Corrigendum

Correction to Multiple stressors: negative effects of nest predation on the viability of a threatened gull in different environmental conditions

Unfortunately, we discovered that we misspecified the matrix model in our recently published article (Bårdsen and Bustnes 2022). This error did not change our overall conclusions or the original article's empirical analyses (i.e. the input values). Here, we highlight the effect of this mistake with reference to the different sections of the original article (using the same headings as in the earlier article).

The Supporting information was also incorrect and is now corrected.

We apologize for these errors.

Abstract

Unaffected by the change in the model.

Introduction

Unaffected by the change in the model.

Material and methods

Model description and computer experimentation

We assumed a post-breeding census model, and hence we should have multiplied our estimated clutch size with adult survival (P_{3+}) and not with juvenile survival (P_0) as we did in our published study (Fig. 1). As before, we defined four age classes where only the last class (adults) reproduced (assumed age at maturity of $\geq$ 4 years; Fig. 1). To ease the comparison, we have used the same numbering of figures and appendices here as in the original article (Fig. 2 was unaffected by the change in the model). As before, we initiated each run based on the stable age-class distribution for the average matrix, which changed due to the changed matrix formulation: $\mathbf{n}_0 = 66$, $\mathbf{n}_1 = 29$, $\mathbf{n}_2 = 26$ and $\mathbf{n}_{3+} = 179$ (i.e. the number of individuals in each class at t_0). As before, we evaluated quasi-extinction over three generations. However, this changed from 36 to 33 years since the estimated generation time depended on the average matrix (now estimated to be 10.60 years). Like before, we fitted generalised additive models (GAMs) to easily interpret the effects of the different manipulations (details provided in Supporting

information). Nonetheless, as we needed to allow a more complex smoothing by the GAMs for some of the new results, we increased the k parameter in the gam function from eight to 16 (Supporting information for details). To show the effect of nest predation in different conditions, we increased the values for the environmental goodness index (EGI) and environmental harshness index (EHI) to 1/15 (i.e. to simulate more intense environmental conditions) in *Experiment I*. In absolute values, we increased EGI and EHI from 0.033 to 0.067, which controls the probability of selecting good and poor years, defined by their ranked estimated apparent survival (Φ_a), respectively (see Bårdsen and Bustnes 2022 for technical details).

(A) Transition matrix

(B) Life cycle graph (post-breeding census)

(C) Breeding chronology

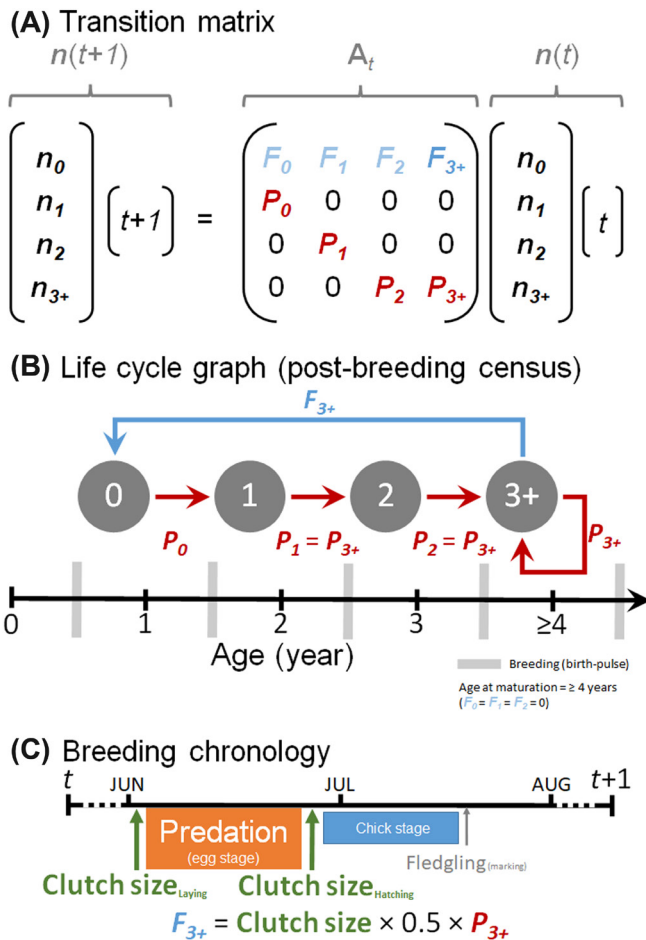$$F_{3+} = \text{Clutch size} \times 0.5 \times P_{3+}$$

Figure 1. Schematic overview of the model showing: (A) the transition matrix (A_t); (B) the life cycle graph; and (C) the timeline for the breeding season. The four age classes consist of individuals being ≤ 0, 1, 2 and ≥ 3 years (3+) old and their associated fecundities (F) and survival probabilities (P). We manipulated nest predation either by using clutch size at hatching (*Control*: estimated clutch size after predation has taken its toll) or at laying (*No predation*: a predator-free estimate) as the basis for calculating F_{3+} (C). Note: We assume an age at maturity of ≥ 4 years as we have used a post-breeding census model (i.e. individuals in age class 3+ were close to being 4 years just before the next census: Kendall et al. 2019).

Results

Long-term effects

Experiment I: continuous manipulation of nest predation

As in the published article, the effect of nest predation was negative and interacted with environmental conditions (Fig. 3), but the threshold value for when predation caused extinctions changed. In the updated version, our manipulation of nest predation was not strong enough to result in extinctions. Strictly speaking, extinctions occur when the population growth rate ($\lambda = N_{t+1}/N_t$), or its simulation approach (λ_s), is below one. Sometimes we refer to λ, on $\log_e$-scale, even though this is the intrinsic rate of increase: $r = \log_e(\lambda)$, where negative values imply negative growth and eventually extinction. We did this since we showed λ_s in the original article (with the figure legends specifying that this was at $\log_e$-scale). in the *Good* environment (within the maximum range of our manipulation of nest predation of 0.75; Fig. 3A). In the *Control* (*status quo*) environment, extinctions occurred when $\geq 64.4\%$ of the eggs were predated (Fig. 3B). By contrast, extinction occurred in the *Poor* environment (Fig. 3C) when predators took only $\geq 39.4\%$ of the eggs. The extinction threshold in both environments represented higher thresholds than in the original runs.

Experiment II: continuous manipulation of the environment

As before, we documented a strong interaction between environmental conditions and the presence (*Control*) and absence (*No predation*) of nest predation. In the improved environments, extinctions occurred in the presence of predation except when environmental conditions improved relative to present-day conditions (EGI ≥ 0.013; Fig. 4A). This contrasted with the *No predation* scenario, where positive growth occurred irrespective of environmental conditions – even though environmental conditions negatively affected population growth and abundance (Fig. 4). A new finding is that extinctions did not appear in the absence of predation under worsened environmental conditions, even though they did for the worst environments (i.e. at high EHI) in the original version of the model Fig. 4B).

Quasi-extinction

Qualitatively the results were similar to before (even though details such as the resulting estimated λ_S changed). The time to reach quasi-extinction increased for the scenario when nest predation occurred in 2005-18. As before, a 30% reduction in population sizes within three generations was likely to occur. Based on matrices covering 2005-18, the probability of quasi-extinction was ~ 0.65 after 24 years when predation was present [*Control*: $\log_e(\lambda_S) = 0.002$ (95% CI $= -0.001, 0.005$); Fig. 5A], but extinctions never occurred in the absence of predation [*No predation*: $\log_e(\lambda_S) = 0.143$ (95% CI $= 0.142$, 0.144); Fig. 5B]. Including 2019 with its low survival rates doubled the speed to reach quasi-extinction (with a probability of ~ 0.65 after 12 years) and resulted in negative long-term
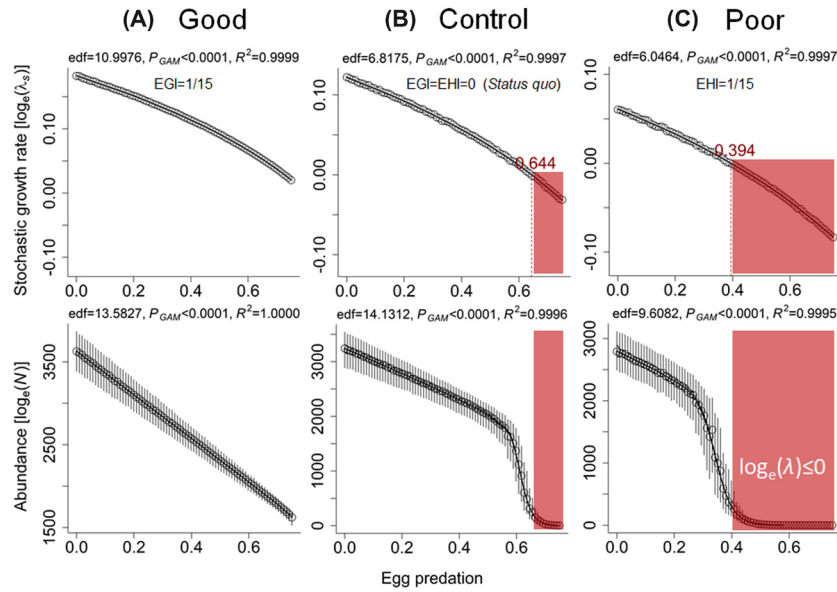
Figure 3. Upper panel: Stochastic population growth rates using a simulation approach (λ_s on $\log_e$-scale; bars representing 95% CIs) and Tuljapurkar's (λ_T) approximation for scenarios where nest predation varied from zero to 0.75. This manipulation of nest predation was crossed with manipulation of the environmental goodness index (EGI) and environmental harshness index (EHI), creating three different environments: 1) *Good* wear an increased probability of selecting years with high (adult) survival occurred (A; EGI = 1/15); 2) *status quo* where all years had a fair chance of being selected (B; EGI = EHI = 0); and 3) *Poor* where the probability of selecting years with low survival increased (C; EHI = 1/15). Red polygons show the range in which population declines ($\lambda < 0$ as defined by the simulations), and we ultimately predicted extinction using generalised additive models (GAMs). Lower panel: Median population abundance (bars show 25th–75th quantiles), on $\log_e$-scale (Supporting information provided technical details). GAM-specific details include the effective degrees of freedom (edf), statistical significance for the degree of smoothing (P_{GAM}) and the adjusted coefficient of determination (R^2). Note the difference in the range of the Y-axis.

growth rates compared to excluding 2019, but only when predation was present (Fig. 5). In 2005-10, when survival and reproduction were high (Fig. 2), the probability of quasi-extinction was low irrespectively of whether nest predation occurred [*Control*: $\log_e(\lambda_S) = 0.103$ (95% CI = 0.101, 0.106); Fig. 5C] or not [*No predation*: $\log_e(\lambda_S) = 0.185$ (95% CI = 0.184, 0.186); Fig. 5D]. Finally, the probability of quasi-extinctions reached ~ 0.65 after < 5 years in 2011-18 when predation was present [*Control*: $\log_e(\lambda_S) = -0.096$ (95% CI = −0.097, −0.095)); Fig. 5E], whereas the risk of quasi-extinction was very low when predation was absent [*No predation*: $\log_e(\lambda_S) = 0.110$ (95% CI = 0.109, 0.111); Fig. 5F]. Adding 2019 did not alter the results for the latest period (results not shown).

When we assessed the long-term behaviour of the system based on a constant transition matrix (using **A** based on the annual vital rates), one (6.7%) vs 11 (73.3%) out of 15 years eventually resulted in extinctions (i.e. $\lambda < 1$) when predation was present and absent, respectively (Supporting information). In the absence of predation, the only year that resulted in an actual collapse (≥80% decline after 33 years) was 2019 due to its low fecundity and low survival estimates. However, when predation was present, seven out of 11 years post-2008 resulted in collapses (63.6%). Similarly, bonanzas (≥80% increases) occurred in four (26.6%) and 14 (93.3%) years when predation was present and absent, respectively (Supporting information). Moreover, keeping one vital rate

at its average and varying the others within their observed range, extinctions occurred more easily when nest predation occurred. For instance, juvenile survival must be at its lowest estimated range before extinctions occur without predation. In contrast, even for average juvenile survival (along with the average values for the other vital rates), negative growth was expected when nest predation occurred (Supporting information).

Prospective and retrospective analyses

The sensitivity and elasticity analyses were similar to before, showing that λ was affected mainly by P_{3+}. The relative importance of F_{3+} and P_0 in the sensitivity analyses depended on whether predation was present or absent. In the *No predation* scenario, juvenile survival was more important than fecundity, whereas the opposite was true in the *Control* scenario (Supporting information). In contrast, the LTRE showed that fecundity had the most significant influence (even though its effect varied; also similar to before).

Discussion

As before, nest predation and environmental conditions interacted and affected the population viability of the lesser black-backed gulls, but nest predation was the most
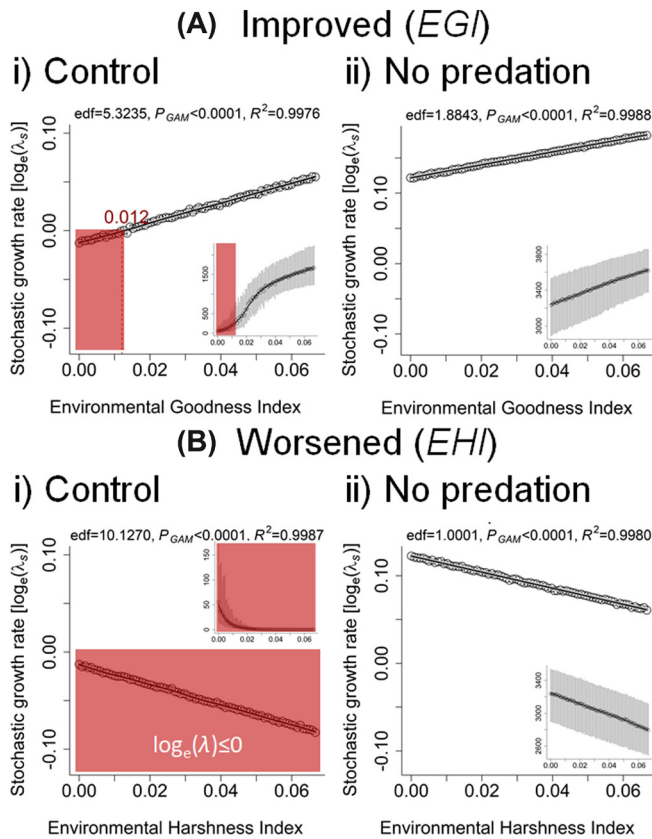
(A) Improved (EGI)

i) Control   **ii) No predation**

(B) Worsened (EHI)

i) Control   **ii) No predation**

Figure 4. Stochastic population growth (λ_s on $\log_e$-scale) along gradients of Improved (A) and Worsened (B) environmental conditions (details provided in Fig. 3). In both cases, zeros simulate the *status quo* where all years had a similar probability of being selected. We crossed environmental scenarios with manipulation of predation where either hatching (*Control*) or laying (*No predation*) clutch size formed the basis for calculating the fecundities (Fig. 1C). Small sub-plots show the resulting population abundance and red polygons indicate the range in which long-term population declines, i.e. the stochastic population growth ($\lambda s < 0$; on $\log_e$-scale), were predicted (Supporting information).

important stressor. Our computer experiments revealed that if predators removed ~ 60% or more of the eggs laid (i.e. less than the average calculated based on the empirical data from our study area), extinctions occurred even under present-day environmental conditions. This threshold predation value for when extinctions happened changed to ~ 40% under worsened environmental conditions. Nest predation also dramatically affected the experiments where we manipulated the frequency of good and poor years, combined with the presence or absence of nest predation. The presence of nest predation poses a significant threat, as demonstrated by the finding that populations subject to predation can only avoid extinction if the frequency of good years increases relative to current conditions.

Conversely, in the absence of nest predation, populations could maintain positive growth even under worsening environmental conditions, although such conditions negatively impacted population growth and abundance. While

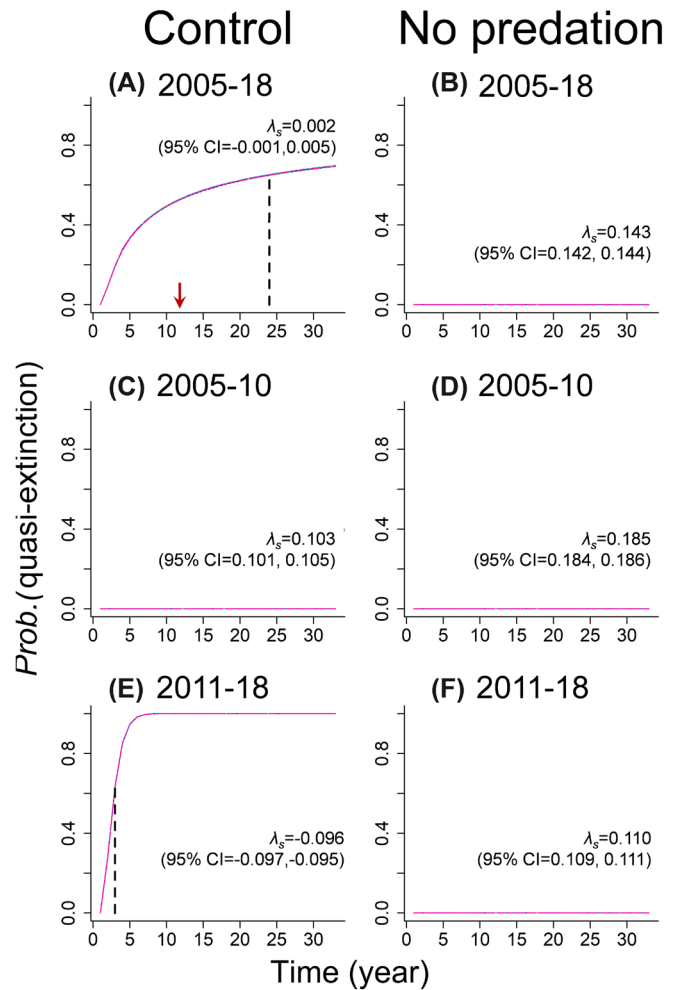**Control**   **No predation**

Figure 5. Probability of quasi-extinction (30% reductions from an initial size of 300 individuals over 33 years) for the whole time series (A, B), the early (C, D) and (E, F) late period. In the *Control* scenario (left panel), nest predation was at its natural level. In contrast, the *No predation* manipulation (right panel) used clutch size at laying as the basis for calculating the fecundities. The dotted lines indicate the time that gave an average probability of quasi-extinction of ~ 0.65 (after 24 and four years in A and E, respectively). The red arrow (A) shows the time to reach the same probability of quasi-extinction if we add the last year of our study (2019) to our assessment. Stochastic population growth rates using a simulation approach [λ_s on $\log_e$-scale; including 95% confidence intervals (CIs)] are also provided (Supporting information for technical details).

these findings suggest that nest predation is a major factor influencing population dynamics, they also highlight the importance of considering the complex interactions between predation and environmental conditions when assessing the viability of the lesser black-backed gulls. More importantly, based on input from the entire time series, it was highly probable that quasi-extinctions (i.e. 30% reductions in population size) occurred within less than three generations when nest predation was present. In contrast, when predation was absent, extinctions only happened if the frequency of poor years increased to a higher degree than the manipulation level

in the present study. Our study still supported the multiple stressor hypothesis for *L. f. fuscus*.

Long-term effects

Nest predation inevitably caused extinctions in our simulations even though its negative effect on population growth and viability interacted with environmental conditions. First, extinction in the long run (*Experiment I*) occurred when predators took $\geq 64.4\%$ of the eggs under present-day environmental conditions. Still, when the frequency of poor years increased, extinctions occurred at much lower ($\geq 39.4\%$) predation rates. Even though these percentages may seem immense, they are well below the average of 70.5% of the eggs laid lost to predation in our study area (>80% if we calculate losses between laying and fledgling; Supporting information) and for the same species elsewhere (see the original article and references therein). Second, nest predation resulted in negative growth except when environmental conditions improved relative to present-day conditions (*Experiment II*). Without nest predation, population growth was always positive but worsened environmental conditions negatively impacted growth. More importantly, under present-day environmental conditions, nest predation resulted in negative population growth and extinctions after < 100 years ($N_{t=200} < 40$). In contrast, a population increase of 983% ($N_{t=200} > 3249$) relative to the initial population size occurred without nest predation.

Quasi-extinction

Even though one of the scenarios under which we assessed quasi-extinction changed a bit, our most important conclusion is still valid. Our assessment of the quasi-extinction probability revealed that corvids' nest predation caused our study population to meet the VU category of the IUCN red list (IUCN 2012, Supporting information). When we included predation, it was highly likely to meet the VU criteria after < 5 and 24 years using data from 2011-18 and 2005-18 (and twice as fast if we included our study's last year), respectively.

Conclusions and prospects

Unaffected by the change in the model.

Supporting information

Details in the appendices presenting model results (Supporting information) were affected by our error, but the conclusions drawn are like those in the original text.

References

Bårdsen, B.-J. and Bustnes, J. O. 2022. Multiple stressors: negative effects of nest predation on the viability of a threatened gull in different environmental conditions. – J. Avian Biol. 2022: e02953.

IUCN. 2012. IUCN red list categories and criteria, ver. 3.1. – International Union for Conservation of Nature (IUCN).

Kendall, B. E., Fujiwara, M., Diaz-Lopez, J., Schneider, S., Voigt, J., and Wiesner, S. 2019. Persistent problems in the construction of matrix population models. – Ecol. Model. 406: 33–43.