

1 Online Appendix A: Multi-event modeling of breeding 2 experience

3 The multievent framework (Pradel 2005) distinguishes the *events*, coded in the capture
4 histories, from the *states* which are not directly observed. When studying experience, there
5 are several states to consider while there are only 2 events.

6 The events are:

- 7 • 0, 'not observed',
- 8 • 1, 'observed'.

9 The states retained are:

- 10 • NB_0 , non-breeder with no previous experience at the onset of the season,
- 11 • B_0 , breeder with no previous experience at the onset of the season,
- 12 • NB_1 , non-breeder with one previous experience at the onset of the season,
- 13 • B_1 , breeder with one previous experience at the onset of the season,
- 14 • NB_2 , non-breeder with >1 previous experience at the onset of the season,
- 15 • B_2 , breeder with >1 previous experience at the onset of the season.

16 A multievent model has three kinds of parameters : the *initial state probabilities*, the
17 *transition probabilities*, and the *event probabilities* (conditional on the underlying state). As
18 every individual in our data set was ringed as a chick, all initial state probabilities are trivially
19 1 for the state NB_0 and this kind of parameters is not used here.

The transitions are best presented in stochastic matrix form with departure states in rows
and arrival states in columns (see also Figure 1 in main text). ϕ is the survival probability, β
the breeding probability. β is indexed according to the level of previous experience: 0 no
previous experience, 1 one previous experience, and 2 two or more previous experiences.

$$\begin{array}{l}
 NB_0 \\
 B_0 \\
 NB_1 \\
 B_1 \\
 NB_2 \\
 B_2 \\
 dead
 \end{array}
 \begin{pmatrix}
 NB_0 & B_0 & NB_1 & B_1 & NB_2 & B_2 & dead \\
 \phi(1-\beta_0) & \phi\beta_0 & 0 & 0 & 0 & 0 & 1-\phi \\
 0 & 0 & \phi(1-\beta_1) & \phi\beta_1 & 0 & 0 & 1-\phi \\
 0 & 0 & \phi(1-\beta_1) & \phi\beta_1 & 0 & 0 & 1-\phi \\
 0 & 0 & 0 & 0 & \phi(1-\beta_2) & \phi\beta_2 & 1-\phi \\
 0 & 0 & 0 & 0 & \phi(1-\beta_2) & \phi\beta_2 & 1-\phi \\
 0 & 0 & 0 & 0 & \phi(1-\beta_2) & \phi\beta_2 & 1-\phi \\
 0 & 0 & 0 & 0 & 0 & 0 & 1
 \end{pmatrix}$$

20 Note that most transitions are impossible, that the last state 'dead' can be reached from any
 21 live state with probability $1 - \phi$ and that once in this state an individual will remain in it
 22 forever (transition from 'dead' to 'dead' is 1 : last row, last column). This basic model can be
 23 particularized, for instance to allow for a first-year survival lower than survival in later years
 24 or to introduce time-dependency on breeding probability.

The event probabilities relate the observations coded in the capture histories to the underlying states. Here, we assume that non-breeders, except chicks at the time of ringing (state NB_0), cannot be observed (event '0' with probability 1) and that breeders, whatever their experience, share the same probability p to be observed. A matrix form with the conditioning state in row and the event in column is again a particularly handy presentation.

$$\begin{array}{l}
 \\
 \\
 \\
 \\
 \\
 \\
 \\
 \end{array}
 \begin{array}{cc}
 & \text{'0'} & \text{'1'} \\
 \begin{array}{l}
 NB_0 \\
 B_0 \\
 NB_1 \\
 B_1 \\
 NB_2 \\
 B_2 \\
 dead
 \end{array} & \begin{pmatrix}
 1 & 0 \\
 1 - p & p \\
 1 & 0 \\
 1 - p & p \\
 1 & 0 \\
 1 - p & p \\
 1 & 0
 \end{pmatrix}
 \end{array}$$

Online Appendix B: Implementation of the generic model in E-SURGE

We present here how to implement the above model using program E-SURGE. The specifics of the model have been kept as general as possible in order to be applicable to data sets other than the one we used in the article. For instance, we have not included the effect of one very cold year on survival. However, some details, which should be easy to adapt, relate to the flamingo example. For instance, no breeding is possible until age 3. We intend this as a template for other studies.

E-SURGE can be downloaded at <http://www.cefe.cnrs.fr/biom/logiciels.htm>. It can read in data in a no-frill MARK format: no comments, no tabulations, no letters in the capture histories (only digits); or alternatively in BIOMECO format (see the associated manual for a description).

After opening a new session and reading in the data (2 first items of the bar menu), the number of states, 7, has to be specified through the 'Modify' button.

It is now possible to go through the 4 steps represented by the coloured buttons at the bottom left.

B.1 specifying the patterns (tool GEPAT)

This stage roughs out the model by specifying the probabilities that will not be used (impossible initial states, transitions, or events)—code '-' (minus sign)—and those that will be calculated from others (because they are the last of a set of exclusive complementary options)—code '*'.
Initial States:

$$\left[\begin{array}{cccccc} * & - & - & - & - & - \end{array} \right]$$

We decompose the transition in two steps: first survival, then the decision to breed.

Survival Step:

$$\left[\begin{array}{cccccc} \phi & - & - & - & - & * \\ - & \phi & - & - & - & * \\ - & - & \phi & - & - & * \\ - & - & - & \phi & - & * \\ - & - & - & - & \phi & * \\ - & - & - & - & - & \phi * \\ - & - & - & - & - & * \end{array} \right]$$

Breeding Step:

$$\begin{bmatrix} \star & \beta & - & - & - & - & - \\ - & - & \star & \beta & - & - & - \\ - & - & \star & \beta & - & - & - \\ - & - & - & - & \star & \beta & - \\ - & - & - & - & \star & \beta & - \\ - & - & - & - & \star & \beta & - \\ - & - & - & - & - & - & \star \end{bmatrix}$$

Event probabilities:

$$\begin{bmatrix} \star & p \\ \star & p \\ \star & - \\ \star & p \\ \star & - \\ \star & p \\ \star & - \end{bmatrix}$$

47 The p on the first row (state NB_0) is needed because chicks are observed. We will clarify
 48 this point in the next step, GEMACO. (Note that GEPAT only displays greek letters; this is
 49 not a problem.)

50 **B.2 specifying the effects (tool GEMACO, Choquet, 2008)**

51 Initial States: there is nothing to do here

Survival step:

$$a(1, 2 : 100)$$

52 This assumes that survival is constant over age past the first year of life. The last number
 53 (100 here) must exceed the number of time steps.

Breeding step:

$$a(3_25).to(2) + a(4_25).to(4) + a(5_25).to(6) + others$$

54 The breeding probabilities of inexperienced individuals ($to(2)$) are estimated from age 3 to
 55 age 25 (maximum age observable in the flamingo data set), those for individuals with one
 56 previous breeding experience ($to(4)$) from age 4 to 25, those for more experienced
 57 individuals ($to(6)$) from age 5 to 25. No individual breeds prior to age 3. The unspecified
 58 breeding probabilities, which should all be 0, are gathered together as a last breeding
 59 probability by the keyword '*others*'.

Event probabilities:

$$firste + nexte.[f(246)].t + others$$

60 Here, we distinguish the initial encounter probability (*firste*) from the subsequent
61 probabilities (*nexte*) of encountering breeders ($f(246)$) which are allowed to vary over years
62 (t). The remainder are the subsequent probabilities of encountering non-breeders (*others*).

63 **B.3 setting some parameter values (tool IVFV)**

64 The last transition corresponds (among others) to the breeding probability prior to age 3
65 and must be set to 0 (by entering the value 0 on the right and checking the box next to it).

66 The first event is the probability of encounter at the time of marking. It must be set to 1. The
67 last event is the probability of encountering adult non-breeders. It has to be set to 0.

68 **B.4 RUN**

69 The model can now be run.

70 Online Appendix C: Results of data analysis

71 C.1 Complete data set: years 1977-2001

72 C.1.1 Assessment of goodness-of-fit

73 There is no goodness-of-fit test available for the breeding probability models. We
 74 examined the fit of the fully time- and age-dependent survival and capture model (Pollock,
 75 1981). This test is obtained by running the test of the Cormack-Jolly-Seber model
 76 separately on each cohort and summing over cohorts (Table C1). Calculations were made
 77 with program U-CARE (Choquet *et al.*, 2009). This led to a variance inflation factor \hat{c} of
 78 2.244 (1355.43/604) for the Pollock model. This value is conservative when applied to a
 79 model that performs better than the Pollock model. We used it for our analysis after
 80 introducing the Pollock model for comparison among the models fitted.

Table C1: Goodness-of-fit tests of the time-dependent survival and capture Cormack-Jolly-Seber model by cohort.

Cohort	χ^2	degrees of freedom
1977	165.95	64
1978	199.48	65
1979	169.96	67
1980	134.80	55
1981	174.96	60
1982	122.35	52
1983	78.69	48
1984	58.65	39
1985	80.05	39
1986	42.09	28
1987	40.08	23
1988	36.52	21
1989	14.53	12
1990	8.94	9
1991	7.51	9
1992	14.43	7
1993	6.43	5
1994	0	1
1995-1998	0	0
Total	1355.43	604

81 C.1.2 Additional models

82 We checked with two models that we could not rid ourselves of the cold spell effect on
 83 survival nor of the temporal variability of capture rates.

Table C2: Some additional models in the analysis of the effects of age and breeding experience on the breeding probability β of greater flamingos marked as chicks from 1977 to 1997 and resighted as breeders in the Camargue, southern France, until 2001. Notations are as in Table 2 of the main document except for $a2$ which means two age-classes, the first one corresponding to the first year of life. CS stands for 'cold spell'. In the models with a cold spell effect, first-year survival in normal years is fixed to 0.763, the sex-averaged value of Balkız (2006) estimates.

Model	Best or Reference model or – hypothesis tested	Deviance	k	Δ QAIC ($\hat{c}=2.244$)
$\beta_{a.e}, \phi_{CS.a2}, p_t$	Best model	53763.22	87	0
$\beta_{a.e}, \phi_{a2}, p_t$	– no effect of cold spell on survival	53803.83	85	14.60
$\beta_{a.e}, \phi_{CS.a2}, p$	– capture rate constant	55295.91	66	641.50
$\phi_{a.t} p_{a.t}$	Reference Pollock model	53883.71	439	757.69

84 **C.2 Detailed data set: years 1985-2001**

85 **C.2.1 Goodness-of-fit**

86 Same procedure as for the complete data set. Variance inflation factor \hat{c} estimated at
87 1.625 (247.07/152) for the Pollock model.

Table C3: Goodness-of-fit tests of the time-dependent survival and capture Cormack-Jolly-Seber model by cohort.

Cohort	χ^2	degrees of freedom
1985	78.04	38
1986	41.59	28
1987	38.74	22
1988	36.52	21
1989	14.53	12
1990	9.41	9
1991	7.51	9
1992	14.43	7
1993	6.30	5
1994	0	1
1995-1998	0	0
Total	247.07	152

88 **C.2.2 estimates from best model**

89 With the reduced data set, more information was available about individuals. Also,
90 during the restricted period, no major climatic events took place so that survival could be

91 considered constant within each class of individuals. We took advantage of this new context
 92 to examine the influence of sex and of individual differences on breeding probabilities and to
 93 refine the modelisation of survival. The age and sex survival structure was matched exactly
 94 to that of Balkız (2006), who has found sex differences and a second-year survival still
 95 somewhat lower than the adult survival. The cost of first reproduction in females (notation
 96 $1rf$), first detected by Tavecchia *et al.* (2001), was introduced as a smoothed function of age
 97 ($\text{logit}(\text{age})$ is a linear function of $\log(\text{age})$ that cancels at 6, see Table C4 below). Individual
 98 differences were introduced through the use of the residuals of the log-log regression of
 99 weight on tarsus length at ringing as a covariate of breeding probability. The best model
 100 retained is $\phi_{a3.s+1rf} \beta_{a2.e+BC.s} p_{t+s}$ i.e. sex- and age-specific survival (with 3 age classes)
 101 with an age-specific cost of first reproduction in females, capture rates varying over time in
 102 parallel (on a logit scale) in the two sexes, and breeding probabilities age- and
 103 experience-dependent and affected by the body condition differently in females and males.
 104 A sex-specific effect of body condition on survival was also tested but not retained (see next
 105 section).

Table C4: Survival estimates.

parameter	estimate	95% C.I.		s.e.
		lower boundary	higher boundary	
female 1st year	0.779	fixed parameter		-
male 1st year	0.747	fixed parameter		-
female 2nd year	0.944	fixed parameter		-
male 2nd year	0.921	fixed parameter		-
female 3+ year	0.970	0.951	0.981	0.007
male 2+ year	0.957	0.943	0.968	0.006
first breeding 3-year-old female	0.651	0.492	0.782	0.076
first breeding 4-year-old female	0.858	0.774	0.915	0.035
first breeding 5-year-old female	0.938	0.900	0.962	0.015

Figure C1: Breeding probability as a function of age and experience for greater flamingos breeding in the Camargue, south of France, estimated from the reduced data set (1985-2001). Plain circle: no previous breeding episode; empty circle: one previous breeding episode; triangle: 2 or more previous breeding episodes. These values are for an average individual in terms of body condition: value 0 of the covariate.

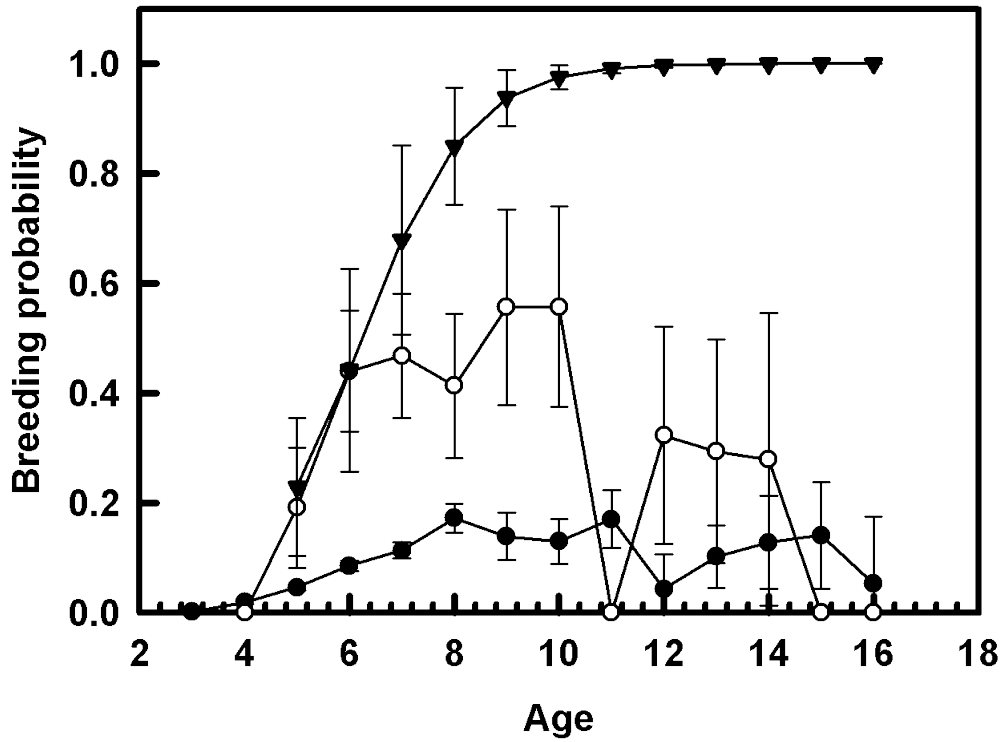


Figure C2: Influence of body condition on breeding probability: a) females, b) males. Positive values of the index correspond to larger than average individuals. The histogram shows the actual distribution of body condition in the population for each sex. The values of the curves are for 8-year-old individuals with one previous breeding experience.

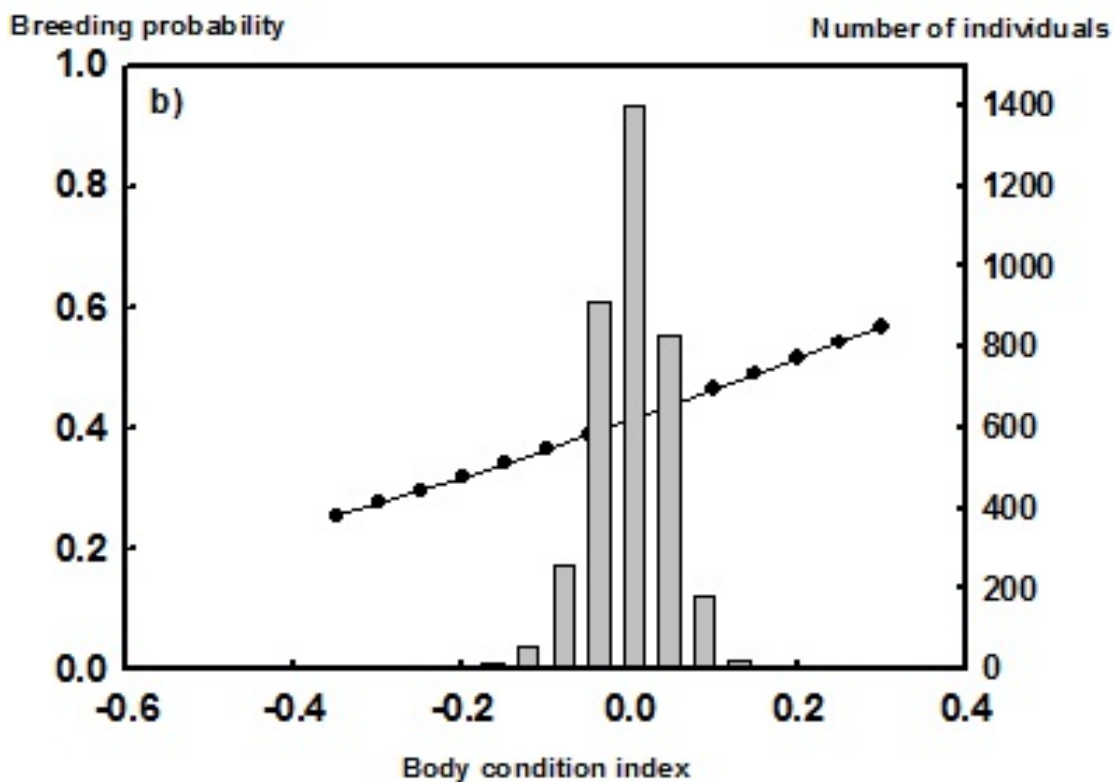
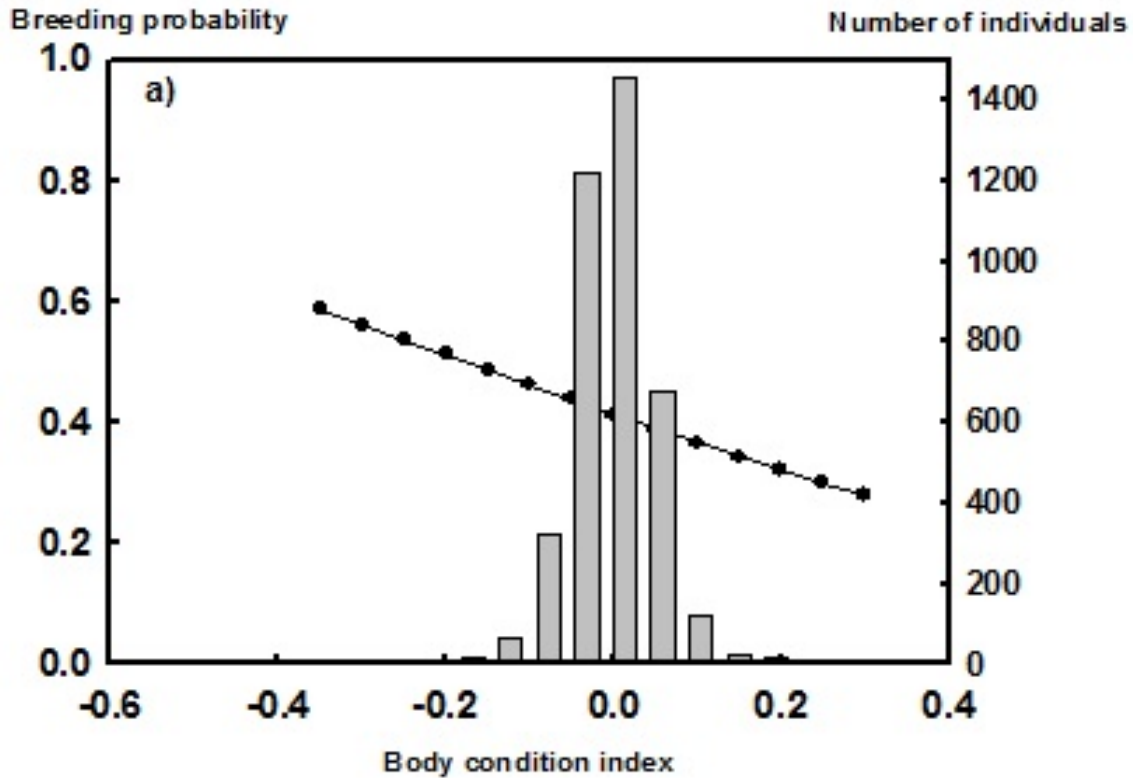


Table C5: Breeding estimates.

# previous breeding episodes	age	point estimate	95% C.I.		s.e.
			lower boundary	higher boundary	
0	3	0.002	0.001	0.005	0.001
0	4	0.020	0.015	0.027	0.003
0	5	0.046	0.037	0.058	0.005
0	6	0.085	0.069	0.105	0.009
0	7	0.114	0.088	0.145	0.014
0	8	0.173	0.128	0.229	0.026
0	9	0.139	0.074	0.246	0.043
0	10	0.130	0.069	0.232	0.041
0	11	0.171	0.091	0.297	0.052
0	12	0.044	0.002	0.469	0.063
0	13	0.102	0.033	0.279	0.057
0	14	0.128	0.032	0.394	0.085
0	15	0.141	0.033	0.442	0.097
0	16	0.053	0.000	0.872	0.123
1	4	0.000	0.000	0.000	0.000
1	5	0.191	0.056	0.486	0.109
1	6	0.440	0.246	0.654	0.110
1	7	0.468	0.265	0.683	0.113
1	8	0.413	0.196	0.671	0.131
1	9	0.556	0.234	0.837	0.178
1	10	0.557	0.228	0.843	0.182
1	11	0.000	0.000	0.000	0.000
1	12	0.323	0.075	0.737	0.197
1	13	0.294	0.057	0.741	0.204
1	14	0.280	0.028	0.838	0.266
1	15	0.000	0.000	0.000	0.000
1	16	0.000	0.000	0.000	0.000
2+	5	0.229	0.069	0.543	0.125
2+	6	0.442	0.154	0.775	0.185
2+	7	0.679	0.310	0.909	0.172
2+	8	0.849	0.525	0.966	0.106
2+	9	0.938	0.731	0.988	0.051
2+	10	0.976	0.870	0.996	0.022
2+	11	0.991	0.943	0.999	0.009
2+	12	0.997	0.976	1.000	0.003
2+	13	0.999	0.990	1.000	0.001
2+	14	1.000	0.996	1.000	0.001
2+	15	1.000	0.998	1.000	0.000
2+	16	1.000	0.999	1.000	0.000

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Table C6: Capture estimates. Confidence intervals are not available for the parameters estimated on the boundary. No individuals were at risk of capture prior to 1988.

year	estimate	95% C.I.		s.e.
		lower boundary	higher boundary	
females				
1988	0.000	-	-	-
1989	0.000	-	-	-
1990	0.496	0.247	0.747	0.140
1991	1.000	-	-	-
1992	0.405	0.296	0.525	0.059
1993	0.254	0.191	0.329	0.035
1994	0.314	0.252	0.384	0.034
1995	0.374	0.314	0.438	0.032
1996	0.241	0.200	0.287	0.022
1997	0.305	0.260	0.354	0.024
1998	0.418	0.367	0.471	0.027
1999	0.179	0.152	0.209	0.015
2000	0.373	0.331	0.417	0.022
2001	0.331	0.293	0.371	0.020
males				
1988	0.000	-	-	-
1989	0.000	-	-	-
1990	0.569	0.304	0.800	0.138
1991	1.000	-	-	-
1992	0.477	0.360	0.597	0.062
1993	0.313	0.239	0.398	0.041
1994	0.381	0.310	0.457	0.038
1995	0.445	0.379	0.512	0.034
1996	0.298	0.250	0.352	0.026
1997	0.370	0.318	0.425	0.027
1998	0.490	0.434	0.547	0.029
1999	0.226	0.193	0.263	0.018
2000	0.443	0.397	0.491	0.024
2001	0.399	0.355	0.443	0.023

C.2.3 effect of body condition on survival

To test for individual differences in survivorship after accounting for the cost of the first reproduction in females, body condition was introduced as a covariate of survival for males and females separately in the best model $\phi_{a3.s+1rf} \beta_{a2.e+BC.s} p_{t+s}$ (see above section). The effect was not significant.

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Table C7: Test of an effect of body condition on survival assessed from the best model $\phi_{a3.s+1rf} \beta_{a2.e+BC.s} p_{t+s}$. Only the survival part is shown below as the remainder is unchanged.

Model	Best model or – difference from best model	Deviance	k	Δ QAIC ($\hat{c}=1.625$)
$\phi_{a3.s+1rf}$	Best model	17575.27	49	0
$\phi_{a3.s+1rf+BC.s}$	– effect of body condition on survival assessed separately on males and females	17574.79	51	3.70

References

- 111
- 112 Balkız, Ö. 2006. Dynamique de la métapopulation de flamants roses en Méditerranée:
113 implications pour la conservation. Ph.D. thesis, Univ Montpellier II, Montpellier, France.
- 114 Choquet, R. 2008. Automatic generation of multistate capture recapture models. The
115 Canadian Journal of Statistics 36:43–57.
- 116 Choquet, R., J. Y. Lebreton, O. Gimenez, A. M. Reboulet, and R. Pradel. 2009. U-CARE:
117 Utilities for performing goodness of fit tests and manipulating CAPture-REcapture data.
118 Ecography 32:1071–1074.
- 119 Pollock, K. H. 1981. Capture-recapture models allowing for age-dependent survival and
120 capture rates. *Biometrics*, 37:521–529.
- 121 Tavecchia, G., R. Pradel, V. Boy, A. R. Johnson, and F. Cézilly. 2001. Sex- and age-related
122 variation in survival and cost of first reproduction in greater flamingos. *Ecology*
123 82:165–174.