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Supplementary material

Appendix 1.

Modelling harrier survival: GOF tests, age and sex effects, trap-dependence.

We performed goodness-of-fit tests (GOF) to confirm the validation of the four hypotheses of the Cormack-Jolly-Seber model using U-Care 2.3.2 (Choquet et al. 2009). Trap-dependence was treated with a multi-state modelling approach as recommended by Pradel, Sanz-Aguilar & Boyce (2012). Birds can be in either of these three states; sighted on a previous occasion, not sighted on a previous occasion or dead, the latter state being unobservable. Transience was accounted for by setting two age classes according to first capture (first year, 2+). This procedure adequately dealt with data heterogeneity (test without $3SR_{male\ \&\ female}$ and $2CT_{female}$: χ^2_{70} = 48.1, P = 0.98). Juvenile dataset also showed some transience due to lower juvenile survival (with and without 3SR respectively: χ^2_{53} = 60, P = 0.24; χ^2_{44} = 36.3, P = 0.80) which was accounted for by age-specific models (ages 1 & 2+). Details on recapture and survival modelling for these three datasets are presented in Table A1 & A2.

We tested the parameterisation of recapture rate p according to time, age and sex (Table A1). In Maine-et-Loire (ML), recapture probability varied with sex (model a1, Table A1) and p was higher for individuals caught in the previous year and higher for males compared to females (p_{male} = 0.70 ± 0.04 and p_{female} = 0.64 ± 0.03 if caught the year before, p_{male} = 0.25 ± 0.07 and p_{female} = 0.43 ± 0.06 otherwise). Recapture rates in Rochefort (RO) did not appear to vary over time for adults and juveniles. Model selection pointed out a constant recapture rate between males and females for adults (model b1, Table A1, p = 0.78 ± 0.03), but identified sex- and age-dependency for juveniles (model c1, Table A1).

For survival, we did not detect any significant correlation between environmental covariates and adult survival rate in ML (ΔAICc between models fitted with S(t) and S(.): −7.1, model a1, Table A2, see also Table 1). By contrast, adult survival rates substantially varied over time in

RO (ΔAICc = 5.1, model b1, Table A2). Juvenile survival, estimated in RO only, was constant but highly depending on age. The model with three age classes (ΔAICc = 1.95, model c2, Table A2) showed a progressive increase of survival over ages (S_{a1} = 0.39 ± 0.15, S_{a2} = 0.54 ± 0.24, S_{a2+} = 0.63 ± 0.05). Because we focused on first-year survival, we considered only two age classes.

Table A1. Results of model selection for recapture probability *p* of Montagu's harriers wing-tagged in Maine-et-Loire (ML) and Rochefort (RO) study areas. Akaike's Information Criterion (*AICc*) and *ΔAICc* are provided (best model in bold) together with the number of parameters *k* and deviance. Age dependence is symbolized by 'a' (2 age-classes considered here). The models could be time-dependent (t), constant (.), or sex-dependent (g). For ML, trap-dependence effects (f) allowed us to estimate *p* for trap-aware and trap-unaware individuals separately (see above). In this study area, transience in adult females was also accounted for by considering two age-classes following initial capture (S(g[aF]).

Model	AICc	ΔAICc	k	Deviance
(a) Adult recapture probability in ML				
1 S (g[aF] × t) p(f × g)	**2060.16**	**0.00**	**38**	**1981.00**
2 S (g[aF] × t) p(f)	2065.23	5.07	36	1990.39
3 S (g[aF] × t) p(f × g + t)	2087.12	26.96	54	1972.67
4 S (g[aF] × t) p(f × g × t)	2152.65	92.49	98	1934.52
(b) Adult recapture probability in RO				
1 S (g × t) p(.)	**869.26**	**0.00**	**35**	**793.14**
2 S (g × t) p(g)	872.24	2.98	37	791.38
3 S (g × t) p(t)	884.52	15.27	50	771.68
4 S (g × t) p(g + t)	885.17	15.91	51	769.78
5 S (g × t) p(g × t)	901.55	32.29	63	754.55
(c) Juvenile recapture probability in RO				
1 S (g × a) p(g + a)	**712.14**	**0.00**	**10**	**691.73**
2 S (g × a) p(a)	712.58	0.43	9	694.24
3 S (g × a) p(g + a(1,2 3))	713.22	1.08	9	694.88
4 S (g × a) p(g × a)	716.30	4.16	12	691.71
5 S (g × a) p(g + a + t)	718.72	6.58	24	668.41
6 S (g × a) p(a + t)	719.26	7.11	23	671.13
7 S (g × a) p(g)	720.97	8.82	8	704.70
8 S (g × a) p(g × a + t)	723.05	10.91	26	668.33
9 S (g × a) p(g + t)	723.27	11.13	22	677.32
10 S (g × a) p(t)	723.88	11.74	21	680.11

11	S (g × a) p(a × t)	736.42	24.27	43	642.83
12	S (g × a) p(g × t)	739.07	26.92	36	661.80
13	S (g × a) p([g + a] × t)	754.64	42.50	58	624.50
14	S (g × a) p(g × a × t)	756.85	44.71	64	611.44

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Table A2. Results of model selection for survival *S* of Montagu's harriers wing-tagged in Maine-et-Loire (ML) and Rochefort (RO) study areas. Same abbreviations were used as in Table A1.

Model	AICc	Delta AICc	k	Deviance
(a) Adult survival in ML				
1 S (g[aF]) p(f × g)	**2040.34**	**0.00**	**7**	**2026.23**
2 S (g[aF] + t) p(f × g)	2047.45	7.11	23	2000.29
3 S (g[aF] × t) p(f × g)	2060.16	19.82	38	1981.00
(b) Adult survival in RO				
1 S (t) p(.)	**850.50**	**0.00**	**18**	**812.91**
2 S (g + t) p(.)	852.33	1.83	19	812.55
3 S (.) p(.)	855.64	5.14	2	851.61
4 S (g) p(.)	859.45	8.95	4	851.36
5 S (g × t) p(.)	869.26	18.75	35	793.14
(c) Juvenile survival in RO				
1 S (a(1,2 3)) p(g + a)	**704.65**	**0.00**	**6**	**692.50**
2 S (a) p(g + a)	706.60	1.95	7	692.39
3 S (g + a(1,2 3)) p(g + a)	706.66	2.00	7	692.45
4 S (g + a) p(g + a)	708.60	3.95	8	692.33
5 S (g × a) p(g + a)	712.14	7.49	10	691.73
6 S (a(1) × t + a(2 3)) p(g + a)	715.61	10.96	17	680.45
7 S (g + a(1,2 3) + t) p(g + a)	726.43	21.77	21	682.66
8 S (g + a(1,2 3) × t) p(g + a)	740.83	36.17	45	642.50

Table A3. Results of model selection for age-specific survival of Montagu's harriers wing-tagged in Maine-et-Loire (ML) and Rochefort (RO) study areas. Same abbreviations were used as in Table A1. We tested for the effect of several environmental covariates: breeding success (BS), vole density (vole), Sahel rainfall (rain), mean NDVI (NDVI), and aridity index (aridity). Interactions between seasonal covariates were tested after transforming them as two-level factors (e.g. f.BS × f.rain, see Methods).

Model	AICc	Delta AICc	k	Deviance
(a) Effect of environmental covariate on adult survival in ML				
1 S (.)	**2040.34**	**0.00**	**7**	**2026.23**
2 S (aridity)	2042.62	2.28	9	2024.44
3 S (NDVI)	2043.61	3.26	9	2025.42
4 S (log NDVI)	2043.62	3.28	9	2025.43
5 S (log BS)	2043.96	3.62	9	2025.78
6 S (rain)	2044.06	3.72	9	2025.87
7 S (log rain)	2044.12	3.78	9	2025.93
8 S (BS)	2044.19	3.85	9	2026.01
9 S (BS + aridity)	2046.33	5.99	11	2024.06
10 S (BS + NDVI)	2047.41	7.06	11	2025.13
11 S (BS + log NDVI)	2047.43	7.08	11	2025.15
12 S (log BS + rain)	2047.70	7.35	11	2025.42
13 S (log BS + log rain)	2047.74	7.39	11	2025.46
14 S (BS + rain)	2047.92	7.58	11	2025.65
15 S (BS + log rain)	2047.97	7.63	11	2025.70
16 S (f.log BS × f.aridity)	2048.11	7.77	13	2021.74
(b) Effect of environmental covariate on adult survival in RO				
1 S (f.BS × f.log rain)	**843.90**	**0.00**	**5**	**833.76**
2 S (BS + log rain)	845.76	1.86	4	837.67
3 S (vole + log rain)	846.12	2.22	4	838.03
4 S (BS + rain)	847.90	4.00	4	839.80
5 S (log rain)	848.79	4.89	3	842.73

6 S (vole + rain)	849.17	5.27	4	841.08
7 S (t)	850.50	6.60	18	812.91
8 S (rain)	851.54	7.64	3	845.48
9 S (BS)	854.21	10.31	3	848.16
10 S (BS + aridity)	854.74	10.84	4	846.65
11 S (aridity)	855.23	11.33	3	849.18
12 S (log BS)	855.36	11.46	3	849.30
13 S (BS + log NDVI)	856.00	12.10	4	847.91
14 S (BS + NDVI)	856.12	12.22	4	848.03
15 S (vole)	856.29	12.39	3	850.23
16 S (log vole)	856.63	12.73	3	850.57
17 S (log NDVI)	857.06	13.16	3	851.01
18 S (vole + aridity)	857.11	13.21	4	849.02
19 S (NDVI)	857.24	13.34	3	851.19
20 S (vole + log NDVI)	858.25	14.35	4	850.16
21 S (vole + NDVI)	858.31	14.41	4	850.22
(c) Effect of environmental covariate on juvenile survival in RO				
1 S (BS + rain)	**704.23**	**0.00**	**8**	**687.97**
2 S (BS)	704.32	0.09	7	690.12
3 S (a(1,2 3))	704.65	0.42	6	692.50
4 S (BS + log rain)	704.73	0.50	8	688.46
5 S (log BS)	704.81	0.58	7	690.60
6 S (rain)	704.85	0.61	7	690.64
7 S (log rain)	705.79	1.55	7	691.58
9 S (vole)	706.27	2.03	7	692.06
10 S (log vole)	706.30	2.07	7	692.09
11 S (BS + NDVI)	706.35	2.12	8	690.08
12 S (BS + log NDVI)	706.36	2.13	8	690.10
13 S (BS + aridity)	706.37	2.13	8	690.10
14 S (aridity)	706.64	2.40	7	692.43
15 S (log NDVI)	706.69	2.46	7	692.48
16 S (NDVI)	706.70	2.47	7	692.49
17 S (vole + rain)	706.90	2.67	8	690.63
18 S (vole + log rain)	707.73	3.50	8	691.46
19 S (vole + aridity)	708.17	3.94	8	691.90

21	S (vole + log NDVI)	708.29	4.06	8	692.02
22	S (vole + NDVI)	708.30	4.07	8	692.03
23	S (f.BS × f.rain)	708.33	4.10	9	689.99
24	S (a(1).t + a(2 3))	715.61	11.38	17	680.45

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Figure A1. Comparative time-series of breeding numbers during the whole study period for Rochefort (RO in green; average = 24 ± 14, CV = 59%, study area of 190 km²) and Maine-et-Loire (ML in blue; 44 ± 9, CV = 21%, 250 km²). For RO, we found evidence for a negative temporal trend (linear model: β = 1.33 ± 0.63, P = 0.052) associated with reduced amplitude in vole cycles (Millon and Bretagnolle 2008), while harrier numbers remained constant in ML (β = 0.25 ± 0.47, P = 0.60).

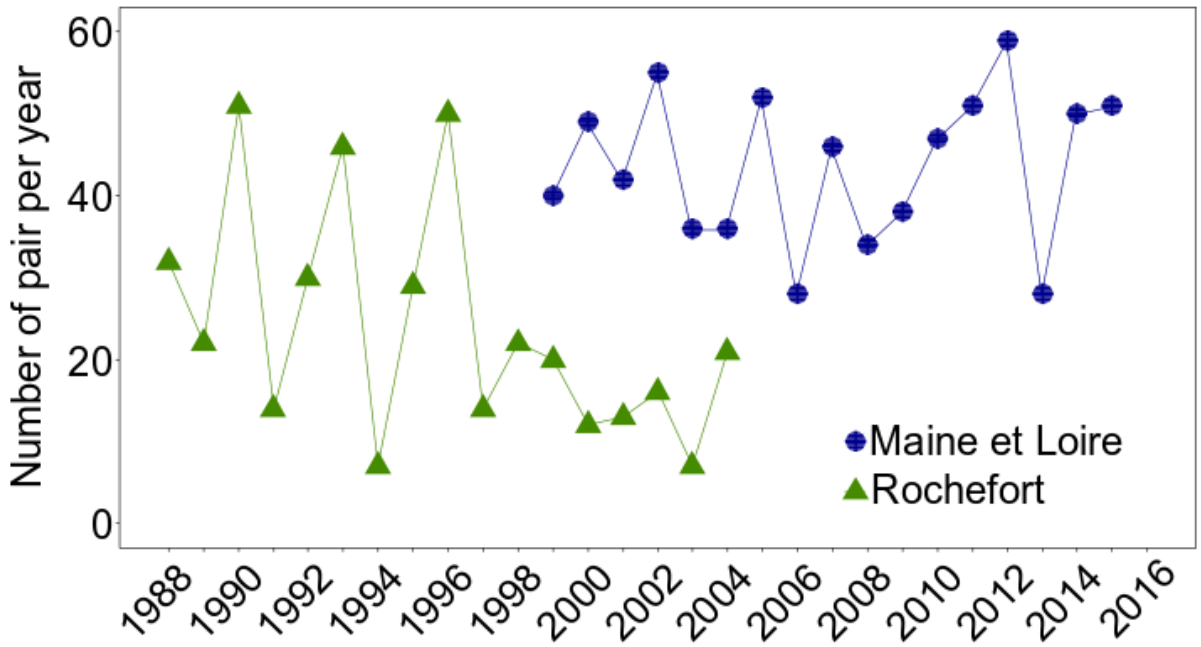


Figure A2. Wintering area of Montagu's harriers in the Western Sahel as defined by 196 wintering sites derived from 33 GPS-tracked birds breeding in Western Europe and tracked between 2009 and 2015 (see Schlaich *et al.* 2016 for details on GPS surveys).

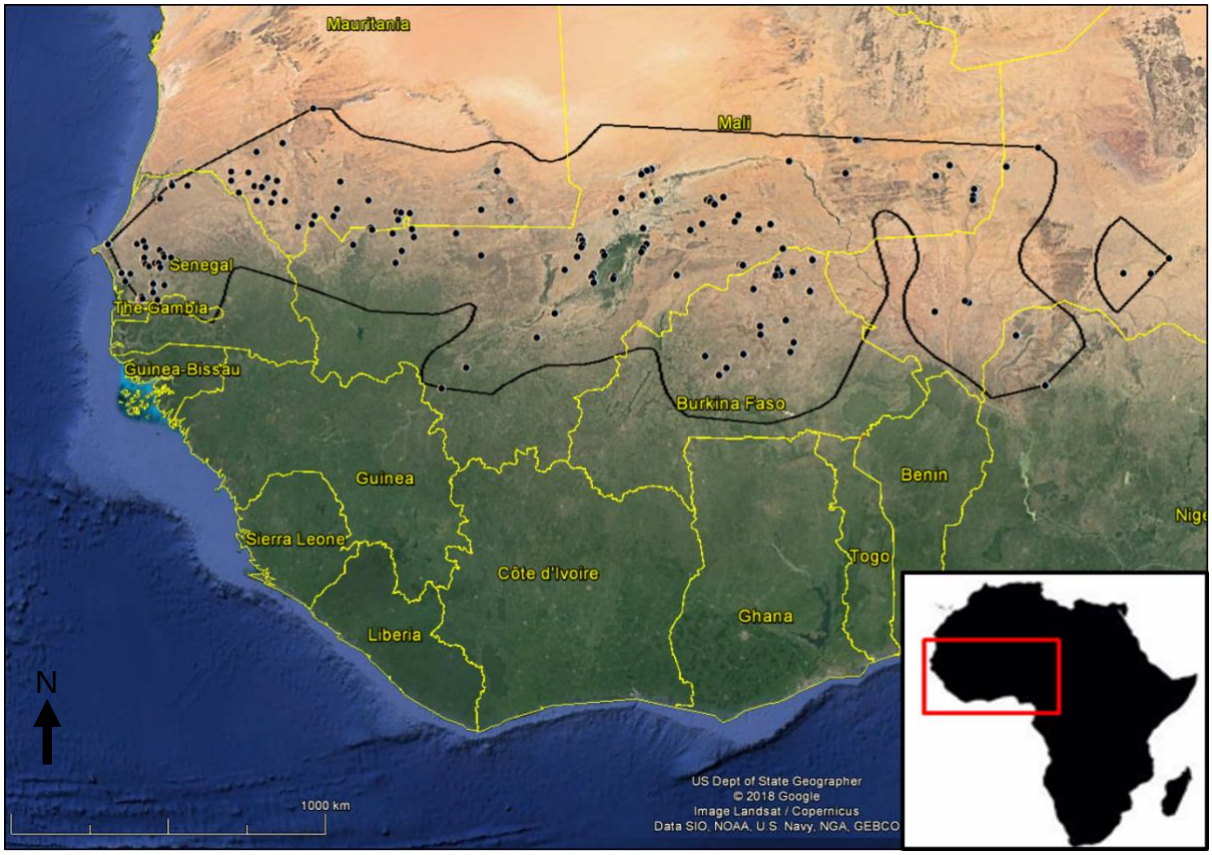
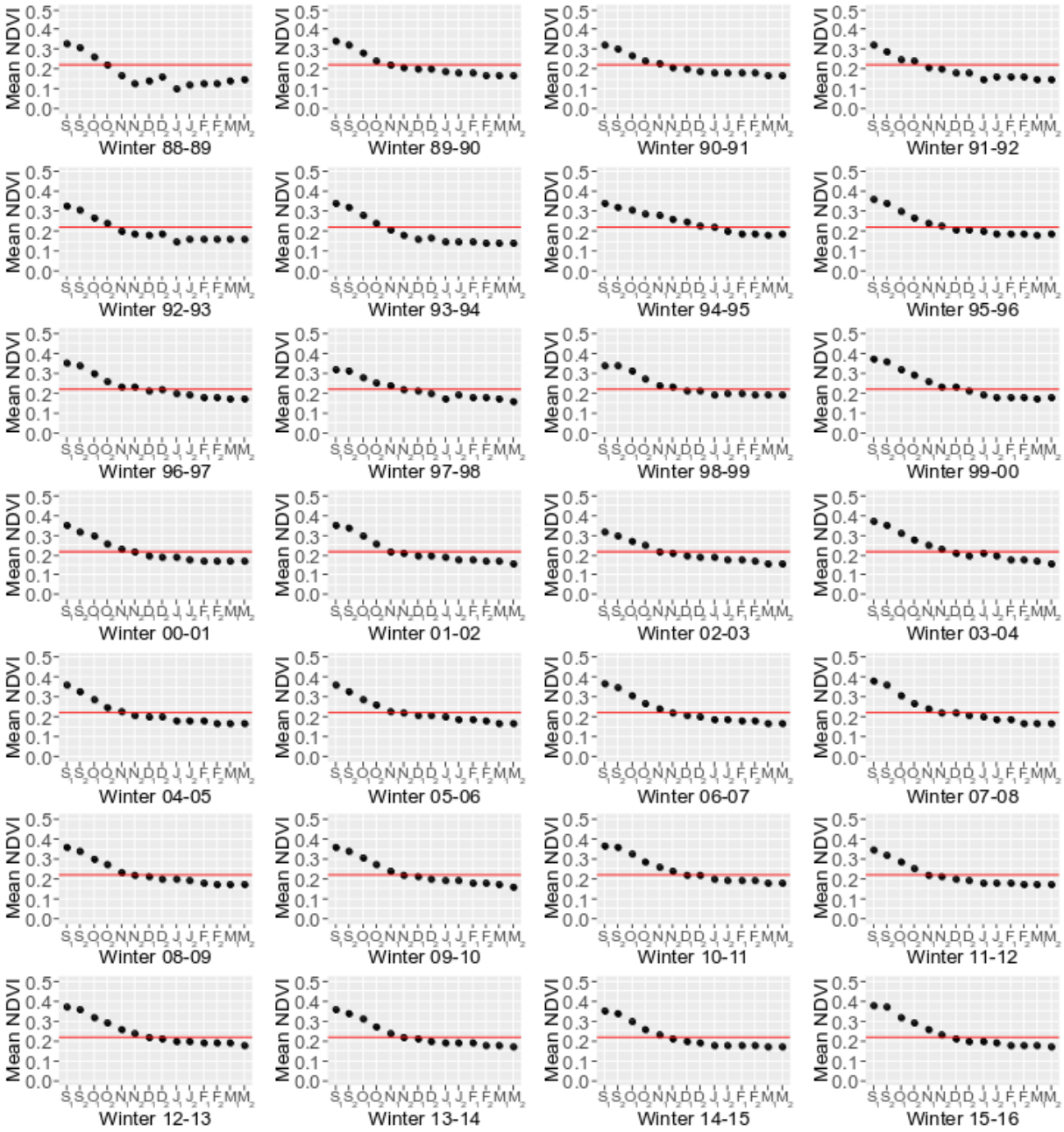


Figure A3. Temporal variation of mean NDVI over winter for each year of the study period. On the x-axis, letters represent months from September to March with two values per month. The red line represents the threshold of NDVI below which wintering conditions are considered rougher for Montagu's harriers. The derived aridity index represents the area below this line (see Methods).



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