Evaluating the influence of diet-related variables on breeding performance and home range behaviour of a top predator

Population Ecology

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ELECTRONIC SUPPLEMENTARY MATERIAL (ESM)

A. Literature review of studies published in international scientific journals reporting factors influencing breeding success and home range behaviour in birds of prey

Methodology

We searched for scientific articles using the databases: Zoological Record (thomsonreuters.com/zoological-record); Scopus (www.scopus.com); Google Scholar (scholar.google.com); JSTOR (www.jstor.org); SORA (sora.unm.edu). We used several combinations of the following search terms: breeding; reproduction; reproductive; success; output; performance; home range; movement; radio-tracking; telemetry; raptors; birds of prey; owls; eagle; kite; kestrel; vulture; buzzard; hawk; harrier; falcon. In addition, we inspected the references of each article analysed to gather other relevant studies. Since the number of results in each search was often very large (generally > 1000 results) we limited our database to the first 250 scientific articles we could access (see references below). In each study we verified: (1) the group of parameters (breeding performance; home range behaviour; or both); (2) the effects tested (see Table S1 for the list of the most common effects); (3) the number of effects considered; (4) the diet-related variables used; (5) the home range parameters analysed.

Results

Most articles only studied one species (92 %; $n = 231$), while the remaining included between 2 and 4 species. We included 79 articles focusing owl species only (32 %), 166 focusing on diurnal raptors only (66 %), and 5 focusing species from both groups (2 %). This review covered 49 species (15 owl species and 34 diurnal raptor species). Each species was included in 1 to 21 studies (mean $\pm$ SD = 5.8 ± 5.6).

We found disproportionally more articles analysing the effects on breeding performance only (86 %; $n = 215$) than analysing the effects on home range behaviour only (12 %; $n = 30$), while just 5 studies (2 %) analysed jointly the effects on breeding performance and home range behaviour. The mean number of radio-

tracked individuals in the studies of home range behaviour was 19.7 ± 20.9 (SD; range: 3–95 individuals; $n = 33$ studies), with 85 % of these studies ($n = 28$) having less than 25 radio-tracked individuals.

When analysing breeding performance parameters (Table S1), the most frequently tested effects were: habitat and nest characteristics (39 %); prey abundance (36 %); and weather (29 %). On the other hand, when analysing home range behaviour parameters, the most frequently tested effects were: habitat and nest characteristics (60 %); individual characteristics (54 %); prey abundance (37 %); and breeding phenology (37 %). Only seldom these studies analysed the potential relationships between diet and breeding performance (13 %) and home range behaviour (3 %).

From the 30 studies analysing the effects of diet-related variables on breeding performance or home range behaviour parameters (Table S2), we found that the most used variables are the numeric or biomass contribution of the main prey groups to the diet (generally expressed as a percentage from the total of prey items or total biomass estimated). The Shannon index has been commonly used as a measure of diet diversity. The remaining diet-related parameters have been less frequently used. Within our review, we found 25 other studies that collected diet-related variables but only used them to search for relationships with other parameters than breeding or home range behaviour, most commonly prey abundance.

Table S1 Percentage of studies analysing each effect on breeding performance and home range behaviour parameters ($n = 250$ studies).

Effects	Breeding performance ($n = 220$)	Home range behaviour ($n = 35$)
Diet	13.2 % (29)	2.9 % (1)
Prey abundance	36.4 % (80)	37.1 % (13)
Individual characteristics (e.g., age, sex, internal state)	20.6 % (46)	54.3 % (19)
Home range behaviour	1.8 % (4)	NA
Habitat and nest characteristics	39.1 % (86)	60.0 % (21)
Weather	28.6 % (63)	2.9 % (1)
Intra-specific competition (including density-dependent effects)	14.5 % (32)	5.7 % (2)
Inter-specific interactions (e.g., competition, predation)	8.6 % (19)	0
Breeding phenology	NA	37.1 % (13)
Mean number of effects tested in each study $\pm$ SD (range)	1.8 ± 1.1 (1–6)	2.1 ± 0.9 (1–5)

Table S2 Use of diet-related variables in 30 studies analysing their effects on breeding performance and home range behaviour.

Diet-related variables	Frequency (%) (number of studies)
Percentage or proportion of prey groups in diet (either numeric or biomass contribution)	83.3 % (25)
Diet diversity (Shannon index)	23.3 % (7)
Diet breadth (Levins index)	16.7 % (5)
Prey species richness	10.0 % (3)
Mean weight of main prey species (or categorical variable relating to prey size)	20.0 % (6)
Food provisioning rate	3.3 % (1)

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B. Procedures used to estimate prey weight

Table S3 Procedures used to estimate prey weight in the diet of eagle owls in Seville (SW Spain).

Prey species or group	Reference weight value or calculation method	Source
Rabbit <i>Oryctolagus cuniculus</i>	$\log(\text{weight}) = 1.411 + 0.028 \times \text{humerus length}$ $\log(\text{weight}) = 1.441 + 0.021 \times \text{femur length}$ $\log(\text{weight}) = 1.407 + 0.019 \times \text{tibia length}$	Donázar and Ceballos 1989
Iberian hare <i>Lepus granatensis</i>	$\ln(\text{weight}) = 3.5689 + 0.0348 \times \text{tibia length}$ $\ln(\text{weight}) = 3.5967 + 0.0386 \times \text{femur length}$	Batista and Almeida 1996; R. Lourenço, unpublished data
Rats <i>Rattus</i> spp.	$\log(\text{weight}) = 4.7170 \times \log(\text{jaw length}) - 4.2923$	Morris 1979
Bird species	Mean weight value	Cramp and Simmons 1977-1994
Unidentified passerines	$\ln(\text{weight}) = -3.8027 + 2.4221 \times \text{humerus length}$	Morris and Burgis 1988
Mammal species	Mean weight value	MacDonald and Barret 1993
Amphibians, reptiles, fish, and invertebrates	Mean weight value based on field measurement of individuals	R. Lourenço, unpublished data

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C. Eagle owl diet in the study area

Table S4 Biomass percentage of main prey groups in the diet of eagle owls in Seville (SW Spain).

Breeding site	Rats <i>Rattus</i> spp.	Rabbit <i>Oryctolagus cuniculus</i>	Hare <i>Lepus granatensis</i>	Red-legged partridge <i>Alectoris rufa</i>	Pigeons (Columbiformes)	Passerines (Passeriformes)	Prey sample size
1	6.0	77.8	0.0	9.9	2.3	0.4	142
2	4.8	72.9	5.3	8.7	2.5	0.4	113
3	7.5	24.8	15.8	7.9	17.6	1.8	78
4	16.6	45.7	4.7	4.5	11.2	0.4	128
5	26.5	56.3	2.1	3.0	3.7	0.3	114
6	3.4	60.5	27.5	4.7	0.0	0.5	67
7	9.5	61.7	16.9	5.8	2.5	0.0	58
8	14.0	43.2	19.6	15.7	1.7	0.2	103
9	6.2	81.1	2.1	7.4	0.3	0.3	228
10	3.3	93.7	0.0	1.5	0.0	0.4	71
11	9.7	75.1	2.7	8.2	1.4	0.2	204
12	2.8	67.7	2.5	19.9	3.3	0.8	137
13	5.8	59.2	9.8	23.1	0.0	0.3	180
14	5.6	75.0	5.8	12.5	0.0	0.0	47
15	7.7	50.5	17.4	9.1	1.6	0.8	239
16	2.2	77.7	9.3	7.6	0.0	0.7	146
17	7.3	68.8	4.1	9.6	3.8	0.4	146
18	3.7	54.7	1.5	6.6	12.5	2.3	123
19	6.5	70.2	4.7	11.6	2.3	0.5	111
20	9.9	61.6	6.7	11.1	4.2	0.4	180
21	3.3	82.3	0.0	7.4	0.9	0.3	160
22	4.2	65.3	6.8	6.4	5.4	2.3	165
23	14.8	73.3	0.0	5.2	0.6	0.3	122
24	3.7	68.6	7.8	12.7	0.0	1.1	182
25	7.1	79.0	0.0	10.4	0.0	0.0	94
26	5.3	75.7	3.7	6.6	0.8	0.6	235

D. Detailed results from statistical analysis – multi-model inference procedure

Table S5 Set of best models ($\Delta AIC_c < 2.00$) analysing the effects on mean breeding success.

Variables in the model	df	log-likelihood	AIC _c	ΔAIC_c	Akaike weight
Superpredation	3	-18.74	44.58	0.00	0.16
Diet diversity	3	-19.11	45.31	0.73	0.11
Null model	2	-20.51	45.54	0.96	0.10
Superpredation + rabbit biomass	4	-18.00	45.91	1.33	0.08
Superpredation + rat biomass	4	-18.14	46.18	1.61	0.07

Table S6 Model averaging results for the analysis of the effects on mean breeding success.

	Model-averaged coefficient	SE	z	P	Relative variable importance
Intercept	2.79	0.71	3.82	<0.001	--
Superpredation	-2.71	1.56	1.65	0.10	0.43
Diet diversity	-1.50	1.09	1.32	0.19	0.30
Rabbit biomass	0.76	0.69	1.06	0.29	0.23
Rat biomass	-0.53	0.84	0.60	0.55	0.17
Rabbit mean weight	-0.001	0.001	0.58	0.56	0.155
Mean weight of alternative prey	-0.00001	0.002	0.005	1.00	0.12

Table S7 Set of best models ($\Delta AIC_c < 2.00$) analysing the effects on the coefficient of variation of breeding success.

Variables in the model	df	log-likelihood	AIC _c	ΔAIC_c	Akaike weight
Rat biomass	3	6.40	-5.71	0.00	0.14
Rabbit biomass + rabbit mean weight	4	7.63	-5.35	0.36	0.12
Null model	2	4.76	-4.99	0.72	0.10
Rat biomass + rabbit mean weight	4	7.44	-4.97	0.75	0.10
Rat biomass + diet diversity	4	7.19	-4.47	1.24	0.08
Rat biomass + superpredation	4	7.10	-4.29	1.42	0.07
Rabbit biomass	3	5.54	-3.99	1.72	0.06
Rat biomass + mean weight of alternative prey	4	6.91	-3.92	1.80	0.05

Table S8 Model averaging results for the analysis of the effects on the coefficient of variation of breeding success.

	Model-averaged coefficient	SE	z	P	Relative variable importance
Intercept	0.21	0.28	0.70	0.48	--
Rat biomass	0.53	0.28	1.80	0.07	0.49
Rabbit mean weight	0.001	0.001	1.28	0.20	0.29
Rabbit biomass	-0.40	0.32	1.20	0.23	0.26
Diet diversity	0.30	0.43	0.66	0.51	0.15
Superpredation	0.41	0.65	0.61	0.54	0.14
Mean weight of alternative prey	0.0003	0.001	0.56	0.57	0.13

Table S9 Set of best models ($\Delta AIC_c < 2.00$) analysing the effects on mean laying date.

Variables in the model	df	log-likelihood	AIC _c	ΔAIC_c	Akaike weight
Rabbit mean weight	3	-46.88	100.85	0.00	0.15
Rabbit mean weight + rat biomass	4	-45.93	101.76	0.91	0.10
Rat biomass	3	-47.36	101.82	0.97	0.09
Rabbit mean weight + diet diversity	4	-46.09	102.08	1.23	0.08
Null model	2	-48.82	102.17	1.32	0.08
Rabbit mean weight + superpredation	4	-46.13	102.17	1.32	0.08

Table S10 Model averaging results for the analysis of the effects on mean laying date.

	Model-averaged coefficient	SE	z	P	Relative variable importance
Intercept	3.80	2.49	1.49	0.14	--
Rabbit mean weight	0.006	0.003	1.76	0.08	0.48
Rat biomass	-3.18	2.19	1.38	0.17	0.30
Superpredation	5.22	4.60	1.08	0.28	0.22
Diet diversity	2.71	3.17	0.82	0.42	0.18
Rabbit biomass	1.38	2.23	0.59	0.55	0.16
Mean weight of alternative prey	-0.002	0.005	0.41	0.68	0.13

Table S11 Set of best models ($\Delta AIC_c < 2.00$) analysing the effects on mean nightly total distance.

Variables in the model	df	log-likelihood	AIC _c	ΔAIC_c	Akaike weight
Edge density + age	4	-227.65	465.21	0.00	0.42

Table S12 Model averaging results for the analysis of the effects on mean nightly total distance.

	Model-averaged coefficient	SE	z	P	Relative variable importance
Intercept	8705.47	2781.23	3.07	0.002	--
Age (older:younger)	2046.48	763.10	2.54	0.01	0.70
Edge density	-19.49	7.68	2.41	0.02	0.62
Dense scrubland	2116.86	1387.42	1.45	0.15	0.12
Rabbit mean weight	4.71	4.39	1.03	0.30	0.07
Sex (female:male)	774.72	789.23	0.93	0.35	0.06
Haematocrit	52.33	52.05	0.96	0.34	0.06
Diet diversity	2625.73	3615.56	0.69	0.49	0.04
Proportion juvenile rabbits	-1212.00	3465.11	0.34	0.74	0.04
Rat biomass	-2699.07	5152.55	0.50	0.62	0.04
Superpredation	1157.23	6324.23	0.18	0.86	0.04
Rabbit biomass	-152.14	2801.79	0.05	0.96	0.04
Mean weight of alternative prey	-1.91	5.17	0.35	0.73	0.04

Table S13 Set of best models ($\Delta AIC_c < 2.00$) analysing the effects on mean nightly home range.

Variables in the model	<i>df</i>	log-likelihood	AIC_c	ΔAIC_c	Akaike weight
Edge density + age	4	1.93	6.05	0.00	0.32
Edge density + mean weight of alternative prey	4	1.70	6.50	0.44	0.26

Table S14 Model averaging results for the analysis of the effects on mean nightly home range.

	Model-averaged coefficient	SE	<i>z</i>	<i>P</i>	Relative variable importance
Intercept	2.96	0.38	7.48	<0.001	--
Edge density	-0.004	0.001	3.67	<0.001	0.97
Age (older:younger)	0.23	0.10	2.11	0.03	0.33
Mean weight of alternative prey	0.001	0.001	2.00	0.045	0.27
Rabbit biomass	-0.49	0.50	0.96	0.34	0.05
Sex (female:male)	-0.11	0.11	0.95	0.34	0.05
Rat biomass	-0.72	0.86	0.81	0.42	0.04
Rabbit mean weight	0.0003	0.001	0.63	0.53	0.04
Haematocrit	-0.004	0.007	0.52	0.60	0.03
Superpredation	-0.44	0.92	0.46	0.65	0.03
Dense scrubland	0.05	0.20	0.23	0.82	0.03
Proportion of juvenile rabbits	0.07	0.51	0.14	0.89	0.03
Diet diversity	0.07	0.54	0.13	0.90	0.03

Table S15 Set of best models ($\Delta AIC_c < 2.00$) analysing the effects on mean step length.

Variables in the model	<i>df</i>	log-likelihood	AIC_c	ΔAIC_c	Akaike weight
Edge density	3	-152.57	312.24	0.00	0.15
Edge density + rabbit mean weight	4	-151.52	312.95	0.71	0.11
Edge density + rat biomass	4	-151.57	313.05	0.81	0.10
Edge density + dense scrubland	4	-151.91	313.73	1.50	0.07
Edge density + proportion of juvenile rabbits	4	-152.10	314.10	1.86	0.06
Edge density + age	4	-152.10	314.11	1.87	0.06

Table S16 Model averaging results for the analysis of the effects on mean step length.

	Model-averaged coefficient	SE	z	P	Relative variable importance
Intercept	596.51	149.97	3.88	<0.001	--
Edge density	-1.15	0.41	2.67	0.008	0.83
Rat biomass	-303.50	244.94	1.18	0.24	0.13
Rabbit mean weight	0.23	0.19	1.14	0.26	0.13
Dense scrubland	87.09	71.27	1.16	0.25	0.12
Age (older:younger)	37.89	41.42	0.87	0.39	0.09
Proportion of juvenile rabbits	-82.08	172.56	0.46	0.65	0.08
Diet diversity	147.87	184.45	0.76	0.46	0.08
Superpredation	135.32	309.51	0.42	0.68	0.07
Rabbit biomass	28.79	153.26	0.18	0.86	0.07
Sex (female:male)	-20.67	39.75	0.49	0.62	0.06
Mean weight of alternative prey	0.04	0.25	0.14	0.89	0.06
Haematocrit	0.36	2.59	0.13	0.90	0.06

Table S17 Set of best models ($\Delta AIC_c < 2.00$) analysing the effects on mean movement speed.

Variables in the model	df	log-likelihood	AIC _c	ΔAIC_c	Akaike weight
Sex + diet diversity	4	-97.97	205.85	0.00	0.09
Sex	3	-100.05	207.19	1.35	0.05
Sex + rabbit biomass	4	-98.79	207.48	1.63	0.04
Rabbit biomass	3	-100.24	207.58	1.73	0.04
Sex + edge density	4	-98.84	207.58	1.74	0.04
Sex + age	4	-98.97	207.84	2.00	0.03

Table S18 Model averaging results for the analysis of the effects on mean movement speed.

	Model-averaged coefficient	SE	z	P	Relative variable importance
Intercept	34.56	20.48	1.65	0.10	--
Sex (female:male)	-9.39	4.91	1.81	0.07	0.36
Diet diversity	36.67	22.91	1.52	0.13	0.24
Rabbit biomass	-24.58	15.92	1.47	0.14	0.20
Age (older:younger)	7.91	5.30	1.42	0.16	0.19
Edge density	-0.08	0.05	1.35	0.18	0.17
Rat biomass	30.83	34.14	0.86	0.39	0.10
Haematocrit	0.28	0.33	0.79	0.43	0.09
Superpredation	9.41	45.67	0.20	0.84	0.08
Rabbit mean weight	0.01	0.03	0.37	0.71	0.07
Proportion of juvenile rabbits	5.31	19.84	0.26	0.80	0.07
Mean weight of alternative prey	0.01	0.04	0.20	0.84	0.07
Dense scrubland	0.76	9.58	0.08	0.94	0.07