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# Supplementary material

# Appendix 1. Description of the Bayesian model of clutch size, egg volume, and incubation duration.

In the model for each reproductive trait, the response variable, *y*, depended on a series of covariates for nest *i* at time *t* for species *j*:

$$y_{i,t} = \alpha_0 + \alpha_{sp_j} + \alpha_{st_k} + \alpha_{yr_{k,m}} + \beta_{day_j}\text{day}_{i,t} + \beta_{day^2{}_j}\text{day}^2{}_{i,t} \qquad \text{(Eq. 1)}$$

where $\alpha_0$ was the intercept and $\alpha_{sp}$, $\alpha_{st}$, and $\alpha_{yr}$ were random effects on the intercept of species *j*, site *k*, and year *m*, respectively.

We estimated species-specific linear effects of day-of-season with a varying-slopes model, where all species-specific values of $\beta_{day}$ were drawn from one distribution defined by a single standard deviation $\sigma_{\beta_{day}}$, thus using the hierarchical modeling framework to share information among species. We defined the parameters for the quadratic effect ($\beta_{day^2}$ and $\sigma_{\beta_{day^2}}$) in the same way. By estimating only one distribution per covariate, a varying-slopes model improves computational efficiency and precision of estimates, especially for groups with small sample sizes, relative to a fixed-effects model that would independently estimate covariate effects for each species (Gelman and Hill 2007). The varying-slopes framework was appropriate for our study system because all species in our analysis were sympatrically breeding ground-nesters, and thus were exposed to similar patterns of seasonal variation in environmental conditions and risks.

We defined the normal distribution from which $\beta_{day_j}$ or $\beta_{day_j{}^2}$ was drawn with a mean of zero and an uninformative hyperprior in the interval 0 to 7 on the standard deviation (a "hyperprior" is a prior used to define a prior distribution). We used uninformative normal priors with a zero mean and SD = 100 for all random effects on the intercept.

# Appendix 2. Description of the Bayesian model of daily nest survival, with explicit estimation of competing causes of nest failure.

For the analysis of daily survival rates of nests (DSR), we generated an encounter history based on the day the nest was found, the last day it was observed to be active, and the first day it was observed to have failed (detailed in Appendix 3, Model Input). When there was a gap in nest monitoring between the last day observed alive and the first day observed failed or hatched, we used the midpoint between the two dates of observation as the fate date.

Daily survival rates may differ between the egg-laying and incubation stages, but shorebird nests are more difficult to detect when they are unattended by parents during the egg-laying stage relative to the incubation stage (Norton 1972, Blomberg et al. 2015). We found only 18% of nests during egg-laying, the majority of which (55%) had laid all but the last egg, so our dataset was not adequate for estimating DSR during the egg-laying stage. We therefore discarded any nest information from prior to completion of the clutch and conditioned upon the first day of incubation (the day on which the last egg was laid; Colwell 2010) as the first day in the encounter history for nests found during egg-laying.

Our model quantified nest survival and the linear and quadratic effects of day-of-season on daily survival rate (DSR). As for Equation 1 (Appendix 1), the effect of day-of-season varied by species (varying-slope model) and we included three random effects on the intercept: species, study site, and year nested within site. The DSR component of the model followed standard implementation of extended Mayfield-type models in a Bayesian framework (Royle and Dorazio 2008, Schmidt et al. 2010, Brown and Collopy 2012).

We extended the DSR model to estimate seasonality in the probability of each cause of failure. We followed a conceptual framework for partitioning risks of nest failure (Etterson et al. 2007), but we implemented the model in a Bayesian framework. For each cause of mortality except the last, the probability of failure to risk *r* and effects of covariates were estimated on the logit scale following Eq. 1 (main text). As in other multistate models, all competing states needed to sum to one, so for a case with *R* risks, each probability was constrained by:

$$\psi_{r,i,t} = \frac{\exp{(y_{r,i,t})}}{1 + \sum_{r=1}^{R-1} \exp{(y_{r,i,t})}}$$

where $y_{r,i,t}$ was the probability of risk *r* for nest *i*, on day *t,* on the logit scale, estimated by Eq. 1; and $\psi_{r,i,t}$ was the probability of the risk on the natural scale (range 0–1) (Kéry and Schaub 2012, p. 300-306). The probability of the final risk, *R*, was then defined as:

$$\psi_{R,i,t} = 1 - \sum_{r=1}^{R-1} \psi_{r,i,t}$$

so that all risk probabilities summed to one.

The final component of the risk-partitioning model defined the probability of transitioning from one state to another (alive, predated, abandoned, or other failure). The probability of a live nest remaining alive was defined by DSR. The probability of a nest that was alive on day *t*–1 failing to risk *r* on day *t* was defined by:

$$p_{r,i,t} = (1 - \mathrm{DSR}_{i,t})\psi_{r,i,t}$$

Each failure state was a terminal state, so any nest that failed to a given risk was prohibited from transitioning further to any other state ($p = 0$). We provide example JAGS code for the risk-partitioning DSR model in Appendix 3.

# Appendix 3. Example JAGS code for the risk-partitioning model of daily nest survival.

## Model input

Response variable:

- The matrix of encounter histories (*EH*) contains one row per nest and one column per Julian day in the nesting season.
- In each cell, data are marked as missing ("NA") for days prior to discovery of the nest, even when the age of the nest indicates the nest was active prior to discovery by an observer. Excluding days prior to discovery avoids positively biasing our estimates of daily survival rate of nests, which would occur if some nests failed prior to being discovered by field crews.
- Each nest is marked as alive ("1") from the day it was found or the first day of incubation (assumed to be the day the last egg was laid), whichever was later, to the last day that it was known to be alive. For nests recorded as hatched, the observed or inferred hatch date is the last day known to be alive. For all other nests, the nest is marked as alive through the last day that the nest was checked and observed to be alive.
- For unsuccessful nests, the state of the nest on the date of failure is defined by the observed cause of nest failure. We defined three states of cause-specific loss: 2 = depredated, 3 = abandoned, and 4 = other or unknown cause of failure. We assumed there was no uncertainty in assigning nests to causes of failure. If there was a gap between the last day observed alive and the day observed failed, we used the mean date as the date of failure.
- For nests with an unknown fate, all days following the last day the nest was known to be alive are filled with "NA", as the status of the nest is unknown for those days.
- All days following the last day of information for each nest are filled with "NA".
- Example: A nest was found on day 1 of a 10-day season, but egg-laying was completed on day 2 of the season. The last day observed alive was day 7 and the nest was recorded as depredated on day 8:

  NA 1 1 1 1 1 1 2 NA NA

Covariate data:

- *day* = matrix of same dimensions as *EH*, giving the day of the season, centered to the mean shorebird nest initiation date (across all species) for the corresponding site and year. For example, if the mean initiation date for a given site is June 5$^{th}$, then June 4$^{th}$ is indicated as day -1, June 6$^{th}$ is day 1, etc. Cannot contain missing values, even where *EH* is missing data in the corresponding cell.
- *inc* = vector listing the incubation period, in days, for each shorebird species in alphabetical order.
- *inc_corr* = correction for the incubation period, if it changes over the season (as per our results for the effect of day-of-season on incubation duration). Matrix with one row per species and one column for each time period at which nest survival is to be predicted (we used three time periods: first, mean, and last nest initiation date). Each cell is filled with

the difference from the species mean, e.g. "-1" indicates the incubation period is reduced by one day, relative to the mean.
- *preddays* = vector listing the day of season, centered to the site-year mean, for which we want to predict DSR for each species. If "day" is standardized to a global mean and SD, *preddays* must be standardized to the same mean and SD.

Grouping variables:
- *species* = vector listing the study species for each nest, as a numerical factor (1, 2, ...). One value per row of *EH*.
- *site* = vector listing the study site for each nest, as a numerical factor (1, 2...). One value per row of *EH*.
- *year* = vector listing the year for each nest, as a numerical factor (1, 2...). One value per row of *EH*.

Values for parameter specification and indexing:
- *nnest* = number of nests (rows in *EH*).
- *nsp* = number of study species.
- *nst* = number of study sites.
- *nyr* = number of years.
- *np* = number of days for which you want to predict DSR (length of *preddays*).
- *f* = a vector with one value per row of *EH*, giving the day (corresponding to column number of *EH*) of first data for the nest in that row.
- *l* = a vector with length = number of rows of *EH*, giving the day (corresponding to column number of *EH*) of last data (0 or 1) for the nest in that row. See "Specification of encounter histories" for details on how to define the first and last days of data.

Initial values of the parameters to be estimated are randomly generated:
- from a normal distribution for parameters that could be positive or negative
- from a uniform distribution for parameters that must be positive (e.g. SD).

## Model Output

- *intercept* = intercept of the DSR submodel (across all species)
- *intercept_psi* = vector giving the intercept for each risk (psi)
- *e_sp, e_sp_psi* = random effect of species on intercept for DSR and each risk
- *e_st, e_st_psi* = random effect of site on intercept for DSR and each risk
- *e_yr, e_yr_psi* = random effect of year on intercept, nested within site, for DSR and each risk
- *eff_day* = species-specific effects of day on DSR
- *eff_day_psi* = global effect of day on each risk
- *dsr_sp* = mean DSR of each species
- *dsr_day_sp* = day-specific estimate of DSR for each species and each day in *pred_days*
- *nsurv_sp* = mean survival of a nest through the incubation period, for each species

- *nsurv_day_sp* = probability of nest survival over the full exposure period, calculated for nests initiated on the first, mean, and last dates observed for each species as:

$$\mathrm{S}_x = \prod_{d=1}^{D_x+3} \mathrm{DSR}_d$$

where $x$ is the nest initiation date, $D_x$ is the incubation duration expected for nests initiated on day-of-season $x$, and $d$ is each day in the corresponding incubation period. We specified $D_x$ for each species according to results from our test for seasonality in incubation duration. We added three days to $D_x$ to describe the full exposure period, including the egg-laying stage, assuming that one egg was laid per day, mean clutch size was four eggs, and full incubation began on the day the last egg was laid (Norton 1972).

## JAGS code

Code for the daily nest survival model, including cause-specific risks of nest failure, was developed following:

- Etterson, M.A., L.R. Nagy, and T.R. Robinson. 2007. Partitioning risk among different causes of nest failure. The Auk, 124:432-433.
- Kéry, M., and M. Schaub. 2012. *Bayesian Population Analysis using WinBUGS: A Hierarchical Perspective.* Academic Press.
- Royle, J. A., and R. M. Dorazio. 2008. *Hierarchical Modeling and Inference in Ecology: The Analysis of Data from Populations, Metapopulations and Communities*. Academic Press.

```
model {
  for(i in 1:nnest){  # loop through nests

# Likelihood:
    for(j in (f[i]+1):l[i]){  # loop through days with data for the nest
      EH[i,j]~dcat(ps[EH[i,j-1],i,j-1,])
    } # j
    for(j in f[i]:(l[i]-1)){

# Model for survival probability/DSR (phi):
      logit(phi[i,j])<-intercept+eff_day[species[i]]*day[i,j]+
        e_sp[species[i]]+e_st[site[i]]+e_yr[site[i],year[i]]

# Model for each risk/cause of failure (psi):
      for(k in 1:2){  # loop through causes of failure
        lpsi[k,i,j]<-intercept_psi[k]+eff_day_psi[k]*day[i,j]+
          e_sp_psi[k,species[i]]+e_st_psi[k,site[i]]+
          e_yr_psi[k,site[i],year[i]]
        psi[k,i,j]<-exp(lpsi[k,i,j])/(1+exp(lpsi[1,i,j])+exp(lpsi[2,i,j]))
      } # k

# Risks must add up to 1. In this case we had 3 causes of failure:
      psi[3,i,j]<-1-psi[1,i,j]-psi[2,i,j]

# Priors and constraints for psi:
  # Probability of failure depends on phi:
```

```
      ps[4,i,j,4]<-phi[i,j]
  # Probability of each cause of failure, for nests currently alive:
      for(k in 1:3){
        ps[4,i,j,k]<-(1-phi[i,j])*psi[k,i,j]
      } # k
  # Forbid nests that fail from further transitioning among states:
      for(k in 1:3){
        ps[k,i,j,k]<-1
        ps[k,i,j,4]<-0
      } # k
      ps[1,i,j,2]<-0
      ps[1,i,j,3]<-0
      ps[2,i,j,1]<-0
      ps[2,i,j,3]<-0
      ps[3,i,j,1]<-0
      ps[3,i,j,2]<-0
    } # j
  } # i

# Define effects on each risk:
  for(k in 1:2){
    intercept_psi[k]~dunif(-5,5)
  # Random species effect on psi:
    sigma_sp_psi[k]~dunif(0,7)
    tau_sp_psi[k]<-sqrt(1/(sigma_sp_psi[k]*sigma_sp_psi[k]))
    for(i in 1:nsp){
      e_sp_psi[k,i]~dnorm(0,tau_sp_psi[k])
    }
  # Random effect of site and year on psi:
    sigma_st_psi[k]~dunif(0,7)
    tau_st_psi[k]<-sqrt(1/(sigma_st_psi[k]*sigma_st_psi[k]))
    for(i in 1:nst){
      e_st_psi[k,i]~dnorm(0,tau_st_psi[k])
      for(j in 1:nyr){
        e_yr_psi[k,i,j]~dnorm(0,tau_yr_psi[k,i])
      }
      sigma_yr_psi[k,i]~dunif(0,7)
      tau_yr_psi[k,i]<-sqrt(1/(sigma_yr_psi[k,i]*sigma_yr_psi[k,i]))
    }
    eff_day_psi[k]~dnorm(0,tau_day_psi[k])
    sigma_day_psi[k]~dunif(0,7)
    tau_day_psi[k]<-sqrt(1/(sigma_day_psi[k]*sigma_day_psi[k]))

# Back-transform the expected probability of each fate:
  # mean and each day of season:
    est_psi[k]<-exp(intercept_psi[k])/(1+exp(intercept_psi[1])+
      exp(intercept_psi[2]))
    for(j in 1:np){
      est_psi_day[k,j]<-exp(intercept_psi[k]+eff_day_psi[k]*preddays[j])/
        (1+exp(intercept_psi[1]+eff_day_psi[1]*preddays[j])+
        exp(intercept_psi[2]+eff_day_psi[2]*preddays[j]))
    } # j
  } # k

# Define the final risk based on all of the others:
  est_psi[3]<-1-est_psi[1]-est_psi[2]
  for(j in 1:np){
```

```
    est_psi_day[3,j]<-1-est_psi_day[1,j]-est_psi_day[2,j]
  }

# Priors for random effect of site and year on phi:
  sigma_st~dunif(0,7)
  tau_st<-sqrt(1/(sigma_st*sigma_st))
  for(i in 1:nst){
    e_st[i]~dnorm(0,tau_st)
    for(j in 1:nyr){
      e_yr[i,j]~dnorm(0,tau_yr[i])
    } # j
    sigma_yr[i]~dunif(0,7)
    tau_yr[i]<-sqrt(1/(sigma_yr[i]*sigma_yr[i]))
  } # i


# Priors for intercept and species effects on phi:
  intercept~dunif(-5,5)
  sigma_sp~dunif(0,7)
  tau_sp<-sqrt(1/(sigma_sp*sigma_sp))
  sigma_day~dunif(0,7)
  tau_sp_day<-sqrt(1/(sigma_day*sigma_day))
  for(i in 1:nsp){
    eff_day[i]~dnorm(0,tau_sp_day)
    e_sp[i]~dnorm(0,tau_sp)

# Back-transform expected mean DSR, mean nest success, and DSR on each day of
  # season for each species:
    dsr_sp[i]<-1/(1+exp(-(intercept+e_sp[i])))
    nsurv_sp[i]<-dsr_sp[i]^inc[i]
    for(j in 1:np){
      dsr_day_sp[i,j]<-1/(1+exp(-(intercept+e_sp[i]+eff_day[i]*preddays[j])))
    }

# Back-transform expected nest success for first, mean, last nest for each
  # species, corrected for seasonal variation in DSR and incubation period:
    for(j in 1:3){
      for(k in 1:(inc[i]+inc_corr[i,j])){
        mylist[i,j,k]<-1/(1+exp(-(intercept+e_sp[i]+
          eff_day[i]*(incdat[i,j]+(k-1)))))
      }
      nsurv_day_sp[i,j]<-prod(mylist[i,j,])
    }
  }
}
```

## Supporting References

Blomberg, E. J. et al. 2015. Biases in nest survival associated with choice of exposure period: A case study in North American upland game birds. - Condor Ornithol. Appl. 117: 577–588.

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## Appendix 4

**Table A1.** Study sites in the Arctic Shorebird Demographics Network, ordered from west to east.

| Site | Location | Latitude | Longitude | Sample size* Clutch size | Egg volume | Incubation duration | Nest survival | Study period |
|---|---|---|---|---|---|---|---|---|
| LKRI | Lower Khatanga River, Krasnoyarsk, Russia | 72.849 | 106.040 | 314 | - | 3 | 107 | 2012–2014 |
| CHAU | Chaun River Delta, Chukotka, Russia | 68.774 | 170.549 | 166 | 79 | 2 | 75 | 2012–2014 |
| NOME | Nome, AK, USA | 64.443 | -164.962 | 877 | 147 | 60 | 526 | 2008–2014 |
| CAKR | Cape Krusenstern, AK, USA | 67.114 | -163.496 | 442 | 412 | 63 | 327 | 2010–2014 |
| BARR | Barrow, AK, USA | 71.302 | -156.760 | 2045 | 1636 | 164 | 1831 | 2008–2014 |
| IKPI | Ikpikpuk River, AK, USA | 70.553 | -154.735 | 513 | 74 | 36 | 321 | 2010–2014 |
| COLV | Colville River, AK, USA | 70.437 | -150.676 | 619 | 568 | 65 | 583 | 2011–2014 |
| PRBA | Prudhoe Bay, AK, USA | 70.256 | -148.339 | 106 | - | 4 | 56 | 2010, 2013 |
| CARI | Canning River, AK, USA | 70.118 | -145.851 | 1200 | - | 69 | 1016 | 2010–2014 |
| MADE | Mackenzie Delta, NWT, Canada | 69.373 | -134.893 | 256 | 25 | 12 | 154 | 2010–2014 |
| CHUR | Churchill, MB, Canada | 58.738 | -93.819 | 287 | 35 | 26 | 241 | 2011–2014 |
| BURN | Burntpoint Creek, ON, Canada | 55.242 | -84.318 | 49 | 3 | 1 | 30 | 2012–2014 |
| COAT | Coats Island, NU, Canada | 62.855 | -82.499 | 49 | 47 | 3 | 38 | 2014 |
| EABA | East Bay, NU, Canada | 63.987 | -81.697 | 202 | 25 | 8 | 126 | 2010–2014 |
| IGLO | Igloolik, NU, Canada | 69.399 | -81.544 | 97 | 85 | 2 | 52 | 2013–2014 |
| BYLO | Bylot Island, NU, Canada | 73.156 | -79.972 | 585 | 117 | 14 | 260 | 2008–2014 |
| Total | | | | 7807 | 3253 | 532 | 5743 | 2008–2014 |

* Number of nests. See Methods for the criteria for inclusion of nests in each analysis.

**Table A2.** Total number of shorebird nests monitored for each species per field site across all data subsets. A subset of each total was used in the model for each reproductive trait depending on the data available for each nest (Table 1). Species codes are defined in Table 1; sites are in Table S1.

| | Site | | | | | | | | | | | | | | | | Species |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Species | LKRI | CHAU | NOME | CAKR | BARR | IKPI | COLV | PRBA | CARI | MADE | CHUR | BURN | COAT | EABA | IGLO | BYLO | total |
| BBPL | 4 | 1 | - | - | - | 10 | 20 | - | 3 | - | - | - | - | 32 | 4 | 36 | 110 |
| AMGP | - | - | - | - | 99 | 1 | 4 | 2 | 10 | 3 | 27 | 1 | 6 | 4 | 28 | 341 | 526 |
| CRPL | 13 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 22 | 35 |
| SEPL | - | - | - | - | - | - | 1 | - | - | 21 | 20 | 1 | - | 29 | - | - | 72 |
| WHIM | - | - | - | - | - | - | - | - | - | 34 | 118 | 6 | - | - | - | - | 158 |
| RUTU | - | - | - | - | 1 | - | 41 | 2 | 9 | - | - | - | - | 32 | 3 | 2 | 90 |
| RUFF | 42 | 10 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 52 |
| STSA | - | - | - | - | - | - | 1 | 3 | 15 | 5 | 3 | - | - | - | - | - | 27 |
| TEST | 34 | 6 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 40 |
| DUNLalp | 32 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 32 |
| DUNLsak | - | 69 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 69 |
| DUNLpac | - | - | 9 | 83 | - | - | - | - | - | - | - | - | - | - | - | - | 92 |
| DUNLarc | - | - | - | - | 314 | 70 | 56 | 2 | 57 | - | - | - | - | - | - | - | 499 |
| DUNLhud | - | - | - | - | - | - | - | - | - | - | 109 | 22 | 9 | 10 | 1 | - | 151 |
| BASA | - | - | - | - | 1 | - | - | - | 2 | - | - | - | - | - | 3 | 127 | 133 |
| LIST | 22 | 1 | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 23 |
| LESA | - | - | - | - | - | - | - | - | - | 4 | 10 | 18 | - | - | - | - | 32 |
| WRSA | - | - | - | - | 6 | - | - | - | - | - | - | - | - | 56 | 19 | 44 | 125 |
| BBSA | - | - | - | - | 1 | 1 | - | 2 | 19 | - | - | - | - | - | - | 2 | 25 |
| PESA | 89 | 25 | - | - | 402 | 40 | 27 | 20 | 405 | 22 | - | - | - | - | 1 | 8 | 1039 |
| SESA | - | - | 258 | 163 | 239 | 246 | 342 | 53 | 394 | 71 | - | - | 27 | 2 | 12 | - | 1807 |
| WESA | - | - | 359 | 160 | 93 | - | - | - | - | - | - | - | - | - | - | - | 612 |
| LBDO | 1 | 1 | 1 | 1 | 147 | 16 | 2 | 4 | 5 | 3 | - | - | - | - | - | - | 181 |
| RNPH | 14 | 53 | 276 | 62 | 58 | 59 | 71 | 14 | 169 | 96 | 12 | 1 | 1 | - | - | - | 886 |
| REPH | 67 | 1 | - | 1 | 702 | 76 | 72 | 4 | 153 | - | - | - | 7 | 44 | 27 | 7 | 1161 |
| Site total | 318 | 167 | 903 | 470 | 2063 | 519 | 637 | 106 | 1241 | 259 | 299 | 49 | 50 | 209 | 98 | 589 | 7977 |

**Table A3.** Parameter estimates from the full model for each reproductive trait for 25 taxa of shorebirds. Values are on the logit scale (mean ± SD). Dash indicates insufficient sample sizes to test a given group. Species codes are defined in Table 1; sites are in Table S1.

| | | | | | Daily nest survival: all nests | | |
|---|---|---|---|---|---|---|---|
| Parameter | Group | Clutch size | Egg volume | Incubation duration | Survival rate | Predation risk | Abandonment risk |
| Intercept | All | 2.44 ± 0.30 | - | 0.12 ± 0.30 | 4.00 ± 0.20 | 4.29 ± 0.40 | 1.01 ± 0.50 |
| $\beta_{day}$ | All | - | - | - | - | -1.38 ± 0.94 | 0.79 ± 1.02 |
| | BBPL | -1.47 ± 0.74 | -0.50 ± 1.37 | - | -0.39 ± 1.03 | - | - |
| | AMGP | -0.53 ± 0.42 | 0.63 ± 0.89 | - | -1.04 ± 0.82 | - | - |
| | CRPL | -2.72 ± 1.05 | - | - | - | - | - |
| | SEPL | -2.27 ± 0.79 | - | -0.36 ± 0.50 | 0.07 ± 1.03 | - | - |
| | WHIM | -1.55 ± 0.47 | - | - | 0.59 ± 0.85 | - | - |
| | RUTU | -0.54 ± 0.66 | -0.13 ± 1.16 | - | 0.47 ± 1.04 | - | - |
| | RUFF | -0.72 ± 0.91 | - | - | -0.14 ± 1.23 | - | - |
| | STSA | -0.07 ± 1.15 | - | - | -0.66 ± 1.30 | - | - |
| | TEST | -1.62 ± 0.93 | - | - | 0.69 ± 1.38 | - | - |
| | DUNLalp | -2.13 ± 1.25 | - | - | - | - | - |
| | DUNLsak | -2.23 ± 0.80 | -1.07 ± 1.19 | - | -1.22 ± 1.30 | - | - |
| | DUNLpac | -1.79 ± 0.61 | -1.60 ± 1.13 | - | -1.65 ± 1.15 | - | - |
| | DUNLarc | -0.52 ± 0.47 | 0.55 ± 0.68 | -0.59 ± 0.60 | -0.53 ± 0.81 | - | - |
| | DUNLhud | -0.08 ± 0.62 | -0.35 ± 1.20 | - | -0.08 ± 0.96 | - | - |
| | BASA | -1.82 ± 1.11 | -0.66 ± 1.28 | - | -0.43 ± 0.97 | - | - |
| | LIST | -0.95 ± 1.35 | - | - | - | - | - |
| | LESA | 0.21 ± 1.36 | - | - | -0.70 ± 1.33 | - | - |
| | WRSA | -1.63 ± 0.69 | -0.09 ± 1.35 | - | -0.61 ± 0.94 | - | - |
| | BBSA | 0.58 ± 1.35 | - | - | -0.31 ± 1.20 | - | - |
| | PESA | -0.34 ± 0.28 | 0.15 ± 0.68 | -1.20 ± 0.53 | -0.65 ± 0.65 | - | - |
| | SESA | -1.36 ± 0.17 | -1.75 ± 0.59 | -0.47 ± 0.29 | 0.50 ± 0.61 | - | - |
| | WESA | -1.80 ± 0.22 | -0.92 ± 0.63 | 0.46 ± 0.32 | -1.02 ± 0.69 | - | - |
| | LBDO | -0.35 ± 0.54 | -0.12 ± 0.89 | - | -2.03 ± 1.03 | - | - |
| | RNPH | -0.10 ± 0.30 | 0.42 ± 0.74 | -1.22 ± 0.38 | -0.90 ± 0.71 | - | - |
| | REPH | -1.11 ± 0.27 | -0.09 ± 0.61 | 0.23 ± 0.45 | -1.14 ± 0.67 | - | - |
| $\beta_{day^2}$ | BBPL | -0.12 ± 0.41 | -0.17 ± 0.97 | - | -2.41 ± 1.78 | - | - |
| | AMGP | -0.49 ± 0.31 | 0.17 ± 0.73 | - | -0.88 ± 1.59 | - | - |
| | CRPL | -0.31 ± 0.50 | - | - | - | - | - |
| | SEPL | 0.16 ± 0.42 | - | -0.02 ± 0.31 | 0.42 ± 1.84 | - | - |
| | WHIM | 0.27 ± 0.40 | - | - | -1.21 ± 1.60 | - | - |
| | RUTU | 0.08 ± 0.43 | -0.16 ± 0.91 | - | 0.34 ± 1.82 | - | - |
| | RUFF | 0.22 ± 0.47 | - | - | -0.32 ± 2.04 | - | - |
| | STSA | 0.05 ± 0.51 | - | - | -0.25 ± 1.98 | - | - |
| | TEST | -0.17 ± 0.48 | - | - | 0.54 ± 2.02 | - | - |
| | DUNLalp | -0.17 ± 0.51 | - | - | - | - | - |
| | DUNLsak | 0.02 ± 0.47 | 0.44 ± 0.94 | - | -0.76 ± 2.03 | - | - |
| | DUNLpac | 0.14 ± 0.36 | 0.06 ± 0.75 | - | -1.67 ± 1.95 | - | - |
| | DUNLarc | -0.10 ± 0.36 | -0.17 ± 0.68 | 0.46 ± 0.68 | -2.56 ± 1.85 | - | - |
| | DUNLhud | 0.34 ± 0.43 | -0.12 ± 0.78 | - | -0.21 ± 1.74 | - | - |
| | BASA | -0.01 ± 0.50 | -0.12 ± 0.99 | - | -1.02 ± 1.88 | - | - |
| | LIST | 0.02 ± 0.51 | - | - | - | - | - |
| | LESA | -0.06 ± 0.51 | - | - | -0.79 ± 2.00 | - | - |
| | WRSA | 0.15 ± 0.37 | -0.18 ± 1.00 | - | -1.10 ± 1.94 | - | - |
| | BBSA | 0.03 ± 0.49 | - | - | -0.09 ± 1.97 | - | - |
| | PESA | -0.28 ± 0.22 | -0.09 ± 0.54 | 0.91 ± 0.75 | -0.90 ± 1.36 | - | - |
| | SESA | -0.65 ± 0.20 | 0.17 ± 0.54 | 0.07 ± 0.32 | -0.49 ± 1.46 | - | - |
| | WESA | -0.17 ± 0.22 | 1.44 ± 0.71 | -0.01 ± 0.31 | -0.32 ± 1.57 | - | - |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | LBDO | -0.30 ± 0.33 | 0.22 ± 0.71 | - | -0.91 ± 1.71 | - | - |
| | RNPH | -0.12 ± 0.18 | 0.32 ± 0.62 | 0.39 ± 0.33 | -1.06 ± 1.39 | - | - |
| | REPH | -0.26 ± 0.24 | -0.15 ± 0.58 | 0.03 ± 0.37 | -0.33 ± 1.55 | - | - |
| $\sigma_{\beta_{day}}$ | All | 3.00 ± 1.17 | 2.06 ± 1.36 | 1.46 ± 1.17 | 2.13 ± 1.26 | 3.65 ± 1.94 | 3.24 ± 2.04 |
| $\sigma_{\beta_{day^2}}$ | All | 0.27 ± 0.20 | 1.05 ± 0.93 | - | 4.17 ± 1.84 | 3.36 ± 2.04 | 3.78 ± 1.97 |
| $\sigma_{species}$ | All | 0.46 ± 0.22 | - | 0.13 ± 0.17 | 0.16 ± 0.10 | 0.44 ± 0.39 | 0.34 ± 0.42 |
| $\sigma_{site}$ | All | 0.31 ± 0.34 | 2.60 ± 1.57 | 0.35 ± 0.45 | 0.18 ± 0.21 | 0.87 ± 0.95 | 1.36 ± 1.21 |
| $\sigma_{year}$ | LKRI | 2.46 ± 1.81 | - | 3.46 ± 2.01 | 2.68 ± 1.91 | 3.25 ± 2.03 | 3.27 ± 2.01 |
| | CHAU | 3.17 ± 1.96 | 2.76 ± 2.01 | - | 3.37 ± 1.87 | 3.35 ± 2.04 | 3.34 ± 2.02 |
| | NOME | 0.40 ± 0.57 | 3.23 ± 1.99 | 0.73 ± 1.11 | 1.60 ± 1.38 | 3.52 ± 1.77 | 2.05 ± 1.79 |
| | CAKR | 1.47 ± 1.53 | 1.74 ± 1.72 | 0.98 ± 1.30 | 2.61 ± 1.61 | 2.40 ± 1.88 | 2.35 ± 1.92 |
| | BARR | 0.58 ± 0.61 | 1.23 ± 1.25 | 2.26 ± 1.43 | 1.01 ± 0.92 | 1.85 ± 1.61 | 2.15 ± 1.75 |
| | IKPI | 2.09 ± 1.79 | 4.56 ± 1.65 | 2.10 ± 1.70 | 2.88 ± 1.69 | 3.08 ± 1.95 | 3.09 ± 1.99 |
| | COLV | 1.52 ± 1.48 | 3.26 ± 1.76 | 1.33 ± 1.42 | 1.43 ± 1.48 | 1.85 ± 1.74 | 2.35 ± 1.89 |
| | PRBA | 2.96 ± 1.98 | - | 3.06 ± 2.02 | 3.34 ± 1.96 | 3.45 ± 2.01 | 3.47 ± 2.02 |
| | CARI | 0.90 ± 1.16 | - | 1.08 ± 1.29 | 1.74 ± 1.43 | 2.26 ± 1.74 | 2.20 ± 1.76 |
| | MADE | 1.72 ± 1.65 | 4.13 ± 1.85 | 3.43 ± 2.02 | 1.85 ± 1.63 | 3.09 ± 1.96 | 3.60 ± 1.97 |
| | CHUR | 2.12 ± 1.70 | 3.21 ± 2.02 | 2.61 ± 1.91 | 1.89 ± 1.56 | 3.36 ± 1.89 | 2.63 ± 1.95 |
| | BURN | 3.13 ± 2.02 | 3.53 ± 2.03 | - | 2.58 ± 1.89 | 2.93 ± 2.01 | 3.17 ± 2.01 |
| | COAT | 4.24 ± 1.81 | 3.50 ± 1.97 | 3.02 ± 2.07 | 2.81 ± 2.02 | 3.47 ± 2.04 | 3.46 ± 2.04 |
| | EABA | 2.03 ± 1.83 | - | 3.17 ± 2.07 | 1.85 ± 1.77 | 3.21 ± 2.00 | 3.07 ± 2.02 |
| | IGLO | 3.42 ± 1.91 | 2.80 ± 2.05 | 4.34 ± 1.73 | 2.81 ± 1.94 | 3.54 ± 2.02 | 3.43 ± 1.99 |
| | BYLO | 1.67 ± 1.67 | 4.31 ± 1.65 | 2.34 ± 1.94 | 2.51 ± 1.60 | 2.95 ± 1.93 | 3.43 ± 2.00 |

**Table A4.** Final parameter estimates for each reproductive trait for 25 taxa of shorebirds. Values are on the logit scale (mean ± SD). Dash indicates insufficient sample sizes to test a given group, or a case in which a quadratic effect of day was not supported. Bold font indicates effects of day where 95% BCIs do not overlap zero. Species codes are defined in Table 1; sites are in Table S1.

| | | | | | Daily nest survival: all nests | | | Daily nest survival: mean initiation date | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Parameter | Group | Clutch size | Egg volume | Incubation duration | Survival rate | Predation risk | Abandon-ment risk | Survival rate | Predation risk | Abandon-ment risk |
| Intercept | All | 2.45 ± 0.31 | - | -0.02 ± 0.37 | 3.94 ± 0.22 | 4.31 ± 0.38 | 1.04 ± 0.52 | 4.15 ± 0.37 | 3.93 ± 0.74 | -0.02 ± 1.26 |
| $\beta_{day}$ | All | - | - | - | - | **-1.81 ± 0.87** | 1.38 ± 0.95 | - | -2.66 ± 1.92 | 1.27 ± 1.80 |
| | BBPL | **-1.58 ± 0.65** | 0.18 ± 1.22 | - | -0.87 ± 0.88 | - | - | - | - | - |
| | AMGP | -0.71 ± 0.41 | 0.60 ± 0.85 | - | **-1.41 ± 0.59** | - | - | -1.29 ± 1.52 | - | - |
| | CRPL | **-2.91 ± 1.01** | - | - | - | - | - | - | - | - |
| | SEPL | **-1.96 ± 0.69** | - | -0.23 ± 0.49 | 0.27 ± 1.02 | - | - | - | - | - |
| | WHIM | **-1.43 ± 0.44** | - | - | 0.23 ± 0.68 | - | - | - | - | - |
| | RUTU | -0.51 ± 0.66 | 0.04 ± 1.09 | - | 0.70 ± 1.07 | - | - | - | - | - |
| | RUFF | -0.64 ± 0.89 | - | - | -0.16 ± 1.36 | - | - | - | - | - |
| | STSA | -0.09 ± 1.16 | - | - | -0.80 ± 1.43 | - | - | - | - | - |
| | TEST | **-1.75 ± 0.89** | - | - | 0.96 ± 1.49 | - | - | - | - | - |
| | DUNLalp | -2.14 ± 1.26 | - | - | - | - | - | - | - | - |
| | DUNLsak | **-2.22 ± 0.79** | -1.00 ± 1.15 | - | -1.56 ± 1.36 | - | - | - | - | - |
| | DUNLpac | **-1.66 ± 0.53** | -1.46 ± 1.07 | - | **-2.24 ± 1.07** | - | - | - | - | - |
| | DUNLarc | -0.81 ± 0.45 | 0.25 ± 0.64 | **-1.12 ± 0.45** | **-1.32 ± 0.61** | - | - | - | - | - |
| | DUNLhud | -0.02 ± 0.57 | -0.27 ± 1.08 | - | -0.11 ± 0.92 | - | - | - | - | - |
| | BASA | -1.82 ± 1.13 | -0.59 ± 1.24 | - | -0.73 ± 0.94 | - | - | - | - | - |
| | LIST | -0.93 ± 1.35 | - | - | - | - | - | - | - | - |
| | LESA | 0.19 ± 1.37 | - | - | -0.91 ± 1.46 | - | - | - | - | - |
| | WRSA | **-1.46 ± 0.56** | 0.58 ± 1.23 | - | -0.86 ± 0.89 | - | - | - | - | - |
| | BBSA | 0.58 ± 1.34 | - | - | -0.39 ± 1.28 | - | - | - | - | - |
| | PESA | **-0.59 ± 0.25** | 0.05 ± 0.58 | 0.14 ± 0.37 | **-1.03 ± 0.40** | - | - | -0.90 ± 1.22 | - | - |
| | SESA | **-1.55 ± 0.17** | **-1.71 ± 0.57** | -0.38 ± 0.29 | 0.35 ± 0.36 | - | - | -0.77 ± 1.06 | - | - |
| | WESA | **-1.82 ± 0.21** | -1.03 ± 0.62 | 0.43 ± 0.30 | **-1.18 ± 0.43** | - | - | -1.59 ± 1.59 | - | - |
| | LBDO | -0.66 ± 0.41 | 0.05 ± 0.76 | - | **-2.51 ± 0.80** | - | - | - | - | - |
| | RNPH | -0.25 ± 0.20 | 0.52 ± 0.66 | -0.27 ± 0.32 | **-1.35 ± 0.46** | - | - | -0.32 ± 1.31 | - | - |
| | REPH | **-1.30 ± 0.22** | 0.05 ± 0.57 | **-1.10 ± 0.33** | **-1.31 ± 0.44** | - | - | -1.80 ± 1.47 | - | - |
| $\sigma_{\beta_{day}}$ | All | 3.05 ± 1.18 | 1.86 ± 1.28 | 1.22 ± 1.09 | 2.71 ± 1.26 | 3.84 ± 1.88 | 3.59 ± 1.94 | 3.61 ± 1.92 | 4.30 ± 1.89 | 3.66 ± 1.98 |
| $\sigma_{species}$ | All | 0.43 ± 0.20 | - | 0.09 ± 0.11 | 0.14 ± 0.08 | 0.42 ± 0.33 | 0.30 ± 0.32 | 0.36 ± 0.66 | 2.55 ± 1.92 | 2.68 ± 1.96 |
| $\sigma_{site}$ | All | 0.38 ± 0.43 | 2.54 ± 1.56 | 0.67 ± 0.92 | 0.20 ± 0.21 | 0.95 ± 1.01 | 1.35 ± 1.21 | 0.58 ± 0.66 | 2.21 ± 1.81 | 2.87 ± 2.01 |
| $\sigma_{year}$ | LKRI | 2.43 ± 1.80 | - | 3.06 ± 1.97 | 2.62 ± 1.92 | 3.27 ± 2.05 | 3.27 ± 2.01 | 3.52 ± 1.99 | 3.46 ± 2.01 | 3.54 ± 2.01 |
| | CHAU | 3.15 ± 1.97 | 2.80 ± 1.96 | - | 3.37 ± 1.87 | 3.43 ± 2.03 | 3.33 ± 2.03 | 3.19 ± 2.01 | 3.44 ± 2.02 | 3.47 ± 2.03 |
| | NOME | 0.41 ± 0.58 | 4.23 ± 1.78 | 3.07 ± 2.03 | 1.56 ± 1.35 | 3.48 ± 1.75 | 2.00 ± 1.77 | 2.96 ± 1.82 | 3.27 ± 1.99 | 3.49 ± 2.01 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| CAKR | 1.36 ± 1.46 | 1.88 ± 1.75 | 1.13 ± 1.40 | 2.59 ± 1.63 | 2.26 ± 1.87 | 2.36 ± 1.88 | 3.18 ± 1.86 | 3.31 ± 2.00 | 3.73 ± 1.96 |
| BARR | 0.57 ± 0.69 | 1.31 ± 1.33 | 2.26 ± 1.42 | 1.05 ± 0.99 | 1.89 ± 1.58 | 2.16 ± 1.76 | 1.45 ± 1.37 | 3.10 ± 2.00 | 3.01 ± 1.97 |
| IKPI | 2.11 ± 1.75 | 2.84 ± 1.99 | 3.43 ± 2.04 | 2.96 ± 1.74 | 3.14 ± 1.96 | 3.15 ± 1.99 | 3.81 ± 1.85 | 3.41 ± 2.01 | 3.47 ± 2.04 |
| COLV | 1.63 ± 1.52 | 3.29 ± 1.79 | 2.87 ± 1.94 | 1.47 ± 1.48 | 1.82 ± 1.75 | 2.35 ± 1.88 | 1.66 ± 1.68 | 3.31 ± 2.02 | 3.37 ± 2.00 |
| PRBA | 2.93 ± 1.96 | - | - | 3.37 ± 1.95 | 3.45 ± 2.02 | 3.36 ± 2.02 | 3.00 ± 2.04 | 3.46 ± 2.01 | 3.42 ± 2.01 |
| CARI | 0.90 ± 1.11 | - | 2.67 ± 1.95 | 1.68 ± 1.39 | 2.27 ± 1.71 | 2.11 ± 1.73 | 1.96 ± 1.66 | 3.29 ± 2.02 | 3.25 ± 2.04 |
| MADE | 1.78 ± 1.70 | 4.60 ± 1.64 | 0.63 ± 0.89 | 1.88 ± 1.67 | 3.13 ± 1.97 | 3.63 ± 1.97 | 3.06 ± 2.03 | 3.53 ± 2.01 | 3.45 ± 2.05 |
| CHUR | 2.08 ± 1.69 | 3.27 ± 2.07 | 3.09 ± 2.03 | 1.92 ± 1.59 | 3.37 ± 1.87 | 2.59 ± 1.96 | 3.30 ± 2.01 | 3.48 ± 2.02 | 3.51 ± 2.02 |
| BURN | 3.02 ± 2.02 | 3.44 ± 2.01 | - | 2.53 ± 1.85 | 2.91 ± 1.98 | 3.2 ± 1.99 | 3.62 ± 1.98 | 3.40 ± 2.02 | 3.47 ± 1.99 |
| COAT | 4.27 ± 1.79 | 3.58 ± 1.99 | 1.51 ± 1.56 | 2.83 ± 2.05 | 3.52 ± 1.99 | 3.46 ± 2.02 | - | - | - |
| EABA | 3.14 ± 1.92 | - | 4.25 ± 1.81 | 1.63 ± 1.65 | 3.24 ± 2.01 | 3.01 ± 1.99 | 3.47 ± 1.97 | 3.36 ± 2.01 | 3.38 ± 2.00 |
| IGLO | 3.38 ± 1.91 | 3.37 ± 2.02 | 2.09 ± 1.69 | 2.83 ± 1.96 | 3.62 ± 2.00 | 3.4 ± 2.00 | 3.50 ± 1.97 | 3.42 ± 2.03 | 3.48 ± 2.02 |
| BYLO | 1.68 ± 1.67 | 4.27 ± 1.66 | 1.06 ± 1.36 | 2.52 ± 1.59 | 3.15 ± 1.96 | 3.49 ± 2.00 | 3.32 ± 1.93 | 3.27 ± 2.01 | 3.31 ± 2.02 |