NAO (PC-based), SST, Wave height, rain, wind speed and wind direction (expressed as the proportion of the month with westerly winds), were calculated for each of the months March, April, May, June and July in all survey years. For each environmental parameter, Pearson correlation coefficients by month with DAP1 and DAP2 were calculated and corrected for multiple testing (within each environmental parameter/DAP correlation) using Holm's method (Holm 1979). There were no autocorrelations within environmental data by year across the study period ($P > 0.05$) tested using the Durbin-Watson test on linear models of the environmental parameter by year. Where relevant, data distributions were tested using the Shapiro-Wilks and Kolmogorov-Smirnov tests, autocorrelations within single data vectors were assessed using the *acf* function, and trends with time assessed using Pearson correlation coefficients and the non-parametric Mann-Kendall trend test.

RESULTS

Total counts in the Coquet Estuary

Ad hoc observations during the study period indicated that Eider broods and crèches hatched on Coquet Island departed towards the Coquet Estuary soon after reaching the sea. Ducklings were generally first seen in the estuarine Northside and river Yacht Club areas (Figure 1b). The Northside area was the most-favoured area by duckling numbers across the season but with the Harbour Bar, Old Water and Cliff House areas also being important (Figure 1b). However, by shoreline distance, the Cliff House area, a rocky shore habitat (Figure 1a, area **j**), increased in duckling density during the season relative to all other areas (Figure 1c). The main areas by duckling counts were 'wildlife areas' which had low or limited direct human disturbance (Table 1). Otherwise, there was considerable variation between years and within seasons in the proportional distribution of ducklings across survey areas and no consistent patterns of habitat use (Supplementary Information: Figure S2).

Dates of first duckling arrivals in the Coquet Estuary were normally distributed (Shapiro-Wilk test, $W = 0.97$, $P = 0.49$) with a mean of 23 May (range 11 May, in 2011, to 3 June, in 2001), and there was no significant trend by year (Pearson rho = -0.28, $t = -1.47$, $df = 25$, $P = 0.15$; Mann-Kendall trend test: tau = -0.224, $P = 0.115$; Supplementary Information, Figure S3) across the 27-year study period.

The first nest dates for Eider on Coquet Island were available from 2001 to 2021 (range 14 April to 2 May, mean and median, 23 April) and these correlated with the first-duckling arrival dates over the same period (Spearman *rho* = 0.44, S = 865.8, P = 0.05). Within each season for the estuary as a whole, total duckling counts during the season varied as a sequence of peaks and troughs (Figure2 and Supplementary Information Figure S4) until late July/early August. We interpret the peaks as arrivals of new ducklings, and the decrease in counts as the loss or disappearance of ducklings from the Coquet Estuary. There was annual variation in the observed rates of duckling loss from the estuary but in most years these were ≤ 0.5 day^{-1} apart from 1998, 2005 and 2020 (Figure 2c). Overall, the mean and median seasonal observed rate of duckling loss from the estuary across years was 0.4 day^{-1} (95% CI 0.3 to 0.45). Eider ducklings and crèches can be seen along the Northumberland coast during the breeding season (Supplementary Information, Figure S5). Apart from the movement of Eider ducklings and crèches out of the estuary, predation could also be a factor in duckling loss. Instances of predation in the estuary by large gulls (mainly Herring Gulls and Lesser Black-backed Gulls), Grey Heron *Ardea cinerea* and mammalian predators (Red Fox *Vulpes vulpes*, Domestic cat *Felis catus*) were recorded during surveys (Supplementary Information, Text 3). Herring and Lesser Black-backed Gulls also breed on Coquet Island, the closest breeding populations to the Coquet Estuary, but there was no significant correlation between numbers of these breeding large gulls and annual rates of duckling loss (Pearson *rho* = 0.144, t = 0.715, P = 0.48).

Duckling arrivals

Between 1995 and 2021 there was a correlation between total observed duckling arrivals each season and the number of nesting females on Coquet Island (Supplementary Information Figure S6; Pearson correlation coefficient = 0.39, df = 25, P = 0.05, 95% CI = 0.007 to 0.668). Conversely, there was no significant correlation between the total duckling arrivals each season and the number of large gulls nesting on Coquet Island (Supplementary Information Figure S6; Pearson correlation coefficient, *rho* = -0.29, df = 24, P = 0.16; 95% CI = -0.6 to 0.11).

Arrival counts may be influenced by environmental conditions. This was tested using generalised linear models. In addition to candidate environmental predictors, all models included year as a random effect and seasonal progression (day in the year, second-order polynomial) as a fixed effect. There were four top models (ΔAICc < 2; Table 2), all of which included tide as an additive effect and rain as an interaction with tide. The top model (ΔAICc = 0) had wind direction (originating quadrant) as an additive effect; models 3 and 4 (Table 2) also included the orthogonal maximum gust component of wind speed (model 3) or wind speed (model 4) as additive effects. Wave height and minimum temperatures did not appear in the top models. However, as main effects only seasonal progression and tide made significant contributions to variance (Analysis of Deviance, P < 0.0001; Supplementary Information Text 2). With respect to tide, arrival counts were significantly higher on rising tides (Figure 3; least-squares means, pairwise comparisons, P < 0.0001). Rain was only significant as an interaction with tide (Analysis of Deviance, P < 0.001), where rain decreased arrival counts at falling and low tides (coefficients relative to rain at high tide: rain on falling tide -0.24, P = 0.014; low tide -0.57, P = 0.0013). The contribution of wind direction to the top models was marginal (Analysis of Deviance, P = 0.1) with model coefficients suggesting higher arrival counts in northerly winds (Table 2; P ≤ 0.04). Coefficients for other variables in the top models were not significant.

The rate at which ducklings arrived in the estuary varied between years (Figure 4a and Supplementary Information, Figure S7). Parameters representing the midpoint and the spread of arrivals from fitted logistic curves were significantly correlated (Figure 4b), indicating greater spread as the midpoint becomes later in the season. To investigate spread or arrival synchrony independently of the midpoint, the principal components of these parameters were used; the major axis, referred to as duckling arrival parameter 1 (DAP1), comprised 88.6% contribution from the midpoint parameter and was only marginally correlated with the first day of duckling arrivals (*rho* = 0.35, df = 25, P = 0.071). Conversely, there was a significant negative correlation between the orthogonal minor axis component, DAP2 (88.6% contribution from the spread parameter) and the first day of duckling arrivals (Figure4c; *rho* = -0.64, df = 25, P = 0.0003). Therefore, duckling arrivals were more synchronised in years when ducklings were late in first arriving. Over the period of the study there was no significant trend by year in DAP1 (Pearson *rho* = -0.27, P = 0.18). However, there was a hint that arrivals had increased in spread in later years (DAP2 by year, Pearson *rho* = 0.35, P = 0.07). DAP2 data were not significantly different from a normal distribution (Shapiro-Wilks test, W = 0.95, P = 0.2; Kolmogorov-Smirnov test, D = 0.23, P = 0.104) and were not autocorrelated (Supplementary Information Figure S8), but parametric correlations could be influenced by outliers. The non-parametric Mann-Kendall trend test supported a trend for increasing DAP2 during the study period (Figure 4d; Mann-Kendall tau = 0.31, P =0.024).

Annual variation in the spread of duckling arrivals during the season might reflect variation in synchrony of breeding by the nesting females, perhaps with birds breeding later and/or the population being less synchronised after winters when foraging conditions were poor. The number of breeding females (nests) on Coquet Island are monitored each year, but few other breeding parameters are routinely measured, primarily to reduce disturbance. First-nest dates have only been recorded on Coquet Island since 2001 but there was no significant correlation between these and duckling arrival parameters DAP1 (Spearman correlation, S = 1231.6, df = 19, P = 0.38) or DAP2 (S = 1351.1, df = 19, P = 0.6) over the same period.

To explore the potential for environmental factors to have influenced duckling arrivals, correlations between monthly NAO indices, SST, Wave height, rain, wind strength and wind direction (expressed as a proportion of days with wind from the westerly quadrant), and DAP1 or DAP2 were investigated. Analyses indicated a positive correlation between DAP1 and the NAO indices for May, and a negative correlation between DAP2 and mean wave height for April (Figure 5 and Table 3).

Attendant females and ducklings

Counts of attendant females associated with crèches increased and decreased during season in parallel with duckling counts (Figure 6). Counts of attendant females and ducklings were significantly correlated each year (P < 0.00001; Spearman's correlation coefficient, averaged across years, 0.887, 95% CI 0.765 to 0.95). Although female Eiders other than attendant females associated with crèches were not systematically recorded, non-attendant females were not noticeably present within the estuary. The slopes of the relationship between ducklings and attendant females varied between years (Figure 6) with a mean of 2.7 ducklings per attendant female (range 1.5 to 3.8) over the study period.

There was a marginal positive relationship, although not statistically significant, between ducklings per attendant female and the year totals for duckling arrival counts (*rho* = 0.36; df = 25, P = 0.07), but not with the number of nesting females on the island (rho = 0.072; df = 25, P = 0.72). Given the positive relationship between total duckling arrivals and the number of nesting females on Coquet Island each year, the varying annual duckling to attendant female ratio may result from annual variation in mean clutch sizes on Coquet Island and/or the proportion of ducklings that survive from hatching to arrival in the Coquet Estuary. Eider clutch sizes show year-to-year variation on Coquet Island and have also declined markedly between 1958 and 2006 (Coulson 1999, 2010). Clutch sizes have not been monitored after 2006 and the available data are insufficient to allow a test of the relationship between ducklings per attendant female and clutch size. However, for the period 1995 to 2006, data for clutch size (Coulson 2010) and the number of nesting females for those years suggest that only 50% of the eggs (range 22 to 76%) reach the Coquet Estuary as ducklings (Table 4).

DISCUSSION

Arrival of ducklings in the Coquet Estuary

During the 27-year survey, the first duckling arrival dates in the estuary varied between years by up to 23 days, and ducklings continued to arrive until late July/early August. Duckling arrival counts do not take into account ducklings that may have arrived and been predated or moved away from the estuary since the previous survey 24 h earlier. For the early years of the survey where clutch size data are available, the total observed arrival of ducklings in the Coquet Estuary each year represented only around 50% of what might be expected from the clutch sizes of females breeding on Coquet Island. Nevertheless, over the whole survey period duckling arrival totals correlated with the number of breeding females on Coquet Island. Herring and Lesser Black-backed Gulls are significant predators of ducklings in many Eider colonies (Mendenhall & Milne 1985, Götmark & Ahlund 1988, Åhlund & Götmark 1989, Donehower & Bird 2008) and losses resulting from predation on nests, eggs and ducklings in transit to the estuary may be considerable. Ducklings will be particularly vulnerable to large gulls when moving from the nest to the shoreline (Minot 1980). It is, of course, possible that not all ducklings from Coquet Island travelled to the estuary, or that some used the estuary only in transit, and later foraged at sites along the coast that were not surveyed.

Apart from seasonal progression, daily arrival counts were affected by a number of factors, particularly tide at the survey time. The behaviour of ducklings on rising tides may make them more visible to the surveyor and likely to be counted; alternatively, travel into the estuary from the island may be facilitated by a rising tide. With a distance of 2 km from the island to the estuary, the expected travel time for a duckling would be around 2 h (Yuan *et al.* 2021). Tidal flow along the coast in a rising (flood) tide is from north to south, and northerly winds, which also had a positive effect on rising-tide arrival counts, will increase surface drift currents in the same direction (van den Bremer & Breivik 2018). Under these conditions, travel of ducklings into the estuary will be facilitated by a rising tidal flow, counteracting the seaward flow of the River Coquet.

The interval between surveys was approximately 24 h, whereas a tidal cycle takes just over 12 h. The times of day at which crèches depart Coquet Island have not been characterised, but anecdotal observations report departure at any time of day and in a variety of weather or sea conditions. However, the safest time to travel may be in low light conditions (Peterson *et al.* 2019), and females nesting on Coquet Island may prefer to take their crèches across from low tide in darkness or twilight as the tidal flow increases from the north. At low tide, the extensive rocky shore around the island is exposed and may provide suitable feeding areas (Minot 1980) slightly closer to the estuary until tides facilitate movement west to the estuary mouth. Other studies have described a preference for departure to nursery areas in rising tides, and at night, but such behaviours are likely to be site specific (Munro & Bédard 1977, Minot 1980). It seems likely, then, that increased arrival counts on rising tides either reflected a preference for, or a consequence of, particular crossing conditions by Eiders and their crèches rather than a being a survey artefact of increased duckling visibility at particular tidal states or weather conditions.

Rain the day before the survey day tended to increase arrival counts on rising tides, but the reason why this might be the case is not clear; poor weather conditions might act as a cover to reduce the chances of predation during the crossing, or encourage crèches into calmer estuarine habitat. Although predation of Eider ducklings by large gulls in nurseries can increase in rainy weather (Mendenhall & Milne 1985), crossing open water is a different context in which ducklings may be protected by vigilance and antipredator responses by attendant females

Duckling losses from the estuary

The count profiles within the estuary each season comprised a series of peaks and troughs, representing arrivals and loss of ducklings. Reductions in duckling counts, with counts reducing by half, on average, each day, will be a consequence of crèches moving out to other areas and/or predation. Predation of ducklings by large gulls in the estuary was observed frequently, but other predators were important too, with Grey Heron, Fox and domestic animals seen predating Eider ducklings. It is also highly likely that crèches moved out of the estuary, and travelled north along the coast (Waltho & Coulson 2015). Apart from a study carried out in 1975 in which 28% of the ducklings in the estuary were estimated to have moved away (reported by Waltho & Coulson 2015), there are only anecdotal reports of Eider duckling crèches along the coast away from the Coquet Estuary. Eiders also breed on the Farne Islands, 32 km north of Coquet Island, and Eider crèches along the Northumberland coast north from the Coquet Estuary could have originated from either site. Identifying the extent of movement out of the estuary and the extent of predation and duckling mortality is a question for further research. However, it seems likely that the Coquet Estuary functions both as a nursery and as a transient reception area. Diet and food availability may vary between and within years, influencing mortality and predation (Waltho & Coulson 2015), and also the movement of crèches from the estuary to alternative feeding areas. Disturbance from commercial and recreational human activities are also likely to be important factors, both with respect to predation (Åhlund & Götmark 1989) and the movement of crèches from the estuary.

Duckling counts and breeding parameters

Intra- and inter-seasonal variation in duckling arrival counts and count profiles should reflect variation in breeding parameters in the local population (breeding females, clutch sizes, laying dates and laying synchrony), coupled with the impact of predation during nesting, hatching and brood movement. On Coquet Island, the number of breeding large gulls has varied as a result of licensed control from a peak of up to 250 in the early years of the survey to a low level of 10-20 in the latter years, but there was no detectable relationship with duckling counts. However, large numbers of immature large gulls regularly use intertidal areas around Coquet Island for roosting and could be responsible for predation of Eider ducklings on Coquet Island, the estuary and in transit. There are no count data for the number of non-breeding large gulls using the estuary or Coquet Island during the breeding season available for analysis.

First-nest dates can give a poor view of population breeding parameters because they can be biased by small numbers of early-breeding females (Waltho & Coulson 2015), and this would account for the lack of correlation with duckling arrival parameters. Nevertheless, nest predation and high age-dependent mortality of Eider ducklings (Öst *et al.* 2008, Waltho & Coulson 2015) may reduce bias from early nesting females. In the absence of data for other measures of breeding synchrony such as interquartile range (Öst *et al.* 2022), duckling arrival parameters in the estuary may be better proxies for summarising the average and spread of laying dates for the Coquet population overall.

Duckling count profiles within the estuary each year were closely matched by the attendant-female counts. Crèches arise as a coalescence of two or more Eider families (Munro & Bédard 1977, Öst *et al.* 2003) and the attendant females, defined on behavioural criteria (Munro & Bédard 1977), may be mothers of some or all of the ducklings within a crèche. Parallel reductions in duckling and attendant-female counts in the Coquet Estuary are likely to be consequence of the movement of crèches out of the estuary and the loss of ducklings by predation. Studies on the Ythan Estuary, Aberdeenshire, suggest a constant turnover of crèche attendant females, with maternal females leaving even when their ducklings were alive, a behaviour which may be a consequence of poor body condition (Kilpi *et al.* 2001, Bustnes *et al.* 2002). Despite such turnover, the ratio of ducklings to attendant females may remain relatively constant (Gorman & Milne 1972), implying behavioural regulation to an optimal number of maternal females (Öst *et al.* 2008) regardless of duckling losses to predation. Therefore, the predation of ducklings within the Coquet Estuary may also result in balancing changes in the number of attendant females. Between years, the variation in ducklings per attendant female in the Coquet Estuary was marginally correlated with total duckling arrivals during the season, but not the number of nesting females, and suggests that ducklings per attendant female is modified by annual variation in clutch sizes, predation or an interaction between these factors.

Eiders are generally sedentary, except where ice conditions at breeding sites necessitate migration to suitable foraging habitat during the non-breeding season (Swennen 1990, Waltho & Coulson 2015). The Eider has been considered as a ‘capital breeder’, using stored body resources accumulated during pre-laying periods for the production of eggs rather than immediate dietary resources. Migratory Eiders may also use resources stored from wintering areas as well as dietary resources from breeding areas occupied up to a month before laying (Sénéchal *et al.* 2011, Hobson *et al.* 2015). Nevertheless, wherever it occurs, resource accumulation will be sensitive to variation in weather and feeding conditions (Christensen 2000, Christensen & Balsby 2020). Most of the energy for incubation is thought to be from stored resources because incubating females only spend short break periods away from the nest (Criscuolo *et al.* 2000, Garbus *et al.* 2018).

The initiation of laying, although underpinned by cues such as photoperiod (Murton & Kear 1978), will be moderated by female body condition or other factors (Mehlum 1991, Schaper *et al.* 2012) and the distribution of laying dates within seasons will be determined by individual variation in ability to exploit available resources (Hennin *et al.* 2016). Inexperienced females, recruited into breeding populations from 2 years of age, tend to breed later and have small clutch sizes (Baillie & Milne 1982); marked fluctuations in annual recruitment driven by the rates of duckling survival in previous years will, therefore, have consequences for the distribution of laying dates in each season.

In a recent study, Ejsmond *et al* (Ejsmond *et al.* 2021) constructed a model of a high-latitude migratory Eider population in which nest initiation was constrained by snow melt. Their model predicted that population breeding would be more synchronous than usual when nest initiation is delayed by a late spring. This was verified by observational data and suggests that delays in nest initiation allow greater time for resource accumulation once Eiders have arrived in the breeding area (Ejsmond *et al.* 2021).

Eiders in the Coquet population are either resident (the majority) or winter within 150 km north along the adjacent coastline (Baillie & Milne 2008), and nest site availability is not constrained by environmental factors such as snow melt. If nesting by Coquet-breeding Eiders is dependent on reaching a day-length threshold each year, individual variation determined by genetics and/or age (Helm & Visser 2010, Franklin *et al.* 2022, Verhoeven *et al.* 2022) will result in a probability distribution of thresholds. In some years, reduction in the availability of sufficient resources necessary for females to come into breeding condition may delay nest initiation to beyond the permissive date threshold, or may result in the abandonment of breeding by individuals for that year entirely (Coulson 2010). A resource-driven delay in nest initiation could be analogous to a snow-melt constraint (Ejsmond *et al.* 2021), and, if so, would predict a similar increase in breeding synchrony in years when nest initiation was later than normal. The pattern of duckling arrivals in the Coquet Estuary where the spread parameter DAP2 decreased in years when first duckling arrivals were later supports this inference. There was also an indication of a trend for DAP2 to increase by year over the study period and this could imply long-term improvement in food availability to support Eider reproduction. This would be a positive sign if the decline in Coquet Eiders has been driven in the past by poor food availability (Coulson 2010), and may demonstrate the long-term value in monitoring the arrivals of ducklings in nursery or reception areas.

Although it has been suggested that variation in perceived predation risk to breeding females can drive changes in breeding synchrony (Abbey-Lee & Dingemanse 2019, Öst *et al.* 2022), apex predators of Eiders such as White-tailed Eagles (Morelli *et al.* 2021, Öst *et al.* 2022) are not present in or near the Coquet Island or Northumberland Eider populations. Therefore, varying environmental conditions impacting on female body condition are likely to be the dominant driver of changes in breeding synchrony in the Coquet Island population.

With an egg-laying interval of around 24 h (Waltho & Coulson 2015), the incubation time for Eiders from clutch completion is around 26 days (Milne 1974). Duckling first arrival times of 11 May to 3 June imply that incubation generally starts within the first half of April to the first week in May on Coquet Island. Exploratory correlations between duckling arrival parameters and environmental conditions suggest that less-intense weather systems and cool, drier weather in May suggested by higher NAO indices (Zhang *et al.* 2022) could have delayed duckling arrivals into the estuary. Conversely, more turbulent seas in April may have decreased the synchrony of nesting. We speculate that wave-induced turbulence may decrease breeding synchrony by increasing food availability, allowing more females to reach sufficient body condition to finish clutches and initiate incubation in April. This is likely to be a site-specific attribute of the Coquet Island environment and needs to be tested by studies on diet and foraging locations of Eiders and how these change in response to environmental conditions.

Conclusions

This study suggests that annual duckling counts throughout the breeding season in nursery or reception areas can provide data for monitoring the breeding parameters and outcomes of Eider populations. The data extend theoretical predictions and observations from a migratory Eider population to a sedentary one and suggest that for a capital breeder relying on local resource accumulation, delays in nest initiation increase nesting synchrony within the population. Nevertheless, future studies would benefit from accurate monitoring of nest initiation dates and clutch sizes within the breeding colony, parameters which could increase the value of duckling monitoring data. Duckling counts within the Coquet Estuary demonstrate the value of estuarine habitats as reception areas, but raise questions about the extent to which estuaries may be good nursery areas able to support ducklings for significant periods of their development to maturity. The dietary resources available to support ducklings within the estuary, as well as the adjacent coastline, is a gap in knowledge which needs to be addressed. Furthermore, the extent and nature of predation at all stage of early duckling development from hatching to their early development in crèches is important to quantify because the recruitment of new females into the breeding population is dependent on duckling survival. Infrastructures for human commercial and recreational use within estuarine environments could be designed to support duckling nursery areas where human and wildlife activities can occur together sympathetically. Facilitating the safe retention of crèches within an estuary could allow conservation objectives to be achieved in a way which is not possible along natural coastlines.

ACKNOWLEDGEMENTS

BirdTrack data (Supplementary Information, Figure S4) were supplied by the British Trust for Ornithology (BTO). BirdTrack is organised by the BTO for the BTO, RSPB, BirdWatch Ireland, SOC and WOS. We thank John Steele for his vignette of Eiders, and Anne Wilson for the Coquet Island breeding Eider counts from her archive of monitoring data for Northumberland islands.

REFERENCES

Abbey-Lee, R.N. & Dingemanse, N.J. 2019. Adaptive individual variation in phenological responses to perceived predation levels. *Nat. Commun.* **10**: 1601.

Åhlund, M. & Götmark, F. 1989. Gull predation on eider ducklings Somateria mollissima: Effects of human disturbance. *Biol. Conserv.* **48**: 115–127.

Baillie, S. & Milne, H. 2008. Movements of eiders Somateria mollissima on the East Coast of Britain. *Ibis (Lond. 1859).* **131**: 321–335.

Baillie, S.R. & Milne, H. 1982. The influence of female age on breeding in the Eider Somateria mollissima. *Bird Study* **29**: 55–66.

Blackwood, C. 2017. England country boundary, Dataset. EDINA. https://doi.org/10.7488/ds/1758

Bustnes, J.O., Erikstad, K.E. & Bjørn, T.H. 2002. Body Condition and Brood Abandonment in Common Eiders Breeding in the High Arctic. *Waterbirds Int. J. Waterbird Biol.* **25**: 63–66.

CAFF. 1997. *Circumpolar Eider Conservation strategy and Action Plan. Conservation of Arctic Flora and Fauna, Reykjavik*. Conservation of Arctic Flora and Fauna (CAFF).

Christensen, T.K. 2000. Female pre-nesting foraging and male vigilance in Common Eider Somateria mollissima. *Bird Study* **47**: 311–319.

Christensen, T.K. & Balsby, T.J.S. 2020. Condition dependent strategies of egg size variation in the Common Eider Somateria mollissima. *PLoS One* **15**: e0226532.

Corey, D.M., Dunlap, W.P. & Burke, M.J. 1998. Averaging correlations: Expected values and bias in combined pearson rs and fisher's z transformations. *J. Gen. Psychol.* **125**: 245–261.

Coulson, J.C. 1999. Variation in Clutch Size of the Common Eider: A Study Based on 41 Breeding Seasons on Coquet Island, Northumberland, England. *Waterbirds Int. J. Waterbird Biol.* **22**: 225–238.

Coulson, J.C. 2010. A long-term study of the population dynamics of Common Eiders Somateria mollissima: Why do several parameters fluctuate markedly? *Bird Study* **57**: 1–18.

Criscuolo, F., Gauthier-Clerc, M., Gabrielsen, G.W. & Le Maho, Y. 2000. Recess behaviour of the incubating Common Eider Somateria mollissima. *Polar Biol.* **23**: 571–574.

Dean, T.R., Myatt, R.W., Cadwallender, M.L. & Cadwallender, T.A. 2015. *Northumbria Bird Atlas 2007-2011*. Northumberland & Tyneside Bird Club, Newcastle upon Tyne.

Donehower, C.A. & Bird, D.M. 2008. Gull predation and breeding success of common eiders on Stratton Island, Maine. *Waterbirds* **31**:454-462.

Ejsmond, A., Forchhammer, M., Varpe, Ø., Jónsson, J.E. & Jørgensen, C. 2021. Nesting synchrony and clutch size in migratory birds: Capital versus income breeding determines responses to variable spring onset. *Am. Nat.* **198**: E122–E135.

Ekroos, J., Fox, A.D., Christensen, T.K., Petersen, I.K., Kilpi, M., Jónsson, J.E., Green, M., Laursen, K., Cervencl, A., De Boer, P., Nilsson, L., Meissner, W., Garthe, S. & Öst, M. 2012. Declines amongst breeding Eider Somateria mollissima numbers in the Baltic/Wadden Sea flyway. *Ornis Fenn.* **89**: 81–90.

Elzhov, T. V, Mullen, K.M., Spiess, A.-N. & Bolker, B. 2023. minpack.lm: R Interface to the Levenberg-Marquardt Nonlinear Least-Squares Algorithm Found in MINPACK, Plus Support for Bounds. https://cran.r-project.org/web/packages/minpack.lm/index.html Accessed 15 May 2023

Fox, A. D., Jónsson, J. E., Aarvak, T., Bregnballe, T., Christensen, T. K., Clausen, K. K., Clausen, P., Dalby, L., Holm, T. E., Pavón-Jordan, D., Laursen, K., Lehikoinen, A., Lorentsen, S.-A., Møller, A. P., Nordström, M., Öst, M., Söderquist, P. & Therkildsen, O. R. 2015. Current and potential threats to Nordic duck populations — a horizon scanning exercise. *Ann. Zool. Fennici* **52**: 193–220.

Franklin, K.A., Nicoll, M.A.C., Butler, S.J., Norris, K., Ratcliffe, N., Nakagawa, S. & Gill, J.A. 2022. Individual repeatability of avian migration phenology: A systematic review and meta-analysis. *J. Anim. Ecol.* **91**: 1416–1430.

Garbus, S.-E., Lyngs, P., Garbus, M., Garbus, P., Eulaers, I., Mosbech, A., Dietz, R., Gilchrist, H.G., Huusmann, R., Christensen, J.P. & Sonne, C. 2018. Incubation Behaviour of Common Eiders in the Central Baltic: Nest Attendance and Loss in Body Mass. *Acrocephalus* **39**: 91–100.

Gorman, M.L. & Milne, H. 1972. Creche Behaviour in the Common Eider Somateria m. mollissima L. *Ornis Scand. (Scandinavian J. Ornithol.* **3**: 21–26.

Götmark, F. & Ahlund, M. 1988. Nest predation and nest site selection among Eiders Somateria mollissima: the influence of gulls. *Ibis (Lond. 1859).* **130**: 111–123.

Hall, R.J. & Hanna, E. 2018. North Atlantic circulation indices: links with summer and winter UK temperature and precipitation and implications for seasonal forecasting. *Int. J. Climatol.* **38**: e660–e677.

Hamilton, D.J. 2001. Feeding Behavior of Common Eider Ducklings in Relation to Availability of Rockweed Habitat and Duckling Age. *Waterbirds* **24**: 233–241.

Helm, B. & Visser, M.E. 2010. Heritable circadian period length in a wild bird population. *Proc. R. Soc. B Biol. Sci.* **277**: 3335–3342.

Hennin, H.L., Bêty, J., Legagneux, P., Gilchrist, H.G., Williams, T.D. & Love, O.P. 2016. Energetic Physiology Mediates Individual Optimization of Breeding Phenology in a Migratory Arctic Seabird. *Am. Nat.* **188**: 434–445.

Hentati-Sundberg, J., Berglund, P.-A., Hejdström, A. & Olsson, O. 2021. COVID-19 lockdown reveals tourists as seabird guardians. *Biol. Conserv.* **254**: 108950.

Hobson, K.A., Jaatinen, K. & Öst, M. 2015. Differential contributions of endogenous and exogenous nutrients to egg components in wild Baltic Common Eiders (Somateria mollissima): a test of alternative stable isotope approaches. *Auk* **132**: 624–633.

Holm, S. 1979. A Simple Sequentially Rejective Multiple Test Procedure. *Scand. J. Stat.* **6**: 65–70.

Holmes, I. 2017. Mean High Water Springs Polygon Dataset. University of Edinburgh. https://doi.org/10.7488/ds/1969

Hurrell, J.W., Kushnir, Y., Ottersen, G. & Visbeck, M. 2003. An overview of the north atlantic oscillation. In *The North Atlantic Oscillation: Climatic Significance and Environmental Impact* (eds J.W. Hurrell, Y. Kushnir, G. Ottersen and M. Visbeck). https://doi.org/10.1029/134GM01

Keller, V.E. 1991. Effects of human disturbance on Eider ducklings *Somateria mollissima* in an estuarine habitat in Scotland. *Biol. Conserv.* **58**: 213–228.

Kennish, M.J. 2002. Environmental threats and environmental future of estuaries. *Environ. Conserv.* **29**: 78–107.

Kilpi, M., Öst, M., Lindström, K. & Rita, H. 2001. Female characteristics and parental care mode in the creching system of Eiders, *Somateria mollissima*. *Anim. Behav.* **62**: 527–534.

Kristjánsson, T.Ö. & Jónsson, J.E. 2011. Effects of down collection on incubation temperature, nesting behaviour and hatching success of common eiders (*Somateria mollissima*) in west Iceland. *Polar Biol.* **34**: 985–994.

Leighton, P.A., Horrocks, J.A. & Kramer, D.L. 2010. Conservation and the scarecrow effect: Can human activity benefit threatened species by displacing predators? *Biol. Conserv.* **143**: 2156–2163.

Lewis, J., Collison, J. & Pillay, D. 2022. Effects of COVID-19 lockdowns on shorebird assemblages in an urban South African sandy beach ecosystem. *Sci. Rep.* **12**: 5088.

Lüdecke, D., Ben-Shachar, M.S., Patil, I., Waggoner, P. & Makowski, D. 2021. *performance:* An R Package for Assessment, Comparison and Testing of Statistical Models. *J. Open Source Softw.* **6**: 3139.

Mehlum, F. 1991. Breeding population size of the common eider *Somateria mollissima* in Kongsfjorden, Svalbard, 1981-1987. *Nor. Polarinstitutt Skr.* **195**: 21–29.

Mendenhall, V.M. & Milne, H. 1985. Factors affecting duckling survival of Eiders Somateria mollissima in northeast Scotland. *Ibis (Lond. 1859).* **127**: 148–158.

Milne, H. 1974. Breeding numbers and reproductive rate of Eiders at the Sands of Forvie National Nature Reserve, Scotland. *Ibis (Lond. 1859).* **116**: 135–152.

Minot, E.O. 1980. Tidal, Diurnal and Habitat Influences on Common Eider Rearing Activities. *Ornis Scand.* **11**: 165-172.

Morelli, F., Laursen, K., Svitok, M., Benedetti, Y. & Møller, A.P. 2021. Eiders, nutrients and eagles: Bottom-up and top-down population dynamics in a marine bird. *J. Anim. Ecol.* **90**: 1844–1853.

Munro, J. & Bédard, J. 1977. Crèche Formation in the Common Eider. *Auk* **94**: 759–771.

Murton, R.K. & Kear, J. 1978. Photoperiodism in waterfowl: phasing of breeding cycles and zoogeography. *J. Zool.* **186**: 243–283.

Natural England (1983). Coquet Island. Accessed 22 November 2022. https://designatedsites.naturalengland.org.uk/PDFsForWeb/Citation/1004492.pdf

Natural England (2013). 23 Jan 2013 condition assessment: unfavourable-recovering https://designatedsites.naturalengland.org.uk/ReportConditionSummary.aspx?SiteCode=S1004492&ReportTitle=Coquet%20Island%20SSSI

Öst, M., Lehikoinen, A. & Jaatinen, K. 2022. Top–down effects override climate forcing on reproductive success in a declining sea duck. *Oikos* **2022**: e08762.

Öst, M., Ramula, S., Lindén, A., Karell, P. & Kilpi, M. 2016. Small-scale spatial and temporal variation in the demographic processes underlying the large-scale decline of eiders in the Baltic Sea. *Popul. Ecol.* **58**: 121–133.

Öst, M., Smith, B.D. & Kilpi, M. 2008. Social and maternal factors affecting duckling survival in eiders Somateria mollissima. *J. Anim. Ecol.* **77**: 315–325.

Öst, M., Ydenberg, R., Kilpi, M. & Lindström, K. 2003. Condition and coalition formation by brood-rearing common eider females. *Behav. Ecol.* **14**: 311–317.

Peterson, S.H., Ackerman, J.T., Herzog, M.P., Hartman, C.A., Croston, R., Feldheim, C.L. & Casazza, M.L. 2019. Sitting ducklings: Timing of hatch, nest departure, and predation risk for dabbling duck broods. *Ecol. Evol.* **9**: 5490–5500.

Robins, P.E., Skov, M.W., Lewis, M.J., Giménez, L., Davies, A.G., Malham, S.K., Neill, S.P., McDonald, J.E., Whitton, T.A., Jackson, S.E. & Jago, C.F. 2016. Impact of climate change on UK estuaries: A review of past trends and potential projections. *Estuar. Coast. Shelf Sci.* **169**: 119–135.

Schaper, S. V, Dawson, A., Sharp, P.J., Caro, S.P. & Visser, M.E. 2012. Individual variation in avian reproductive physiology does not reliably predict variation in laying date. *Gen. Comp. Endocrinol.* **179**: 53–62.

Sénéchal, É., Bêty, J., Gilchrist, H.G., Hobson, K.A. & Jamieson, S.E. 2011. Do purely capital layers exist among flying birds? Evidence of exogenous contribution to arctic-nesting common eider eggs. *Oecologia* **165**: 593–604.

Stanbury, A., Eaton, M., Aebischer, N., Balmer, D., Brown, A., Douse, A., Lindley, P., Mcculloch, N., Noble, D. & Win, I. 2021. The status of our bird populations: the fifth Birds of Conservation Concern in the United Kingdom, Channel Islands and Isle of Man and second IUCN Red List assessment of extinction risk for Great Britain. *Br. Birds* **114**: 723–747.

Swennen, C. 1990. Dispersal and Migratory Movements of Eiders *Somateria mollissima* Breeding in The Netherlands. *Ornis Scand.* **21**: 17–27.

van den Bremer, T.S. & Breivik. 2018. Stokes drift. *Philos. Trans. R. Soc. A Math. Phys. Eng. Sci.* **376**: 20170104.

Verhoeven, M.A., Loonstra, A.H.J., McBride, A.D., Kaspersma, W., Hooijmeijer, J.C.E.W., Both, C., Senner, N.R. & Piersma, T. 2022. Age-dependent timing and routes demonstrate developmental plasticity in a long-distance migratory bird. *J. Anim. Ecol.* **91**: 566–579.

Waltho, C. & Coulson, J. 2015. *The Common Eider*. Bloomsbury Publishing PLC, London, England.

Yuan, Z.M., Chen, M., Jia, L., Ji, C. & Incecik, A. 2021. Wave-riding and wave-passing by ducklings in formation swimming. *J. Fluid Mech.* **928**: R2.

Zhang, L., Yang, X. & Zhao, J. 2022. Impact of the Spring North Atlantic Oscillation on the Northern Hemisphere Tropical Cyclone Genesis Frequency. Front. Earth Sci. 10. https://doi.org/10.3389/feart.2022.829791

TABLES

Table 1. Survey areas, monitored from 1995 to 2021 inclusive, categorised by predominant use. Areas with very little direct human disturbance were classified as wildlife areas for the purpose of this study.

Label	**Survey area**	**Predominant uses**
a	River Coquet	Wildlife/recreational
b	Old Water	Wildlife
c	Northside	Wildlife
d	Yacht Club	Recreational
e	Marina	Recreational
f	Little Dock	Commercial
g	Harbour	Wildlife/Commercial/recreational
h	Harbour Bar	Wildlife/recreational
i	Little Shore	Recreational
j	Cliff House	Wildlife

Table 2. Arrival counts in relation to environmental variables. Generalised linear mixed-effects models with zero inflation, a negative binomial family distribution and with year as a random effect. All models included seasonal progression (survey day in the year) as a 2nd-order polynomial fixed effect (omitted from the Table). (a) Analyses of Deviance, type III Wald chi-square (X^2) tests; chi-square rounded to nearest whole number. M, model number. Terms are given (left to right) in the order specified in the models; fixed effects were additive except for rain as an interaction with tide. (b) Model-averaged coefficients for conditional fixed effects.

(a) Analyses of Deviance, contributions of fixed effects to top models

M	ΔAICc	df	Fixed-effects terms and contribution: Analysis of Deviance, Chi-sq (X^2) and P-value											
			tide (df = 3)		rain (df = 1)		wind direction (df = 3)		gust		speed		tide:rain (df = 3)	
			X^2	P	X^2	P	X^2	P	X^2	P	X^2	P	X^2	P
1	0	16	37	< 0.0001	1	0.34	6	0.1					17	0.0006
2	0.3	13	37	< 0.0001	1	0.37							18	0.0004
3	0.9	17	38	< 0.0001	1	0.33	6	0.1	1	0.29			18	0.0005
4	1.9	17	37	< 0.0001	1	0.35	6	0.1			0.1	0.74	18	0.0006

(b) Model-averaged coefficients, conditional fixed effects

				Included in Model			
Term	**Coefficient**	**Model**	**P**	**1**	**2**	**3**	**4**
Tide, Falling	0.03[¶]	Full	0.7 NS	✓	✓	✓	✓
Tide, Rising	**0.45[¶]**	**Full**	**< 0.0001**	✓	✓	✓	✓
Tide, Low	-0.04[¶]	Full	0.7 NS	✓	✓	✓	✓
Rain	0.07	Full	0.34 NS	✓	✓	✓	✓
Wind direction, South	0.106[¶¶]	Subset	0.38 NS	✓		✓	✓
Wind direction, West	0.11[¶¶]	Subset	0.39 NS	✓		✓	✓
Wind direction, North	**0.27[¶¶]**	**Subset**	**< 0.05**	✓		✓	✓
Rain: Falling tide	**-0.25[¶r]**	**Full**	**< 0.05**	✓	✓	✓	✓
Rain: Rising tide	0.004[¶r]	Full	0.97 NS	✓	✓	✓	✓
Rain: Low tide	**-0.58[¶r]**	**Full**	**< 0.01**	✓	✓	✓	✓
Wind, PCA1	0.008	Subset	0.74 NS				✓
Wind, PCA2	-0.34	Subset	0.29 NS			✓	

[¶] Relative to High tide

[¶¶] Relative to East wind

[¶r] Relative to rain at High tide

Table 3. Exploratory analyses of potential relationships between environmental parameters and patterns of duckling arrivals (principal components of mid-point, DAP1, and spread, DAP2) each year by month within the season: pairwise correlation coefficients (*rho*) and P values adjusted for multiple comparisons (Holm method) by rows. Two correlations of interest (P = 0.05) are in bold.

DAP1 with:	***March***		***April***		***May***		***June***		***July***	
	rho	***P***	***rho***	***P***	***rho***	***P***	***rho***	***P***	***rho***	***P***
NAO	-0.34	0.32	0.21	0.61	**0.49**[¶]	**0.05**	0.27	0.50	0.09	0.64
SST	-0.38	0.24	-0.39	0.24	-0.30	0.38	-0.20	0.62	0.00	1.00
Wave height	0.24	0.94	-0.05	1.00	-0.23	0.94	-0.28	0.76	0.05	1.00
Wind speed	0.04	1.00	0.11	1.00	0.27	0.84	0.10	1.00	-0.21	1.00
*Westerly wind**	0.12	1.00	-0.33	0.35	0.16	1.00	0.40	0.19	-0.14	1.00

DAP2 with:	***March***		***April***		***May***		***June***		***July***	
	rho	***P***	***rho***	***P***	***rho***	***P***	***rho***	***P***	***rho***	***P***
NAO	0.11	1.00	0.29	0.51	0.30	0.51	-0.05	1.00	-0.38	0.25
SST	-0.17	1.00	0.14	1.00	-0.03	1.00	0.10	1.00	0.07	1.00
Wave height	-0.20	0.60	**-0.49**[¶]	**0.05**	-0.33	0.37	-0.21	0.60	0.26	0.59
Wind speed	-0.03	1.00	-0.35	0.36	0.33	0.36	-0.09	1.00	0.24	0.70
*Westerly wind**	0.21	1.00	-0.07	1.00	0.43	0.13	-0.03	1.00	-0.18	1.00

*Proportion of days with wind from westerly quadrant.

[¶] Ignoring sign, these values for *rho* (and associated P values) are identical only because of rounding to two decimal places.

Table 4. Estimated minimum proportion of Eider ducklings from Coquet Island that survived to reach the Coquet Estuary between 1995 and 2006 inclusive.

Year	**Ducklings arrived**	**Coquet nests**	**Mean clutch***	**Predicted ducklings**	**Survival proportion¶**
1995	682	367	3.47	1275	0.53
1996	718	379	3.43	1301	0.55
1997	252	326	3.50	1140	0.22
1998	312	324	3.76	1218	0.26
1999	341	323	3.71	1197	0.28
2000	464	309	3.38	1043	0.44
2001	290	211	3.41	720	0.40
2002	342	240	3.20	767	0.45
2003	381	198	3.18	629	0.61
2004	525	184	3.75	691	0.76
2005	520	230	3.61	831	0.63
2006	522	211	3.81	804	0.65

*Coulson (2010)

¶Mean 0.48; range 0.22 to 0.76

FIGURE LEGENDS

Figure 1. Study area (a) showing Coquet Island, the nesting colony, and to the west the survey areas, outlined in red, within the estuary of the River Coquet and Amble Harbour. Map consists of 1 m spatial resolution LIDAR composite Digital Surface Model (DSM) 2017 data (UK Government Environment Agency; 2019-04-18 revision; https://data.gov.uk/dataset/80c522cc-e0bf-4466-8409-57a04c456197/lidar-composite-dsm-2017-1m), overlaid with mean high water springs polygon (dashed green line; Holmes 2017) and mean low water springs (blue dashed line: Extent of Realm or England Country Boundary; Blackwood 2017). Map colour represents height (m) as indicated by the scale to the right. Each survey area is identified by letters and classified by use or interest: **a**, River Coquet (bounded to the west by a weir across the river, covered at high tide but forming a barrier otherwise); **b**, Old Water; **c**, Northside; **d**, Yacht Club; **e**, Marina; **f**, Little Dock; **g**, Harbour; **h**, Harbour Bar; **i**, Little Shore; and **j**, Cliff House. A west-to-east rock-armour breakwater marks the northerly extent (North Pier) of survey areas **g** and **h**, which are predominantly sand, river and habitats; within g there is a line of wooden pilings which are the remains of the north jetty along the sand marking the river edge. Area **h** is bounded to the east by the estuary mouth formed by the eastern extremity of this breakwater and one to the south (South Pier) which marks the northern extent of survey area **j**. Survey areas **h** and **i** are separated by wooden pilings of the South Jetty which allows free tidal movement. Areas **i** and **j** are separated by a rock-armour breakwater extending north and then east at the estuary mouth (South Pier). Survey area **i** is sand and shallow water at low tide. The intertidal wave-cut rock platform of area **j** is unbounded seawards. Areas **e** and **f** are part of the port infrastructure of the estuary with mud or mud and boulder habitats at the edges at low tide. Blue stars mark vantage points used to survey areas **a**, **b**, **c**, **d** and **e**. Areas **g** and **f** were surveyed from the harbour edge consisting of the southern boundary of **g**; areas **h** and **i** from the wooden pier and **j** from the breakwater. The graphs b and c show 5-day running means of total duckling counts (b) and counts per shoreline metre (c) per area for all survey years by day in the year. The Eider vignette in c is by John Steele.

Figure 2. Eider ducklings in the Coquet Estuary study area. a, an example of seasonal counts (peaks in black-filled circles, troughs in grey-filled circles, otherwise unfilled circles) for 1996. Further examples are in Supplementary Information Figure S4. b, 1996 data with fitted decline curves from peaks to troughs (solid grey lines). The graph in c summarises median observed rates of duckling decline (peaks to troughs; decay coefficient units, ordinate, are day^{-1}) in the Coquet Estuary each season (filled black circles) during the study period with vertical grey bars representing 95% confidence intervals for the medians.

Figure 3. The influence of tidal state on duckling arrival counts. Marginal means from the generalised linear model 1 in Table 1. Error bars are 95% confidence intervals.

Figure 4. Cumulative duckling arrivals in each year. a) logistic curves fitted to cumulative (as a proportion of the seasonal total) duckling arrival counts for each year (Supplementary Information, Figure S7); b) the correlation (*rho* = 0.77; 95%CI: 0.55 to 0.89; df = 25, P < 0.0001) between logistic parameters for midpoint and spread; c) the correlation between DAP2 (Duckling Arrival Parameter 2; 88.6% spread) and the first day of duckling arrival in each year; d) Trend of DAP2 by year. Fitted lines are median-based linear models.

Figure 5. Duckling arrival parameters and environmental conditions. (a) Duckling arrival parameter DAP1 (midpoint independent of spread) in relation to the NAO index for May. (b) DAP2 (spread independent of midpoint) in relation to mean wave height for April.

Figure 6. The relationship between ducklings and attendant females in each year. A separate regression line (weighted regression to account for variance heterogeneity but not skew) has been plotted for each year; regression lines are constrained to go through the origin. The same colour has been used for the data (open circles) and regression lines for each year, with different colours for each year. Examples of yearly data are shown in Supplementary Information (Figure S9).

FIGURES

Figure 1.

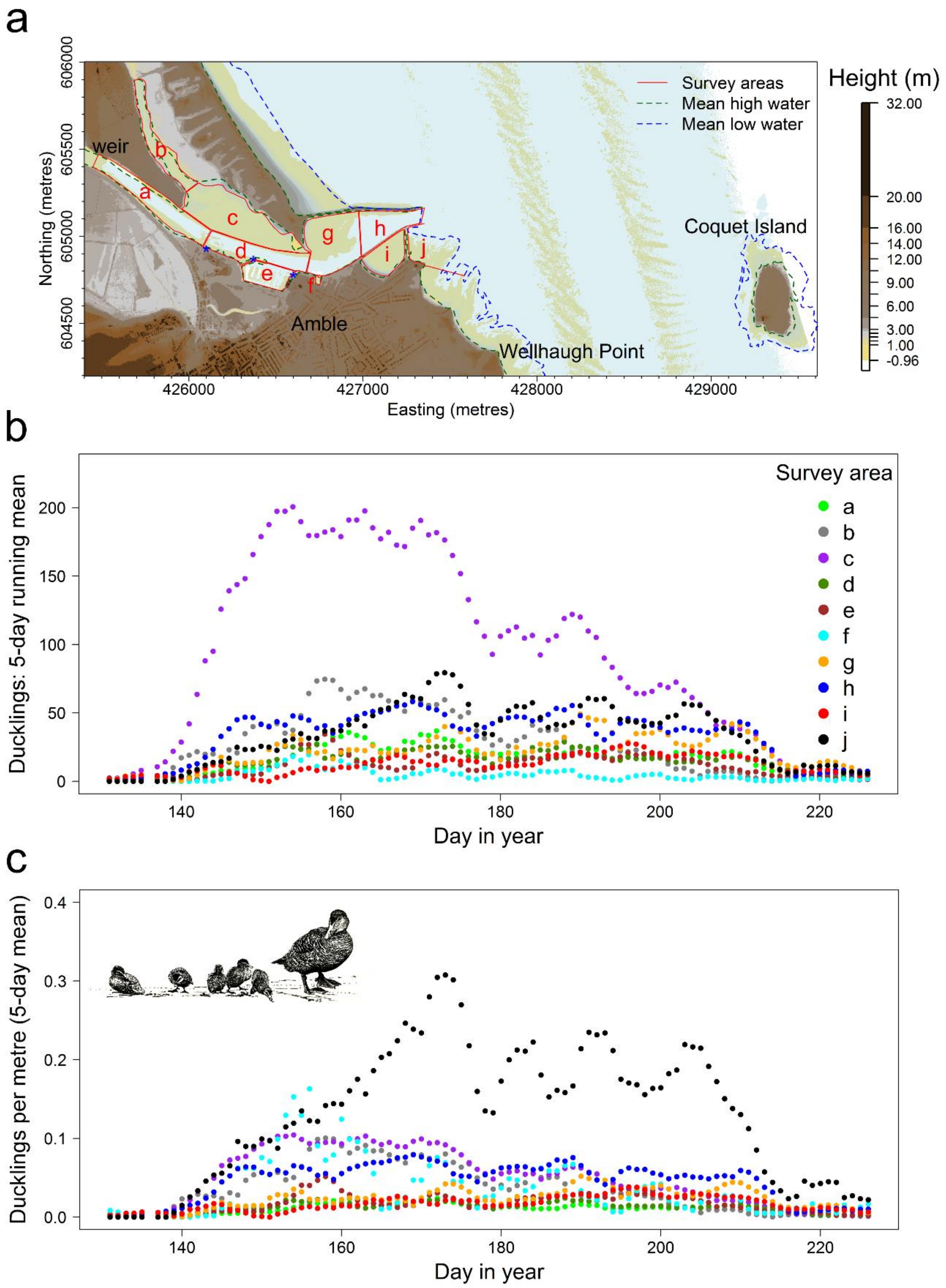


Figure 2

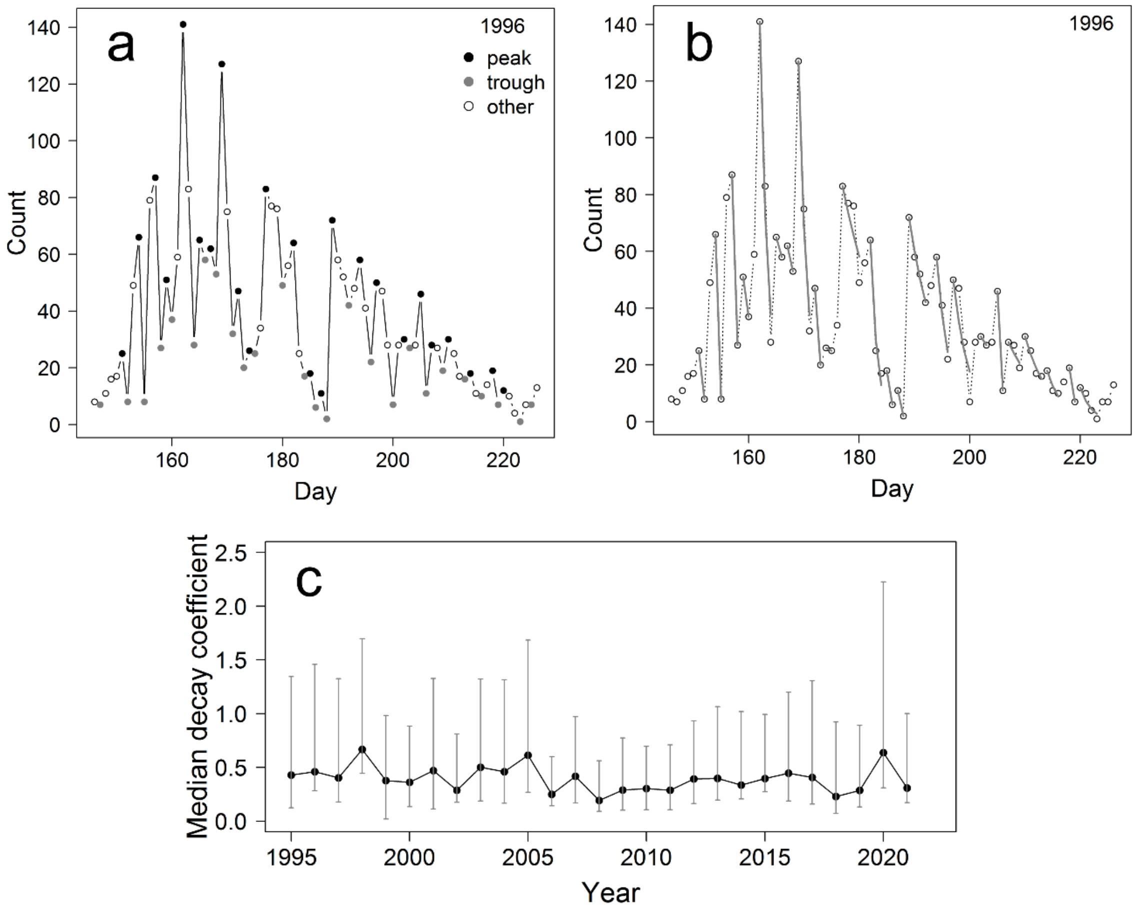

a
1996
peak
trough
other
Count
Day
0
20
40
60
80
100
120
140
160
180
200
220
b
1996
Count
Day
c
Median decay coefficient
Year
0.0
0.5
1.0
1.5
2.0
2.5
1995
2000
2005
2010
2015
2020

Figure 3.

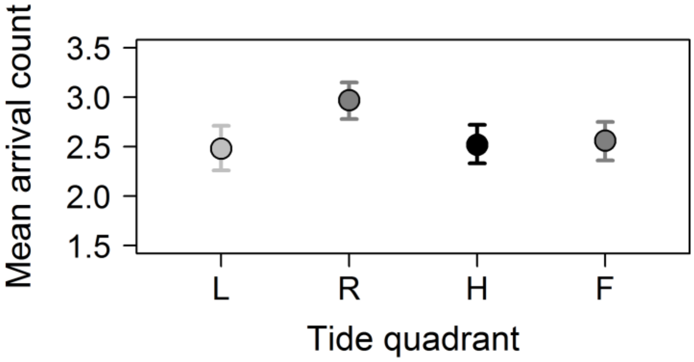


Figure 4.

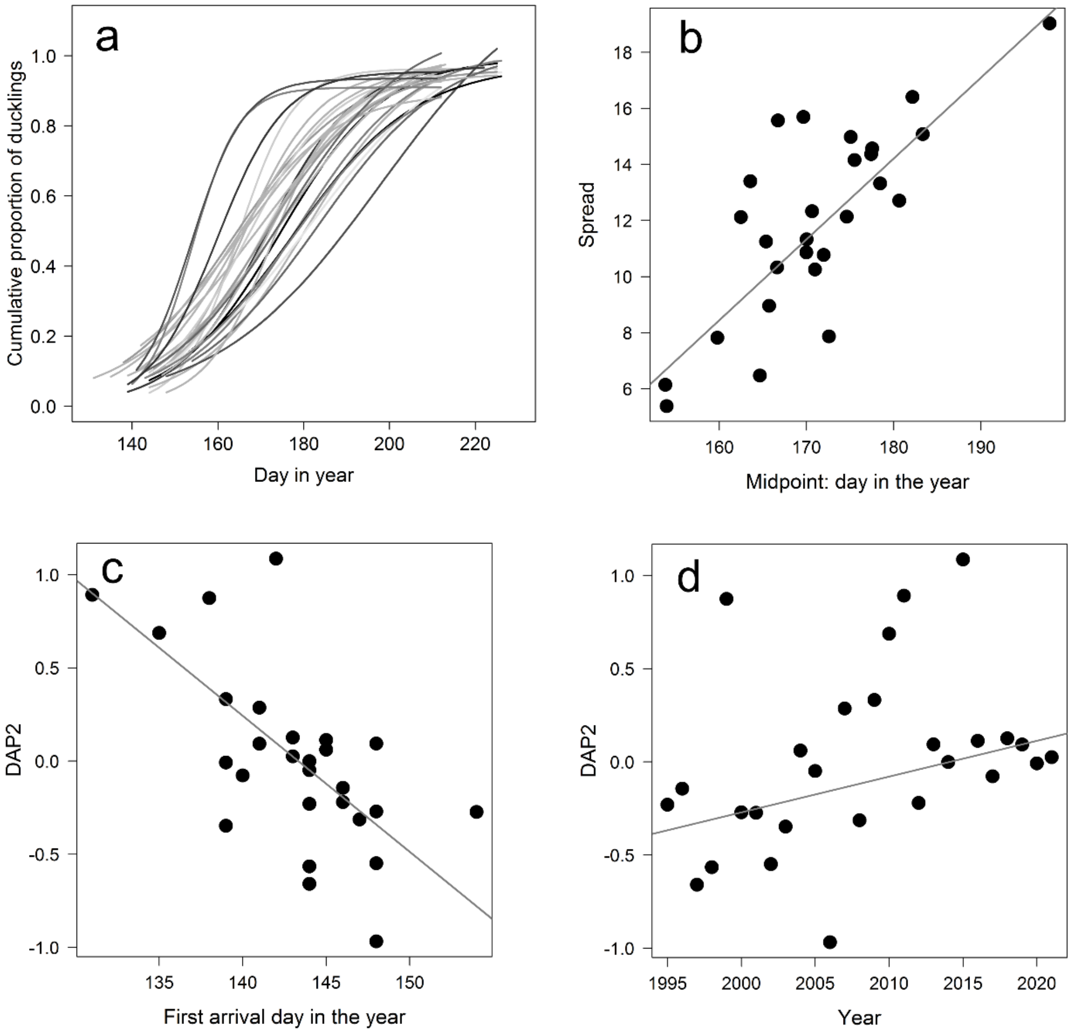


Figure 5.

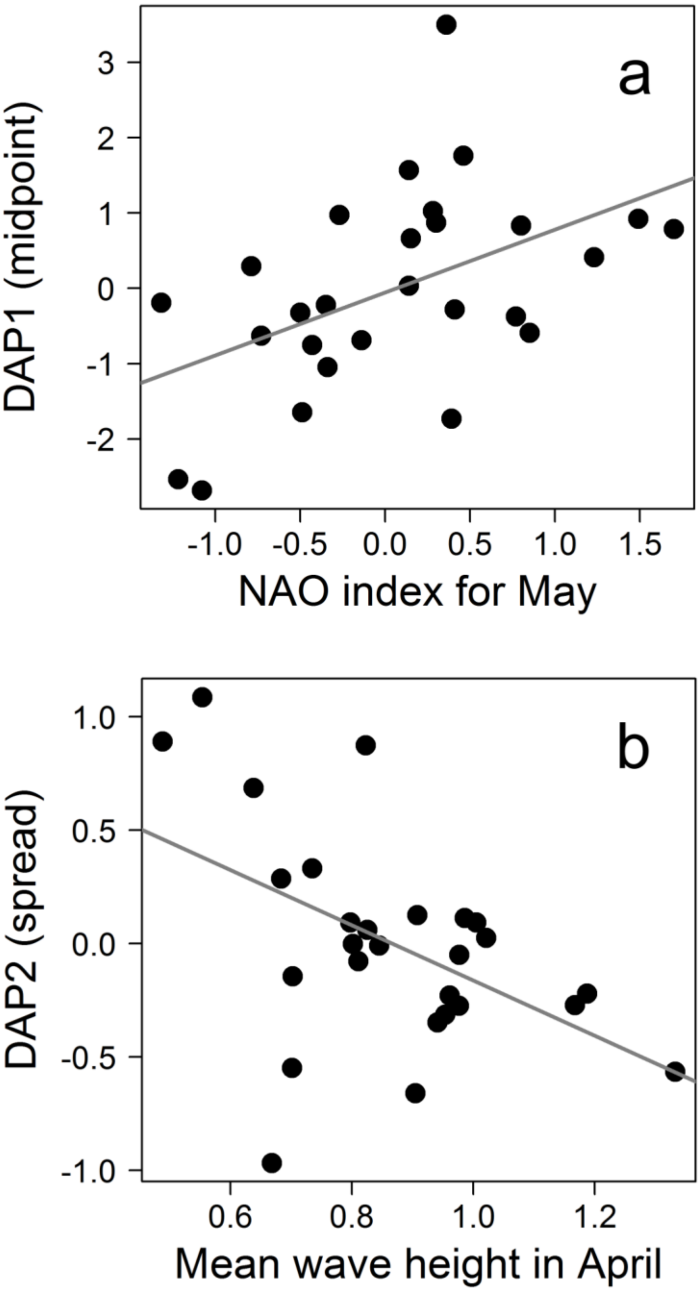
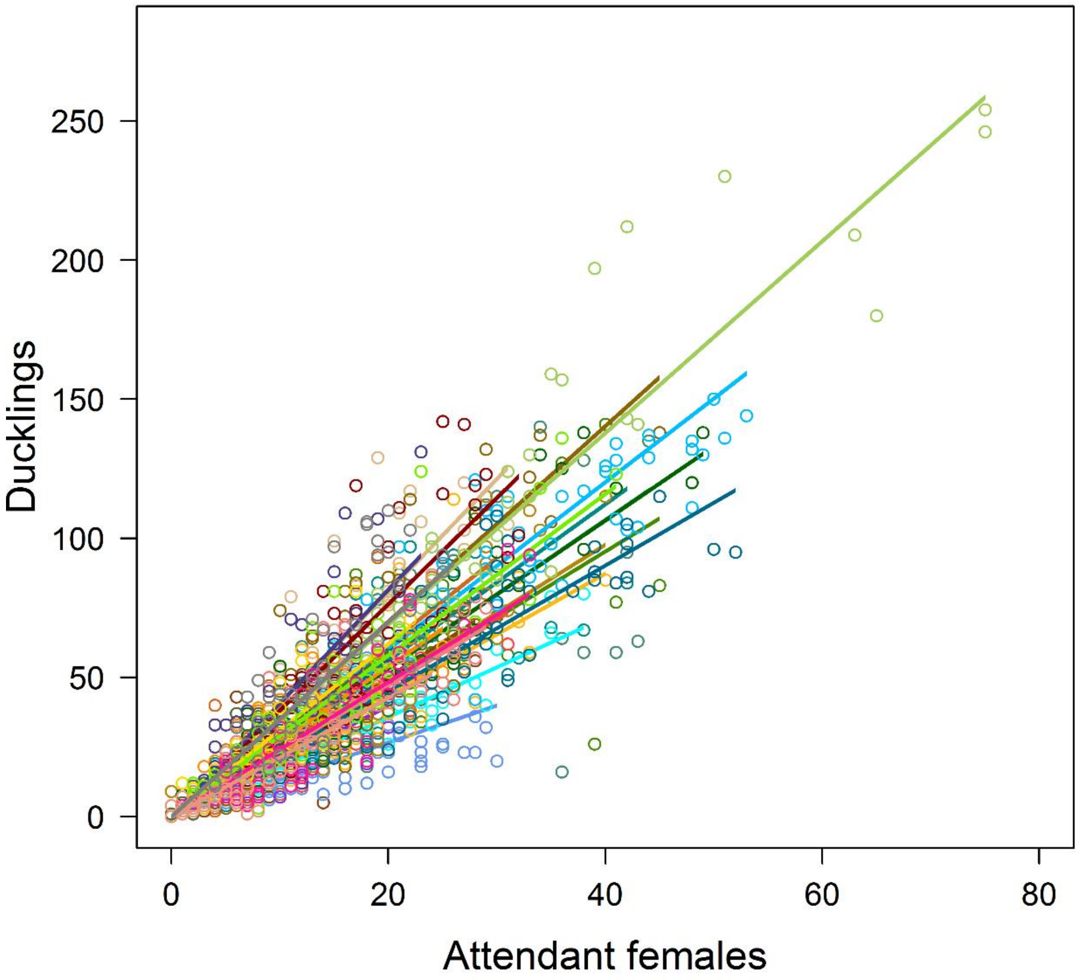

a
DAP1 (midpoint)
3
2
1
0
-1
-2
-1.0
-0.5
0.0
0.5
1.0
1.5
NAO index for May
b
DAP2 (spread)
1.0
0.5
0.0
-0.5
-1.0
0.6
0.8
1.0
1.2
Mean wave height in April

Figure 6.



SUPPLEMENTARY INFORMATION

Identifying targets for conservation: the arrival and loss of Common Eider *Somateria mollissima* ducklings in an estuarine nursery

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Figure S1: **Sea surface wave significant height data** from a random day to show the cell used for wave-height data. The relevant cell is outlined with a red dotted line, and contains Coquet Island (red arrow). The mouth of the Coquet Estuary is marked with a blue arrow. Cell colour is wave significant height (metres) according to the legend to the right of the graph.

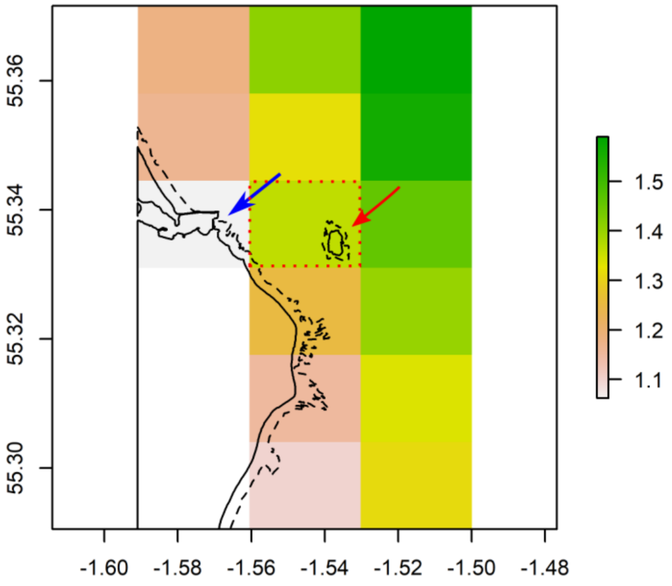
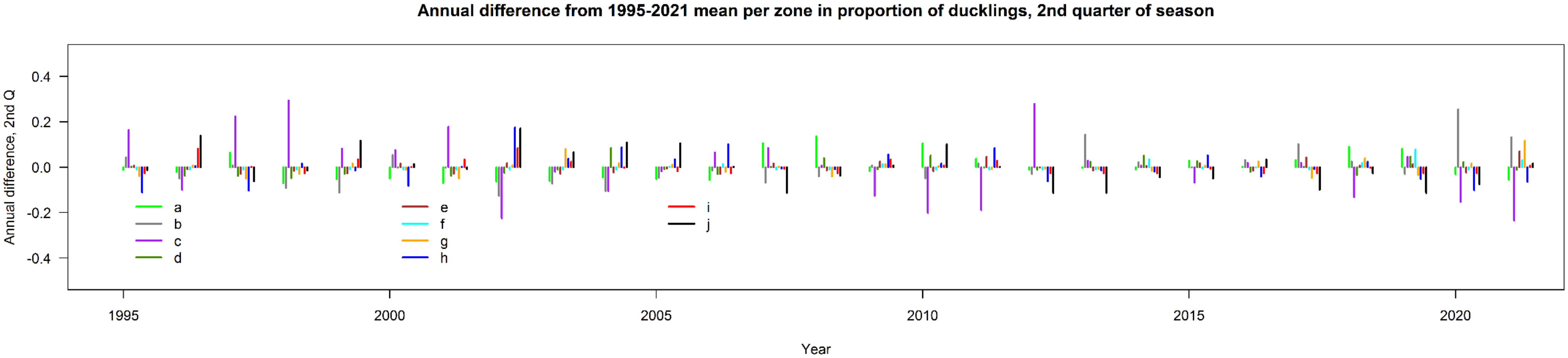
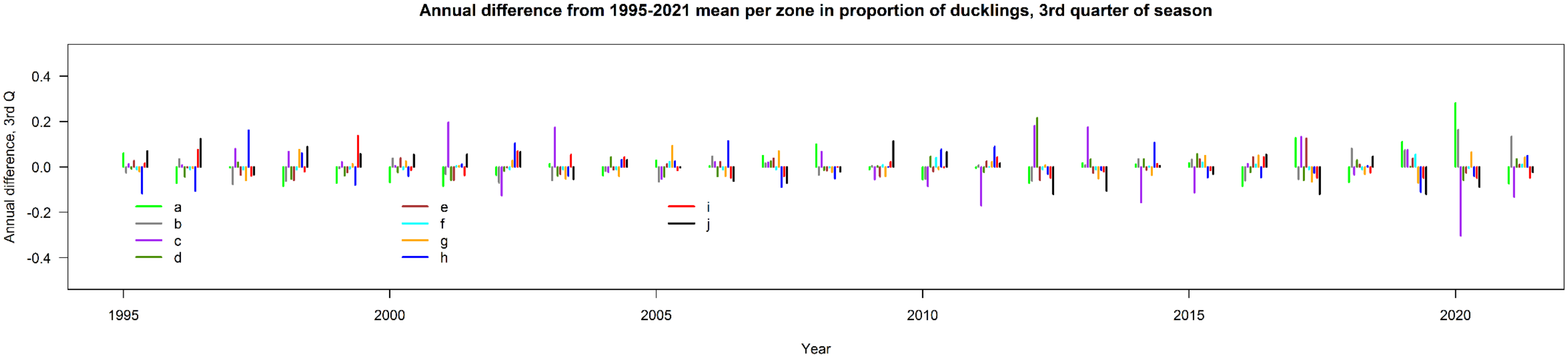


Figure S2. Variation between years and within seasons in the distribution of duckling counts across survey areas. As in Fig. 1 in main text, survey areas are indicated by letters and colours (see legends): **a**, River Coquet; **b**, Old Water; **c**, Northside; **d**, Yacht Club; **e**, Marina; **f**, Little Dock; **g**, Harbour; **h**, Harbour Bar; **i**, Little Shore; and **j**, Cliff House.





For the 2nd and 3rd quarters of each year (breeding season), the histograms show the proportional distributions of ducklings across survey zones expressed relative to the mean for the respective quartile for all years combined (1995-2021). Therefore, intra-seasonal variation is indicated by comparing the 2nd and 3rd quartiles (vertical comparisons), and inter-year variation by horizontal comparisons.

Figure S3. Dates (day in the year) of first duckling arrivals by year

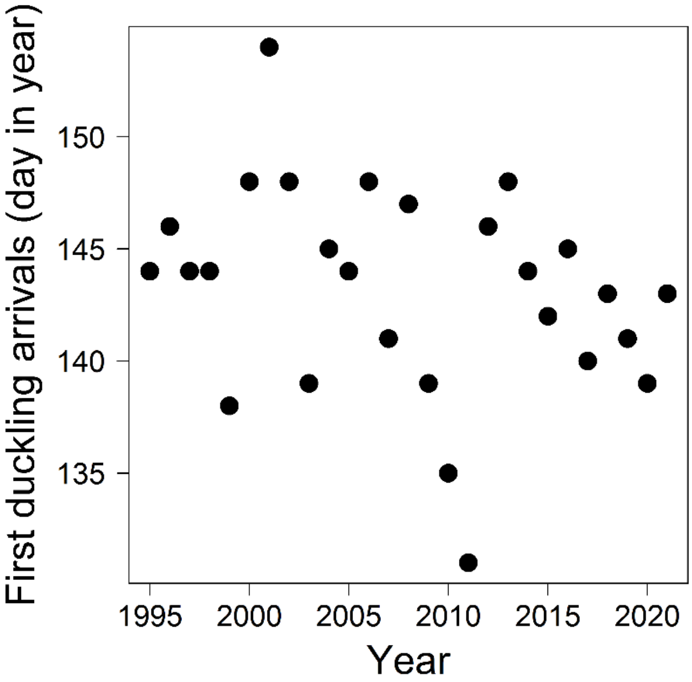
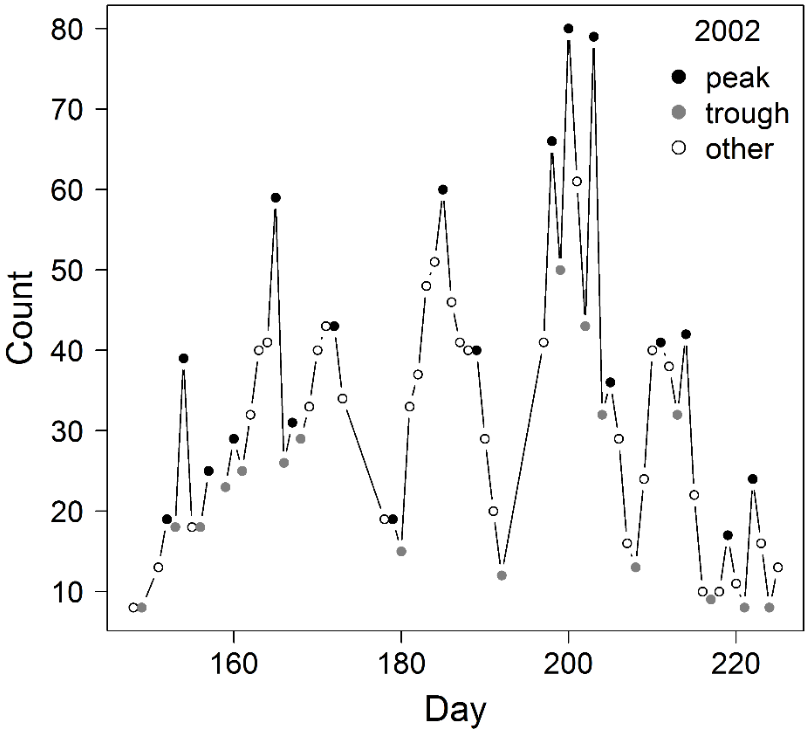


Figure S4. Yearly duckling counts. Additional data examples: years 2002 (upper) and 2007 (lower).



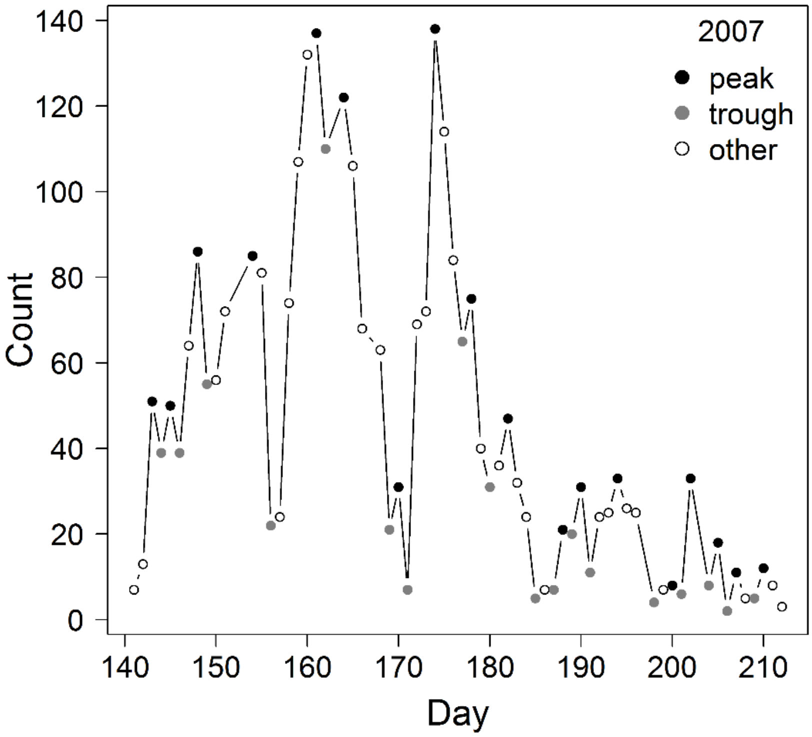


Figure S5. **Eider duckling data from BirdTrack (1995-2021) and Birds in Northumbria (BIN; 1995-2019)**. The approximate locations of reports of Eider ducklings and crèches are plotted on a regional map (a) coloured by marine (light blue), supra/sublittoral (orange) and terrestrial (grey) habitats. Map units (ordinate: northings; abscissa: eastings) are metres. The red rectangle is the Coquet Estuary study area and the Farne Islands approximately 32 km to the north are encircled in black. The Farne Islands have over 300 breeding Eider females and Eider crèches along the coast from the Farnes to Coquet Island, 32 km south, could have originated from either site. Sightings of Eider ducklings south of Coquet Island are uncommon. Histograms to the right (b) show the frequencies of duckling counts for each report from BirdTrack data (upper) and Birds in Northumbria data (lower). Reports with no duckling count recorded were excluded.

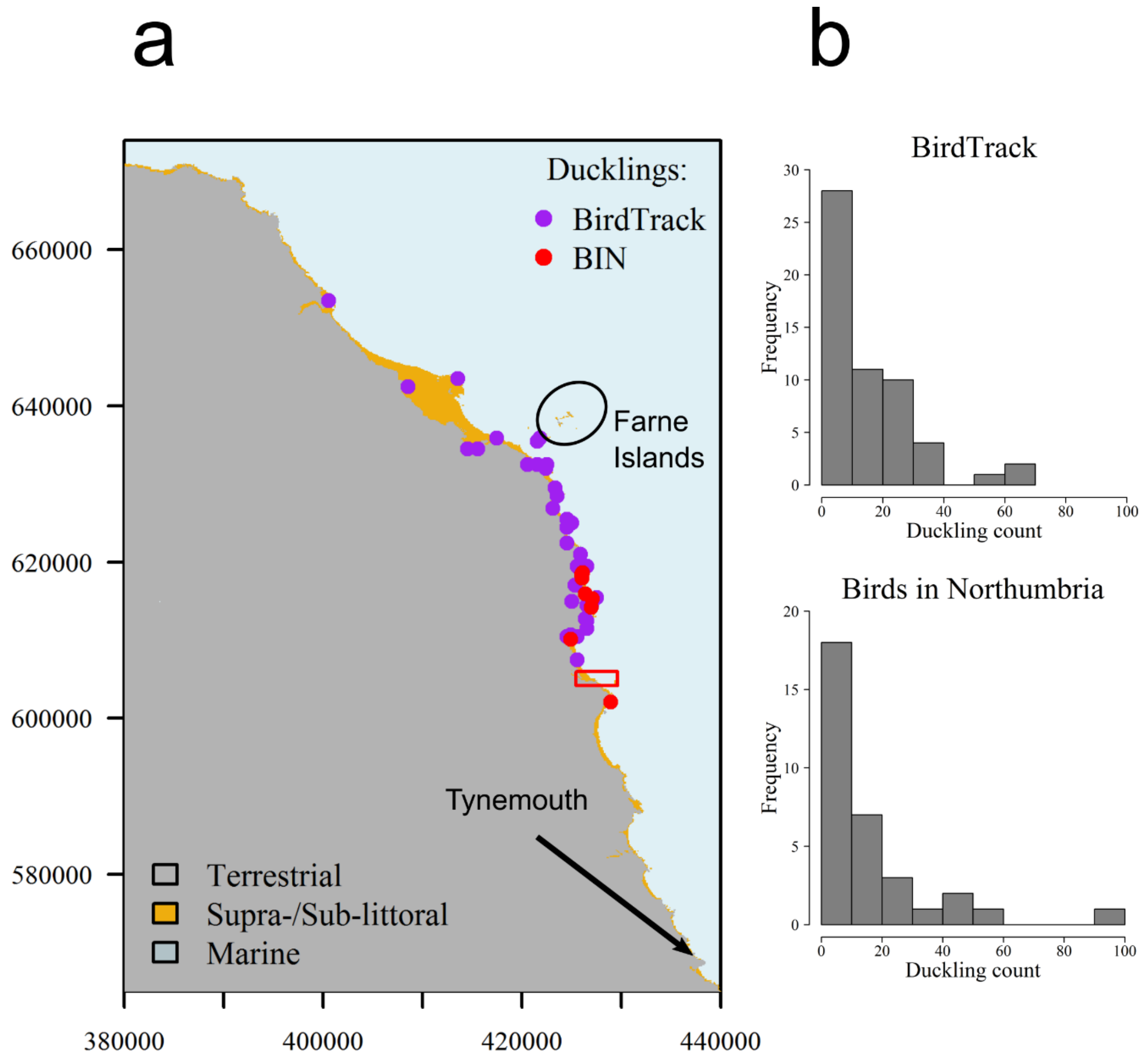


Figure S6. Duckling arrivals in relation to Eiders and large gulls breeding on Coquet Island. a, Correlation between the seasonal totals for observed duckling arrivals in the Coquet Estuary each year and the number of nesting females on Coquet Island (Pearson correlation coefficient = 0.39, df = 25, P = 0.05, 95% CI = 0.007 to 0.668). The fitted line is a median-based linear model. b, No correlation between the number of breeding large gulls and observed duckling arrivals each year (Pearson correlation coefficient = -0.296, df = 25, P = 0.13). This plot was done using an imputed value for 2003 (mean of 2002 and 2005 values) because a count was missing for that year. The correlation test in the main text was done using the data without an imputed value (as in panel c, below). c, The number of breeding large gulls (pairs) on Coquet Island by year during the study period. Breeding large gulls were controlled from 2000 to reduce and maintain breeding large gulls at a low level.

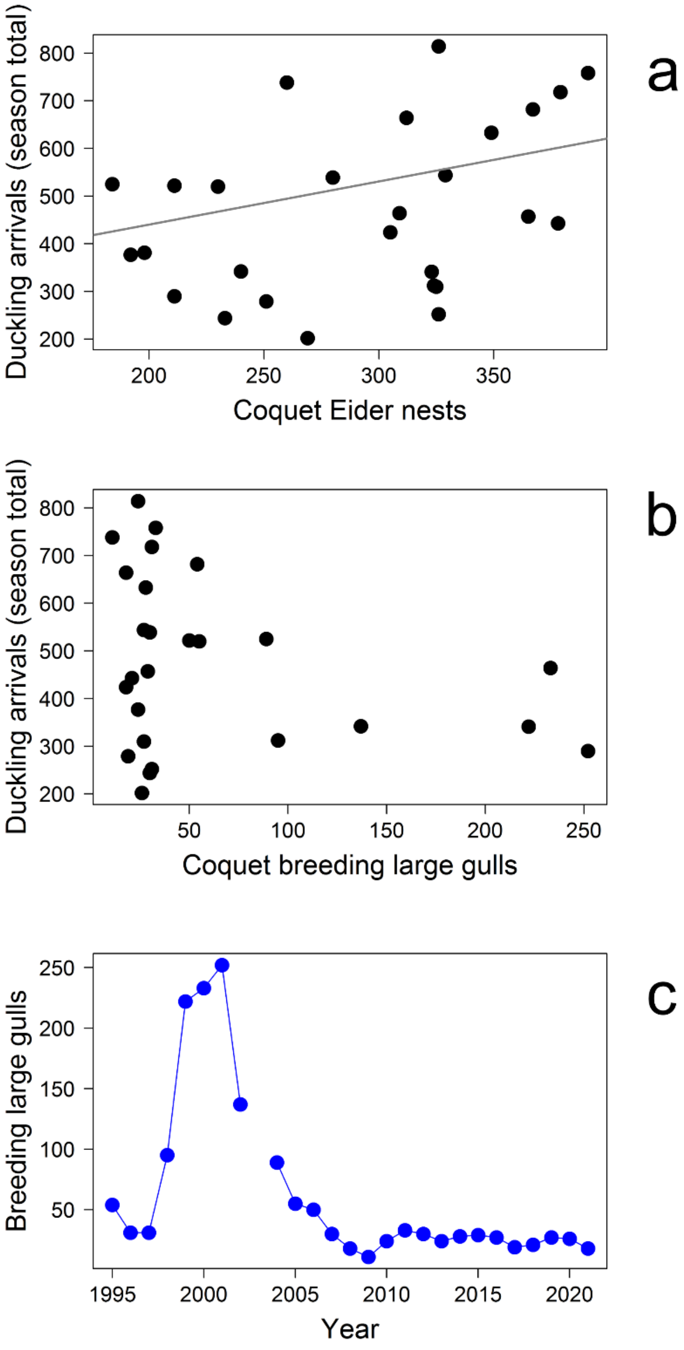


Figure S7. Data for cumulative logistic curves. Each year is a different colour and day-to-day data points (cumulative proportion of seasonal total) are joined by lines.

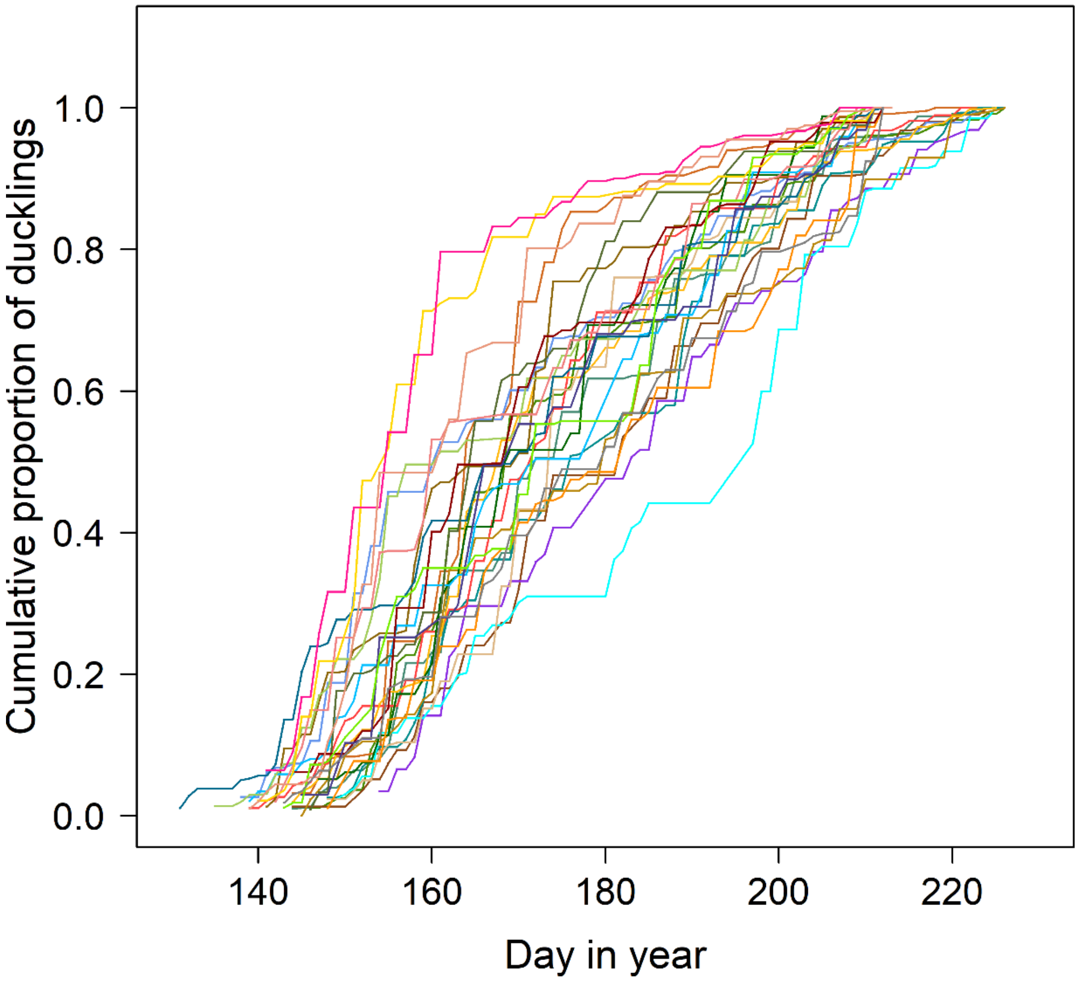

Cumulative proportion of ducklings
0.0
0.2
0.4
0.6
0.8
1.0
140
160
180
200
220
Day in year

Figure S8: DAP2 values by year: lack of autocorrelation. Ordinate: autocorrelation function coefficient (ACF). The dotted blue lines indicate the correlation required for statistical significance at P = 0.05. Abscissa: lag (years). At lag 0 there is perfect correlation by definition. At lags > 0 there is no significant correlation.

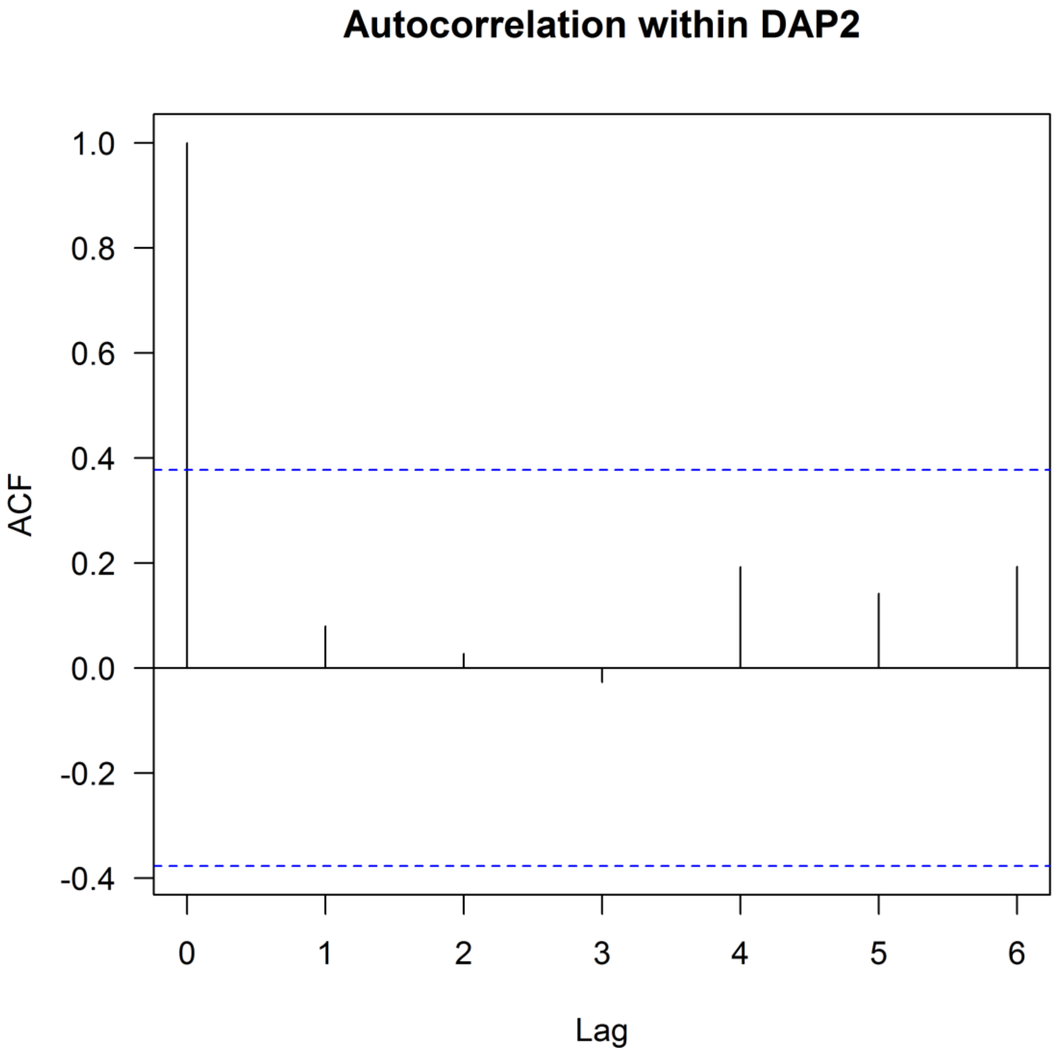
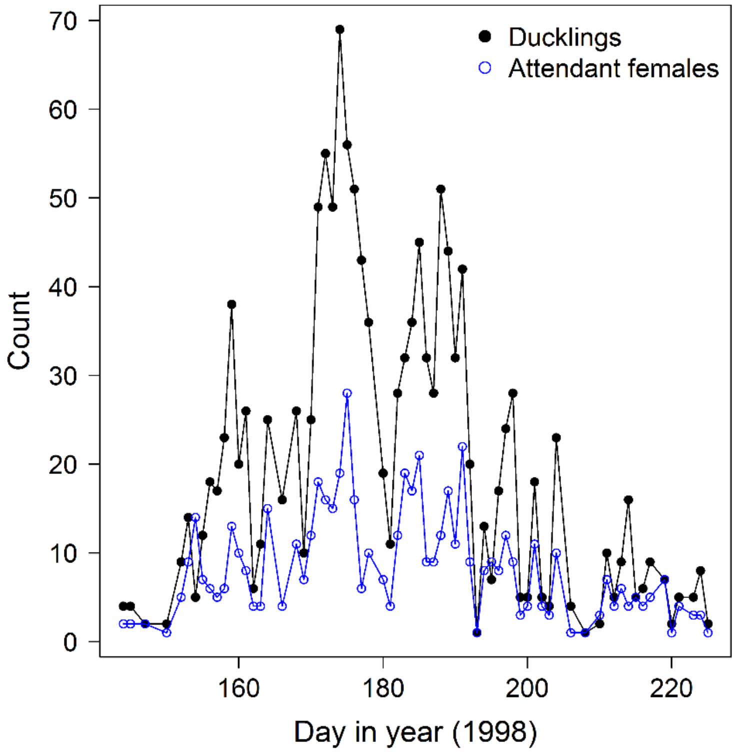
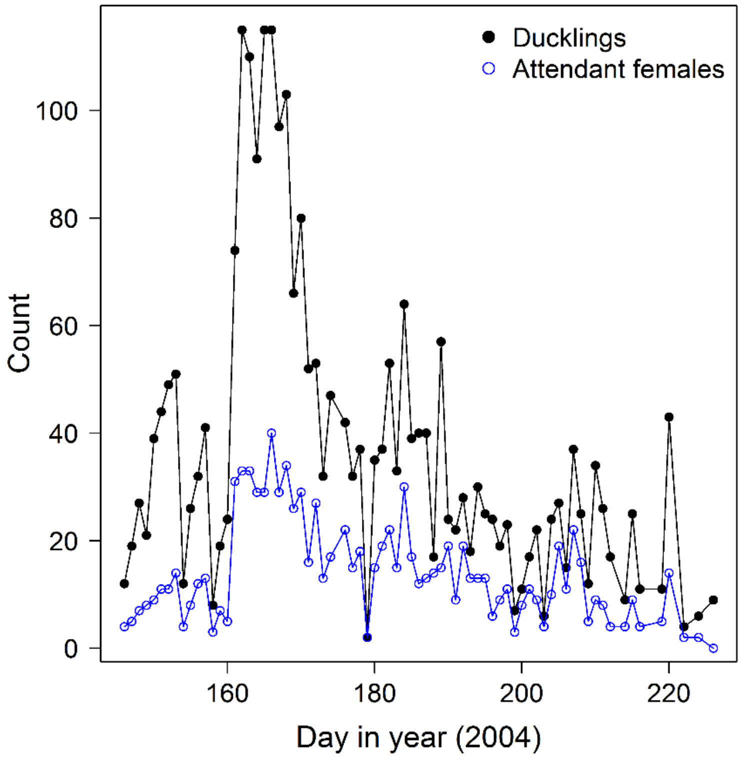


Figure S9: Examples of yearly data for ducklings and attending females: 1998 (upper) and 2004 (lower)





Supplementary Text 1:

Preliminary NAO analyses

Preliminary analyses were carried to assess whether principal-component based NAO indices during the study period might be relevant to duckling arrival parameters DAP1 and DAP2. These involved Pearson correlation coefficients (no correction for multiple testing) between DAP1 or DAP2 and NAO indices for the periods December-January-February-March (DJFM), December-January-February (DJF) and March-April-May. For DAP1 there was no correlation with any of these three periods ($P \geq 0.4$). However, for DAP2, there were no indications for Pearson correlations with DJFM and DJF ($P > 0.7$) but a hint for a relationship with MAM ($P = 0.09$), and this was also the case for March alone with DAP1 ($P = 0.08$) but not DAP2 ($P = 0.58$). On the basis of these results, only monthly NAO indices for the period March to July (inclusive) were used to investigate possible relationships between environmental parameters (NAO, weather, wave height) and duckling arrival parameters. For comparisons with monthly indices, Holm's method (Holm 1979) was used to correct for multiple comparisons across months for each set of duckling arrival parameter/environmental parameter correlations (see manuscript text).

Supplementary Text 2:

Effects of weather and environmental parameters on duckling arrivals.

Arrivals counts each day during the season were either 0 or a positive figure representing an increase in count relative to the day before. Data for the 27 years of the study were analysed to explore the possible environmental factors which may affect duckling arrival counts. Variables used for deriving independent predictors of daily arrival counts in generalised linear mixed-effects models (GLMMs) were: wind speed and maximum gust speed (knots), wind direction from four quadrants (N, S, E and W), wave height (m), precipitation (rain, mm in 24 h period), mean of minimum night and daytime temperature, and day in the year. Rain and wind parameters were for the day before the count day (00:00 h to 24:00); wave heights were for 09:00 on the day before the count day to 00:00 on the count day. Although wave height is largely a function of wind speed, wind direction and tide, it may also independently affect duckling/parental decision to move from Coquet Island to the mainland and therefore was included in the analysis as a separate effect. Minimum temperature measurements were daytime measurements for the day before the count day (09:00 to 21:00) and night-time measurements from 21:00 the day before count day to 09:00 on the count day; the means of these values were used but were strongly correlated with seasonal progression (day in the year); therefore, residuals from a linear model of minimum temperature predicted by day in the year were used in GLMMs. Rain and wave heights were centred and scaled for inclusion in models. Wind speed and maximum gust speed were strongly correlated and the two orthogonal principal components were derived and used in models. Tide states were assigned to approximate tidal cycle quadrants as High (H), Falling (F), Low (L) or Rising (R) with quadrant boundaries at H ± 1.5 h and L ± 1.5 h.

GLMMs were fitted, using the *glmmTMB* package in R and with year as a random effect, to daily arrival counts during the survey periods and assessed using Akaike's corrected Information Criterion (AICc). Day in the year was included as a second-order polynomial effect in all models and there was no autocorrelation (Durban-Watson test, $P > 0.9$). In preliminary analyses, the best fits were obtained with the quadratic parameterization (Hardin & Hilbe 2007) of the negative binomial distribution with a zero-inflation term, and were used in all subsequent GLMM fits. There were four top models with ΔAICc < 2; all included tide state as an additive factor (in addition to the polynomial seasonal progression term). Coefficients reported in the main text were averaged across either the full model or model subsets using the *model.avg* function of the *MuMIn* package.

Supplementary Text 3:

Observations during the study of predation/potential predators and Eider interactions with other species

1999	1 June:	Attendant female Eider attacked Mute Swan *Cygnus olor* as it approached crèche.
	7 June:	Attendant female Eider chased Large Gulls (Herring Gull *Larus argentatus* and/or Lesser Black-backed Gull *L. fuscus*) away from crèche.
	22 June:	Domestic Dog *Canis lupus familiaris*, Red Fox (Fox) *Vulpes vulpes* and several Grey Herons *Ardea cinerea* on Northside.
2000	4 June:	Observed one Fox take 6 duckling (all hanging from its mouth) it then attempted to attack a Shelduck *Tadorna tadorna*.
2001	14 June:	Grey Heron predated a duckling.
2002	18 June:	Large Gull harassing crèche; Harbour Bar.
	6 July:	Fox observed on North Pier.
	7 July:	Fox stalked crèches on Northside but no predation observed.
	24 July:	Fox with a cub observed in the Northside area.
2003	22 May:	Large Gull observed predating an Eider duckling.
	5 June:	257 Large Gulls observed on Northside pier and 178 on wave basin wooden staithes.
2004	14 June:	Fox observed on Northside.
	19 June:	Male Shelduck attacked crèche but no fatalities.
2005	18 June:	Fox present on Northside. Northside deserted of all birds.
	21 June:	Fox present on Northside.
	8 July:	Family of Otters *Lutra lutra* (1 adult and 2 juvenile) on Coquet River bank.
	15 July:	Dolphin species present in Harbour Bar. Observed what appeared to be the Dolphin playing or harassing the juvenile Eider as the Eider tried repeatedly to try and distance itself from the Dolphin.
2006	11 June:	Fox present on North Pier.
	7 June:	Large Gull predated a duckling in Northside area.
2007	26 May:	Male Shelduck chased attendant female Eiders and ducklings in Northside area.
	29 July:	Eider Duckling observed with fishing line around its neck.
2008	26 May:	Approximately 500 Large Gulls observed on Helsay Point/Northside.
	12 June:	Fox observed on Northside mudflats. Crèches moved to water edge.
	14 June:	Crèche attacked by Large Gull in the Yacht Club area. Female Eider dragged the gull into the water and appeared to try and kill it. Gull escaped and flew off. No successful predation.
	18 June:	Large Gull predated a duckling in the Harbour Bar area.
	27 June:	Large Gull predated a duckling in the Northside area.

12 July: Grey Heron disturbed a crèche on the Northside area.

2009 27 May: A duckling was predated by a Grey Heron in the Northside area.

2010 24 June: Harassment of crèche by a male Shelduck in the Northside area.

2011 30 May: A duckling was predated by a Large Gull.

2012 28 June: Crèche chased by a male Shelduck in the Northside area.

2014 25 May: One crèche on this date had larger ducklings- much larger than the others counted on that day: a possible mainland breeder
12 June: Crèche chased by a male Shelduck.
26 June: Crèche attacked by a male Shelduck, held female Eider under the water- she escaped.

2017 1 June: Large Gull predated a duckling in the Northside area.
15 June: 83 assorted Large Gulls on the Wave Basin Staithes.

2019 2 June: Male Shelduck attacked Eider duckling in the Northside area.
12 June: Male Shelduck attacked crèche in the Northside area.

2020 31 May: Grey Heron attempted predation in the Northside area.
31 May: Predation by Large Gull on a crèche that was being released by wardens.
2 June: Predation by a Grey Heron on a duckling in the Northside area.

Cat: Between 2015 and 2019 a stray cat was present, initially living in the Marina area then latterly it was adopted by Harbour shop keepers. The cat had been observed in the Marina area on at least one occasion with an Eider duckling in its jaws.

Seals: The increasing numbers of Grey Seals *Halichoerus grypus* around Coquet Island could be a threat to Eider ducklings. Local fishermen have reported observing seals take Eiders.

ACKNOWLEDGEMENTS

BirdTrack data were supplied by the British Trust for Ornithology (BTO). BirdTrack is organised by the BTO for the BTO, RSPB, BirdWatch Ireland, SOC and WOS.

REFERENCES

Birds in Northumbria 1995-2021**,** various editors, The Northumberland & Tyneside Bird Club.

Hardin, J. & Hilbe, J. 2007. *Generalized Linear Models and Extensions, 2nd Edition*.

Holm, S. 1979. A Simple Sequentially Rejective Multiple Test Procedure. *Scand. J. Stat.* **6**: 65–70.