

ESM to: “Feather corticosterone and stable isotopes explain fledging and adult breeding success in a burrow-nesting seabird, the Yelkouan shearwater *Puffinus yelkouan*”.

Electronic supplementary material to:

“Feather corticosterone and stable isotopes explain fledging and adult breeding success in a burrow-nesting seabird, the Yelkouan shearwater *Puffinus yelkouan*”.

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All data and R code are available at <https://doi.org/10.5281/zenodo.17219417>

Each table and figure are referred to in the manuscript text.

Fledgling biometrics

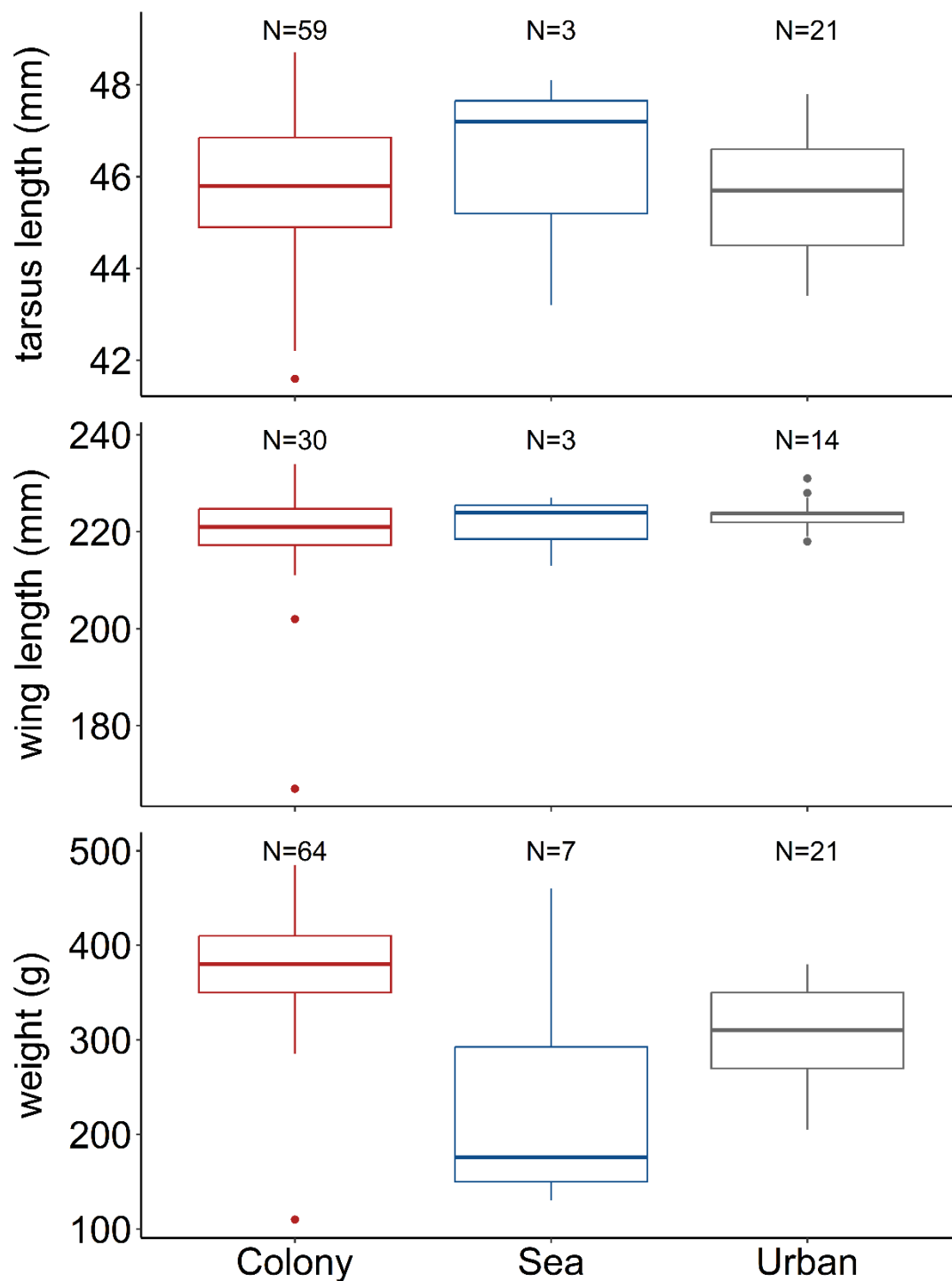


Figure S1. Tarsus length, wing length and weight of Yelkouan shearwater chicks at colonies and those with failed fledging, which were either found at sea unable to fly or grounded on land in urban areas. Sample size (N) is denoted per group and measurement above each box plot. The central mid-line in each boxplot corresponds to the median, the lower and upper horizontal lines to the first and third quartiles and the vertical whiskers extend to the values at 1.5 of the inter-quartile range.

Chick growth

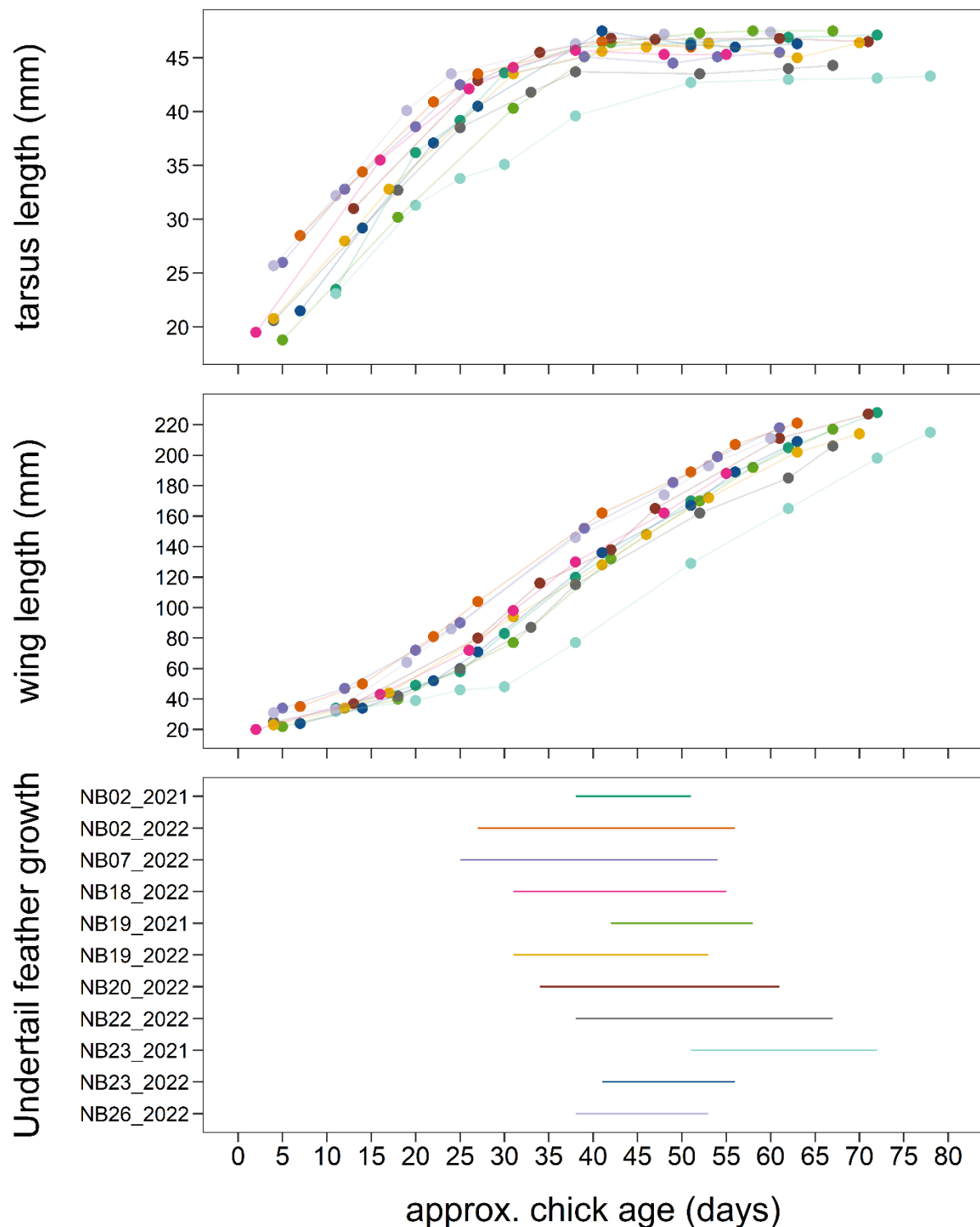


Figure S2. Tarsus and wing length in 11 nestlings measured regularly between hatching and fledging in 2021 and 2022 at Rdum tal-Madonna (RM) colony nest boxes. Undertail feather growth denotes the age when these feathers emerged in pin to when growth was complete per individual.

Plate distribution of corticosterone measurements

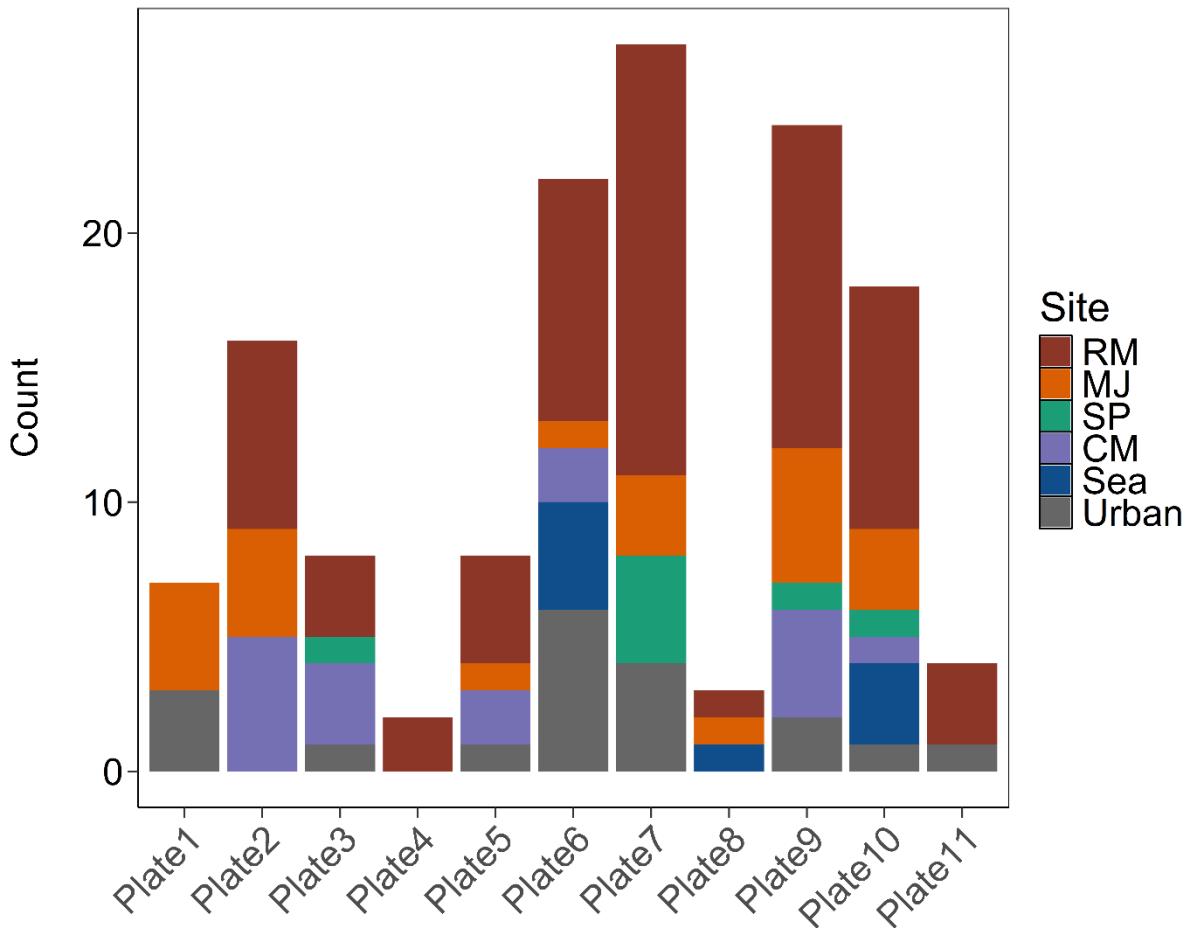


Figure S3. Distribution of corticosterone measurements in Yelkouan shearwater chick feathers sampled at different sites, across 11 plates (ELISA kit (ADI-901-097, Enzo Life Sciences Inc., New York, USA).

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Sample sizes for measurements of CORT, stable isotopes and Hg

Table S1. Number of successful measurements of CORT_f, bulk stable isotopes and Hg in Yelkouan shearwater nestlings and fledglings per colony or site of rescue (at sea or urban areas) and year (Y20: 2020, Y21: 2021, Y22: 2022).

	Rdum tal-Madonna (RM)			Comino & Cominotto (CM)			St Paul's Islands (SP)			Čumnija & Majjistral (MJ)			Sea			Urban		
	Y20	Y21	Y22	Y20	Y21	Y22	Y20	Y21	Y22	Y20	Y21	Y22	Y20	Y21	Y22	Y20	Y21	Y22
CORT _f	21	21	24	7	5	5	0	5	2	10	4	8	0	5	3	7	8	4
δ ¹⁵ N & δ ¹³ C	20	24	25	6	5	5	0	7	2	9	4	10	0	5	4	5	10	4
CORT _f , δ ¹⁵ N & δ ¹³ C	13	20	24	6	5	5	0	5	2	7	3	8	0	5	3	5	8	4
Hg	0	0	25	0	0	5	0	0	2	0	0	10	0	0	4	0	0	4
CORT _f & Hg	0	0	24	0	0	5	0	0	2	0	0	8	0	0	3	0	0	4
δ ¹⁵ N & Hg	0	0	25	0	0	5	0	0	2	0	0	10	0	0	4	0	0	4

All model outputs related to CORT, stable isotopes and Hg

Table S2: All Generalised linear mixed models (GLMMs) and generalised linear models (GLM) used to test relationships between stable isotope values of nitrogen ($\delta^{15}\text{N}$) and carbon ($\delta^{13}\text{C}$), log transformed feather corticosterone (CORT_f), and Hg in Yelkouan shearwater chicks at different colonies (RM, CM, SP, MJ) or rescued at sea or in urban areas on failed fledging, as well as and daily survival rate (DSR) estimates at colony level as an indicator of adult breeding success. Resulting parameter estimates $\pm$ their standard error, p-values, lower and upper 95% confidence intervals are shown for fixed effects, while variance and standard deviation are shown for random effects. We present the sample size of the dependent variable for each model denoted by N as well as the residual degrees of freedom (df.resid), while the number of asterix behind N denote the number of significant outliers which were removed. Unless otherwise stated all GLMMs and GLMs were fit with a Gaussian family.

Dependent Variable	Fixed Effect	Parameter estimate	Sd Error	P-value	Lower 95%CI	Upper 95%CI	Random Effect	Variance	Standard Deviation
$\delta^{15}\text{N}$ <i>N=142***</i> <i>df.resid=138</i>	(Intercept)	19.0643	1.5784	<0.0001	15.9706	22.1580			
	$\delta^{13}\text{C}$	0.4677	0.0855	<0.0001	0.3002	0.6352			
							Year	0.0032	0.0564
							Residual	0.2162	0.4650
$\log(\text{CORT}_f)$ <i>N=123</i> <i>df.resid=116</i> <i>Gamma (log)</i>	(Intercept)	-1.0362	1.4583	0.4774	-3.8944	1.8221			
	$\delta^{15}\text{N}$	-0.1269	0.0502	0.0115	-0.2253	-0.0285			
	$\delta^{13}\text{C}$	-0.1472	0.0659	0.0256	-0.2764	-0.0180			
	Feather Growth	-0.0757	0.0764	0.3216	-0.2253	0.0740			
							Year	<0.0001	<0.0001
							Plate ID	0.0041	0.0640
							Residual	<0.0001	<0.0001

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Hg	(Intercept)	5.9827	3.1556	0.0641	-0.2022	12.1676			
<i>N=50</i>	$\delta^{15}\text{N}$	0.4285	0.1331	0.0023	0.1677	0.6894			
<i>df.resid=47</i>	$\delta^{13}\text{C}$	0.4869	0.1342	0.0007	0.2239	0.7498			
log(CORT _f)	(Intercept)	0.0711	2.3932	0.9763	-4.6195	4.7617			
<i>N=46</i>	Hg	-0.0626	0.1173	0.5936	-0.2926	0.1674			
<i>df.resid=39</i>	$\delta^{15}\text{N}$	-0.1866	0.1134	0.1000	-0.4089	0.0357			
<i>Gamma (log)</i>	$\delta^{13}\text{C}$	-0.1268	0.1145	0.2684	-0.3513	0.0977			
	Feather Growth	-0.1673	0.1070	0.1180	-0.3770	0.0425			
							Plate ID	0.0161	0.1270
							Residual	<0.0001	<0.0001
Site effects; all estimates in reference to RM									
$\delta^{15}\text{N}$	(Intercept)	17.0182	1.5926	<0.0001	13.8968	20.1396			
<i>N=143***</i>	$\delta^{13}\text{C}$	0.3484	0.0866	0.0001	0.1786	0.5182			
<i>df.resid=133</i>	MJ	-0.4698	0.1127	<0.0001	-0.6907	-0.2489			
	SP	-0.0819	0.1573	0.6028	-0.3902	0.2264			
	CM	-0.1314	0.1193	0.2708	-0.3652	0.1024			
	Sea	-0.2751	0.1603	0.0860	-0.5892	0.0390			
	Urban	-0.3734	0.1141	0.0011	-0.5971	-0.1498			
							Year	0.0067	0.0820
							Residual	0.1836	0.4284
log(CORT _f)	(Intercept)	0.5750	1.8529	0.7563	-3.0566	4.2065			
<i>N=123</i>	$\delta^{15}\text{N}$	-0.1339	0.0661	0.0430	-0.2635	-0.0042			
<i>df.resid=111</i>	$\delta^{13}\text{C}$	-0.1181	0.0861	0.1701	-0.2869	0.0506			
	Feather Growth	-0.0415	0.1044	0.6908	-0.2462	0.1631			
	MJ	0.0695	0.1212	0.5662	-0.1681	0.3072			
	SP	-0.1487	0.1632	0.3623	-0.4685	0.1711			
	CM	-0.1700	0.1143	0.1368	-0.3939	0.0540			

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	Sea	0.7608	0.1634	<0.0001	0.4406	1.0810		
	Urban	0.2178	0.1171	0.0628	-0.0117	0.4473		
							Year	<0.0001
							Plate ID	0.0004
							Residual	0.1554
Hg	(Intercept)	5.8743	3.1639	0.0704	-0.3269	12.0755		
<i>N=50</i>	$\delta^{15}\text{N}$	0.2960	0.1420	0.0432	0.0177	0.5744		
<i>df.resid=42</i>	$\delta^{13}\text{C}$	0.4019	0.1422	0.0072	0.1231	0.6806		
	MJ	-0.3181	0.1798	0.0842	-0.6705	0.0344		
	SP	-0.0348	0.3015	0.9088	-0.6256	0.5561		
	CM	0.0415	0.2004	0.8369	-0.3513	0.4343		
	Sea	-0.1441	0.2270	0.5290	-0.5891	0.3009		
	Urban	-0.5386	0.2261	0.0218	-0.9818	-0.0954		
log(CORT _f)	(Intercept)	0.7536	2.3026	0.7434	-3.7594	5.2667		
<i>N=46</i>	Hg	-0.0425	0.1354	0.7538	-0.3079	0.2229		
<i>df.resid=34</i>	$\delta^{15}\text{N}$	-0.1927	0.1226	0.1159	-0.4329	0.0475		
<i>Gamma (log)</i>	$\delta^{13}\text{C}$	-0.0908	0.1175	0.4394	-0.3211	0.1394		
	Feather Growth	-0.1734	0.1162	0.1358	-0.4012	0.0544		
	MJ	-0.1176	0.1486	0.4286	-0.4089	0.1736		
	SP	-0.1337	0.2041	0.5123	-0.5337	0.2663		
	CM	0.0884	0.1418	0.5331	-0.1895	0.3662		
	Sea	0.3583	0.1760	0.0418	0.0132	0.7033		
	Urban	-0.0230	0.1712	0.8930	-0.3586	0.3125		
							Plate ID	0.0136
							Residual	<0.0001
Tests on proportionally different $\delta^{15}\text{N}$ and CORT _f in failed fledglings; estimates in reference to chicks at colonies								
$\delta^{15}\text{N}$	(Intercept)	21.9171	1.9776	0.0000	18.0410	25.7932		
<i>N=79**</i>	$\delta^{13}\text{C}$	0.6203	0.1078	<0.0001	0.4090	0.8316		
<i>df.resid=73</i>	Sea	-0.0528	0.1659	0.7503	-0.3781	0.2724		
	Urban	-0.2620	0.1128	0.0203	-0.4832	-0.0408		

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							Year	0.0039	0.0626
							Residual	0.1632	0.4039
log(CORT _f)	(Intercept)	1.2975	0.0775	<0.0001	1.1456	1.4495			
N=81	Sea	0.9054	0.1688	<0.0001	0.5747	1.2362			
df.resid=75	Urban	0.3512	0.1165	0.0026	0.1228	0.5796			
							Year	<0.0001	<0.0001
							Plate ID	0.0247	0.1570
							Residual	0.1624	0.4030
Daily nest survival rates, estimates per colony									
scaled(DSR)	(Intercept)	0.5511	0.4018	0.1702	-0.2364	1.3386			
N=12	MJ	-1.5518	0.1448	0.0000	-1.8357	-1.2680			
df.resid=6	SP	0.0757	0.1448	0.6012	-0.2082	0.3596			
	CM	-0.7283	0.1448	<0.0001	-1.0122	-0.4445			
							Year	0.4528	0.6729
							Residual	0.0315	0.1774
scaled(DSR)	(Intercept)	1.3241	0.6291	0.0353	0.0910	2.5572			
N=10	Mean CORT _f	-0.3186	0.0775	<0.0001	-0.4704	-0.1668			
df.resid=5							Colony	0.4118	0.6417
							Year	0.5932	0.7702
							Residual	0.0101	0.1003
scaled(DSR)	(Intercept)	-10.5080	1.4057	<0.0001	13.2632	-7.7528			
N=10	Mean $\delta^{15}\text{N}$	1.0119	0.1287	<0.0001	0.7597	1.2641			
df.resid=5							Colony	0.1656	0.4070
							Year	0.3738	0.6114
							Residual	0.0029	0.0542
scaled(DSR)	(Intercept)	40.2165	27.2518	0.1400	13.1960	93.6291			
N=10	Mean $\delta^{13}\text{C}$	2.1825	1.4799	0.1403	-0.7181	5.0831			
df.resid=5							Colony	0.1167	0.3416

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Year	0.8362	0.9145
Residual	0.0610	0.2471

GLMMS were fit using in 'glmmTMB' package (Brooks et al. 2017), while residual diagnostics, dispersion and outliers were checked with the 'DHARMA' package (Hartig 2022).

Apparent breeding success and daily survival rates

Table S3. Apparent adult breeding success and nest daily survival rate (DSR) estimates of Yelkouan shearwaters per colony and year, based on the number of nests (N) monitored with at least three visits and chicks reaching four weeks of age. Variations in the sample size are due to constraints on making the minimum of three visits required imposed by sea and access conditions in reaching various sub-colonies.

Colony	Year	N	breeding	DSR			
			success (%)	estimate	DSR se	DSR lcl	DSR ucl
CM	2020	12	75.00	0.9945	0.0018	0.9895	0.9972
CM	2021	8	50.00	0.9908	0.0030	0.9824	0.9952
CM	2022	7	42.86	0.9939	0.0021	0.9879	0.9969
MJ	2020	43	55.81	0.9931	0.0013	0.9899	0.9953
MJ	2021	16	31.25	0.9883	0.0026	0.9819	0.9925
MJ	2022	33	63.64	0.9922	0.0017	0.9881	0.9950
RM	2020	40	75.00	0.9958	0.0009	0.9936	0.9973
RM	2021	39	53.85	0.9930	0.0014	0.9897	0.9952
RM	2022	37	67.57	0.9953	0.0010	0.9928	0.9970
SP	2020	8	50.00	0.9960	0.0015	0.9915	0.9981
SP	2021	9	55.56	0.9932	0.0023	0.9867	0.9966
SP	2022	8	87.50	0.9955	0.0017	0.9906	0.9978

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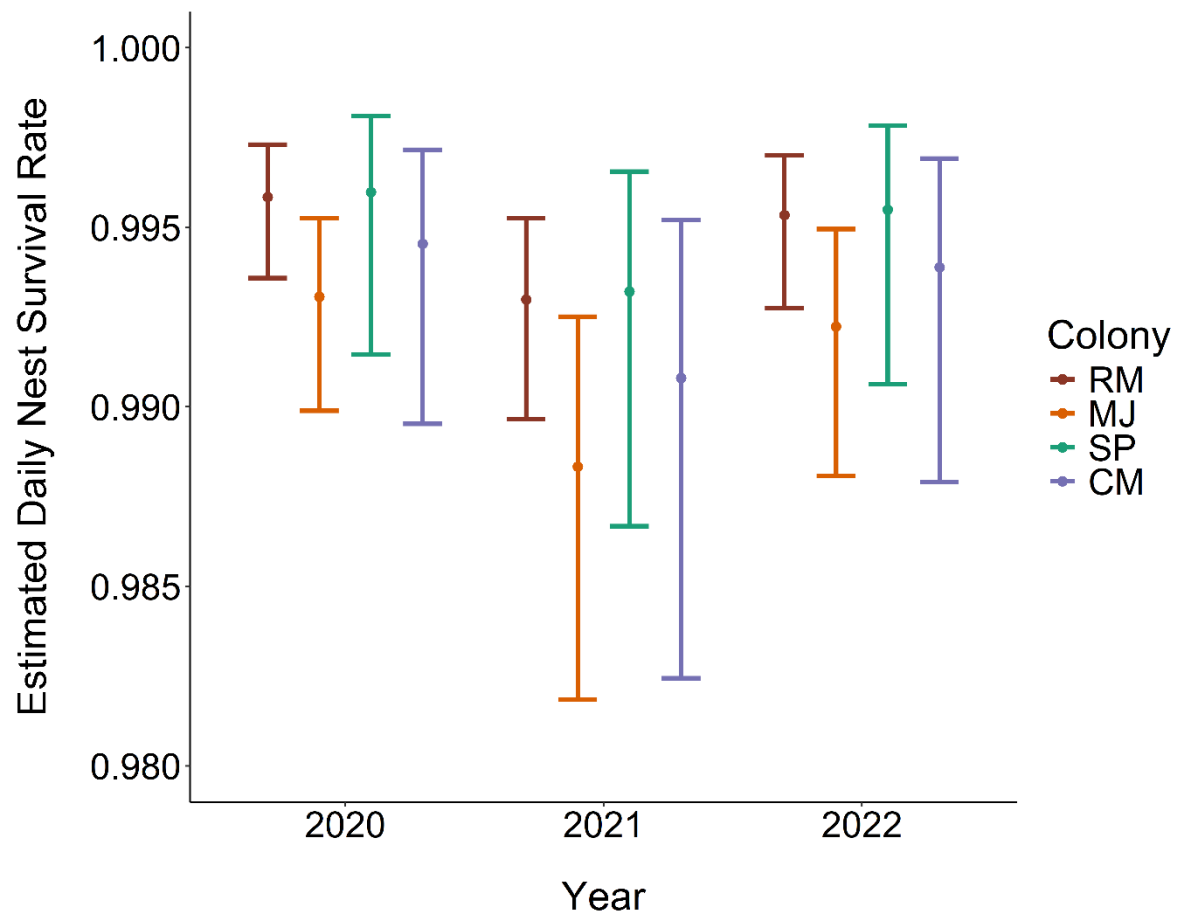


Figure S4. Yelkouan shearwater daily nest survival rate estimates (DSR) with lower and upper confidence intervals per colony (RM, MJ, SP and CM) and year, estimates based on the nests in Table S3.

Differences in foraging ecology

Table S4: Generalised linear mixed models showing different trip metric characteristics for adult Yelkouan shearwater tracked using GPS-loggers during the chick-rearing period at two colonies (RM, MJ) in Malta. Tracking data took place in 2012-2014, 2019, 2021-2022, and only complete trips were retained (RM=88 trips of 30 individuals, MJ=35 of 23 individuals). Resulting parameter estimates $\pm$ their standard error, p-values, lower and upper 95% confidence intervals are shown for fixed effects, while variance and standard deviation are shown for random effects.

Dependent Variable	Fixed Effects	Parameter estimate	Sd Error	P-value	Lower 95%CI	Upper 95%CI	Random Effect	Variance	Standard Deviation
log(duration)	(Intercept)	3.4444	0.0965	<0.001	3.2552	3.6336			
	MJ	0.4595	0.1802	0.011	0.1063	0.8128	individual ID year	<0.0001 <0.0001	<0.0001 <0.0001
log(max distance)	(Intercept)	4.7701	0.1160	<0.001	4.5427	4.9974			
	MJ	0.5439	0.1822	0.003	0.1868	0.9009	individual ID year	<0.0001 0.0375	<0.0001 0.1937
log(total distance)	(Intercept)	5.7726	0.1177	<0.001	5.5420	6.0033			
	MJ	0.5216	0.1946	0.007	0.1403	0.9030	individual ID year	<0.0001 0.0291	<0.0001 0.1705
log(mean speed)	(Intercept)	2.3525	0.0472	<0.001	2.2600	2.4449			
	MJ	-0.0011	0.0878	0.990	-0.1731	0.1708	individual ID year	0.0020 0.0016	0.0451 0.0402

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GLMMS were fit using in ‘glmmTMB’ package (Brooks et al. 2017), with a with a Gaussian family distribution, while residual diagnostics, dispersion and outliers were checked with the ‘DHARMA’ package (Hartig 2022).

Differences in foraging ecology: year 2021

In 2021 chick-rearing period, we obtained 14 trips from 6 individuals at MJ and 30 trips from 8 individuals at RM. The mean value of scale restricted search values for MJ and RM was 8.5, and we used this value as the smoothing parameter for utilisation distribution. Representativeness was calculated at 78.7% for MJ and at 77.8% for RM. Overlap in area used by shearwaters from both colonies in 2021 was estimated at 12.00% (Fig. S5).

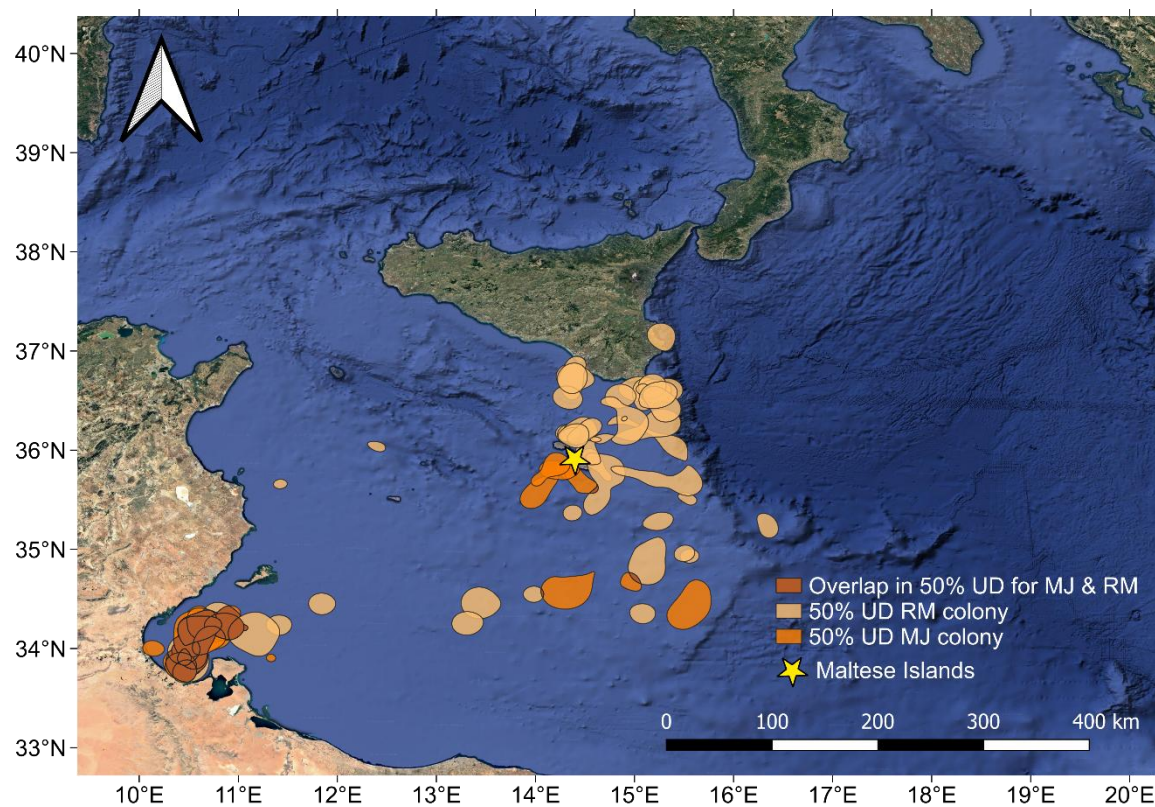


Figure S5. Overlap in 50% Utilization distributions (UDs) for adult Yelkouan shearwaters from two colonies (MJ, RM) on Malta during the chick-rearing period. GPS-tracks from 2021. The study site is marked with a yellow star. Base map source: Google.com

Based on complete trips only (MJ = 13 trips, 6 individuals; RM = 28 trips, 7 individuals), trip metrics were tested for an effect of colony, and parameter estimates are presented in Table

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S5. Here we present means $\pm$ standard deviation (SD) per colony. Adult shearwaters breeding at MJ colony made longer trips both in duration (MJ 93.46 hr $\pm$ 67.52, RM 55.38 hr $\pm$ 72.68), and distance (MJ 957.81 km $\pm$ 588.61, RM 537.70 km $\pm$ 620.05), travelled further away from the colony (MJ 307.10 km $\pm$ 173.64, RM 153.29 km $\pm$ 129.70) but not faster (MJ 11.71 km hr⁻¹ $\pm$ 4.86, RM 11.33 km hr⁻¹ $\pm$ 4.05) than RM shearwaters.

Table S5: Generalised linear mixed models showing different trip metric characteristics for adult Yelkouan shearwater tracked using gps-loggers during the chick-rearing period at two colonies (RM, MJ) in Malta. Tracking data was filtered to those in 2021, and only complete trips were retained (RM=28 trips, MJ=13). Resulting parameter estimates $\pm$ their standard error, p-values, lower and upper 95% confidence intervals are shown for fixed effects, while variance and standard deviation are shown for random effects.

Dependent Variable	Fixed Effect	Parameter estimate	Sd Error	P-value	Lower 95%CI	Upper 95%CI	Random Effect	Variance	Standard Deviation
log(duration)	(Intercept)	3.4450	0.1847	<0.001	3.0830	3.8070			
	MJ	0.6874	0.3280	0.0361	0.0445	1.3303			
							individual ID	<0.0001	<0.0001
log(max distance)	(Intercept)	4.7274	0.1590	<0.001	4.4157	5.0391			
	MJ	0.6931	0.2824	0.014	0.1395	1.2467			
							individual ID	<0.0001	<0.0001
log(total distance)	(Intercept)	5.8021	0.1788	<0.001	5.4516	6.1526			
	MJ	0.7318	0.3176	0.021	0.1094	1.3543			
							individual ID	<0.0001	<0.0001
log(mean speed)	(Intercept)	2.3598	0.0790	<0.001	2.2049	2.5147			
	MJ	0.0458	0.1340	0.733	-0.2168	0.3084			
							individual ID	0.0092	0.0958