The following supplement accompanies the article

Reproductive success in the European shag is linked to annual variation in diet and foraging trip metrics

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SUPPLEMENTARY MATERIALS AND METHODS

Text S1: Cleaning and preparation of GPS- and TDR-logger data

GPS-loggers were originally programmed to take a location every 20-60 seconds but was standardized to an interval of ~60 s. GPS data was then screened for faulty locations. We used a maximum speed of 30 m s^{-1} to filter out locations that were likely caused by locational errors. Birds normally fly in relatively straight lines, so when trajectories between continuous location showed a clear spike (angle cos > 0.97), we reduce maximum allowed speed to 15 m s^{-1}. All spiked trajectories were not removed, as we believe some can be realistic behaviour at feeding areas or at the colony. This procedure removed 748 of the 530962 GPS locations to be used in the analysis.

The TDR-loggers were configured to record temperature and pressure every second. The TDR raw data files were calibrated and summarized in R (R Development Core Team, 2016) using the library diveMove (Luque 2007). Dive threshold was set to 1 m (i.e. shallower dives were not included). We used the zoc method (Luque 2007) for calibrating the surface with three sequential filters: an initial median smoothing filter with 3-s window width, followed by a 0.1 quantile filter with 3-s window width and ending with a 0.02 quantile filter with 60-s window width. The process was bound to depths between -2 and 2 m.

For each dive, depth and duration was calculated. Dives at a speed of > 3 m s^{-1} were regarded as unlikely (Watanuki et al. 2008) and removed from the dataset (N = 58). All the removed dives had a short duration (2-6 s) but relatively deep max depth (6-50 m, mean = 16 m). In total, 81752 dives were recorded in this study, 62430 (76.4%) within the time duration

of functional GPS loggers. Of these, 88 % of the dives were part of a complete foraging trip (see below). Dives were assigned to a trip based on date and time.

We identified a foraging trip as a movement path where the bird spend ≥ 5 minutes ≥ 500 m away from colony without returning to colony (Figure S1). Trips were considered incomplete when (1) the trip include the first or last GPS location from the logger, i.e. locations at the colony were not available either before or after the trip, (2) there were ≥ 10 minutes between last or first location in the trip and the next or previous location at the colony. The trips occasionally included time gaps in GPS location >1 minute due to the inability of GPS-loggers to acquire locations when submerged (i.e. when the bird is diving). We were able to confirm this pattern in our data by plotting TDR- and GPS-location data against time for each logger-bird (Figure S2) and these trips were therefore considered complete. Incomplete trips were removed from further analyses.

After cleaning trips, 141 individuals with GPS- and TDR-data remained for the combined analyses of trip- and dive-data, in addition we used data from 100 individuals with only GPS-loggers, giving a total of 241 individuals included in the trip analyses.

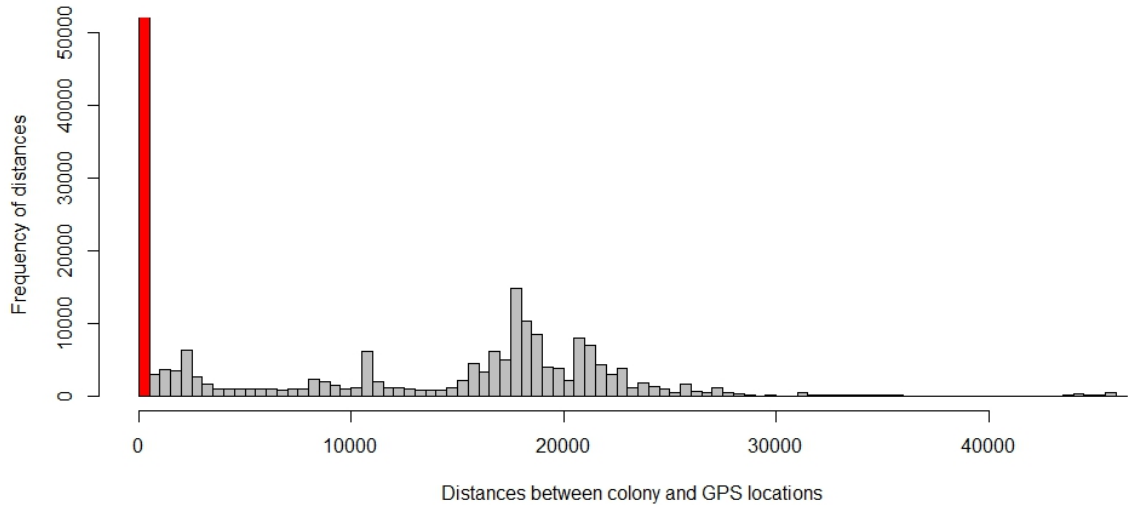

Fig. S1. Distribution of distance between GPS locations and the colony for shags at Sklinna. Distance within 500 meters of colony is shown in red (each bar represents 500 m). For better visualizations, the *y*-axis was restricted to 50 000 although the frequency for first column was ~378 000).

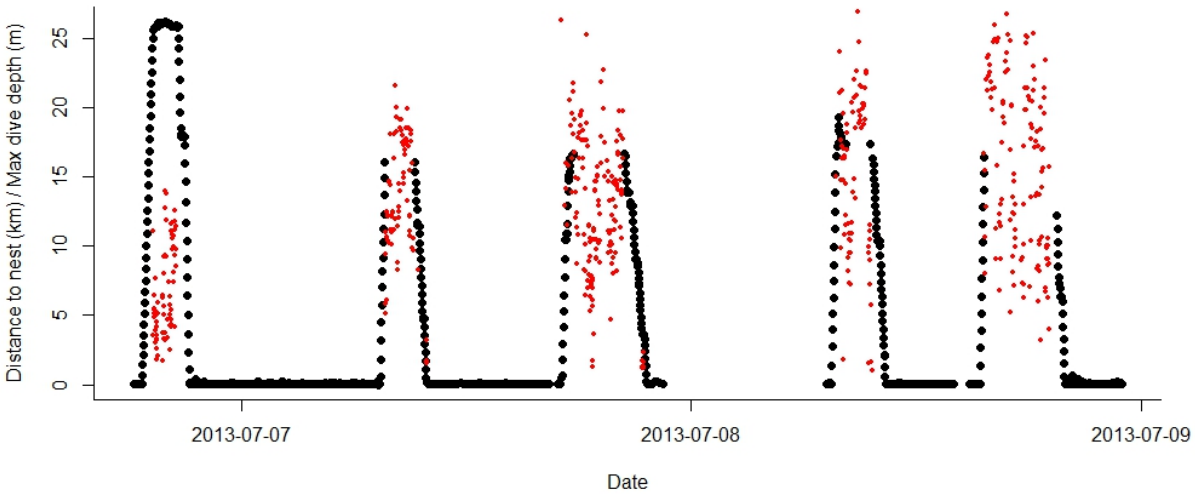

Fig. S2. Individual data from one shag fitted with GPS- and TDR logger during ~2 days. GPS data is plotted as the distance from the nest (black dots) and TDR data as the maximum depth for each dive (red dots) in relation to date and time. This show that gaps in the GPS data are mostly synchronised with diving activity. The gaps without diving activity most likely represent time at the nest where the bird has been under rocks shielding access to satellites (as no diving occurred).

LITERATURE CITED

Luque SP (2007). Diving behaviour analysis in R. R News 7(3): 8–14

Watanuki Y, Daunt F, Takahashi A, Newell M, Wanless S, Sato K, Miyazaki N (2008) Microhabitat use and prey capture of a bottom-feeding top predator, the European shag, shown by camera loggers. Marine Ecology Progress Series, 356, 283–293

SUPPLEMENTARY TABLES AND FIGURES

Table S1. Summary of annual numbers of control nests, breeding success (defined as number of chicks >20 days of age/number of control nests), breeding population size and mean hatching day (±SD).

Year	Control nests	Breeding success	Population size	Mean hatching date (± SD, days)
2011	52	0.87	2264	17.06.2011 ± 5.5
2012	52	0.13	1564	02.07.2012 ± 4.4
2013	54	0.48	1925	26.06.2013 ± 5.9
2014	54	1.63	2570	16.06.2014 ± 6.1
2015	50	0.96	2186	20.06.2015 ± 11.6
2016	51	1.06	2161	24.06.2016 ± 7.6

Table S2. Linear mixed model assessing the effect of year (Y), main diet (D), sex of shag (S) and chick age (C) on distance and total dive depth during a foraging trip in European shags at Sklinna, Norway. All models included individual bird as a random intercept. Top ranked model is marked in bold and models <2 ΔAIC in italic.

Model	ΔAIC	
	Distance	Dive depth
Y+D+S+C	**0**	10.4
Y+D+S	*1.0*	**0**
Y+D+C	*1.6*	15.4
Y+S+C	8.4	13.7
D+S C	74.6	21.3
Y+D	*2.5*	5.0
Y+S	9.8	3.2
Y+C	10.0	17.0
D+S	72.0	11.6
D+C	76.1	22.8
Y	11.2	6.6
D	73.4	13.2
S	88.9	14.4
C	92.7	23.6
Null	90.4	14.3

Table S3. Multiple comparison of means (Tukey contrast) for trip distance and total dive depth during foraging trips by shags for the covariates year and diet based on the linear model presented in Table 1 (main paper).

	Trip distance			Dive depth sum		
	β	SE	p	β	SE	p
Year combinations						
2011–2012	–4.67	4.57	ns	–0.66	0.25	ns
2011–2013	0.04	4.50	ns	–0.28	0.20	ns
2011–2014	19.52	3.55	<0.001	0.12	0.19	ns
2011–2015	6.50	4.08	ns	–0.26	0.19	ns
2011–2016	6.95	4.45	ns	–0.23	0.21	ns
2012–2013	4.71	3.69	ns	0.38	0.17	ns
2012–2014	24.19	3.60	<0.001	0.78	0.17	<0.001
2012–2015	11.14	4.01	ns	0.40	0.18	ns
2012–2016	11.61	3.87	<0.05	0.43	0.18	ns
2013–2014	19.48	3.44	<0.001	0.40	0.09	<0.001
2013–2015	6.44	3.83	ns	0.02	0.10	ns
2013–2016	6.91	3.60	ns	0.05	0.11	ns
2014–2015	–13.04	3.34	<0.01	–0.38	0.09	<0.001
2014–2016	–12.58	3.40	<0.01	–0.34	0.11	<0.01
2015–2016	0.47	3.76	ns	0.03	0.11	Ns
Diet combinations						
Other gadids–Mixed diet	–0.46	7.37	ns	1.50	0.49	<0.05
Other gadids–Saithe 0-year	2.31	7.00	ns	1.63	0.48	<0.01
Other gadids–Saithe 1-year	–2.47	6.46	ns	1.45	0.48	<0.01
Mixed diet–Saithe 0-year	2.77	2.96	ns	0.15	0.10	ns
Mixed diet–Saithe 1-year	2.94	3.59	ns	–0.03	0.12	ns
Saithe 0-year–Saithe 1-year	0.16	2.67	ns	–0.18	0.08	ns

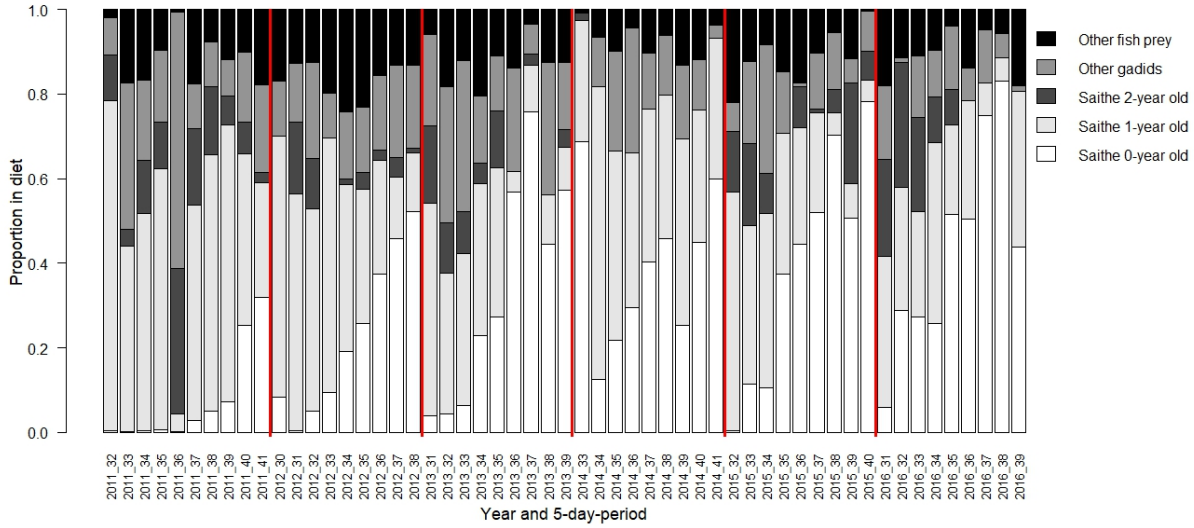

Fig. S3. Seasonal and annual differences in the occurrence of the different prey types of European shags at Sklinna, Norway. The bars represent each 5-day period of diet sampling during each breeding season and are plotted in chronological order. Labels show year and 5-day period where period 35 includes the median hatching date (see original paper for details). The red lines mark the different years of study (2011–2016).

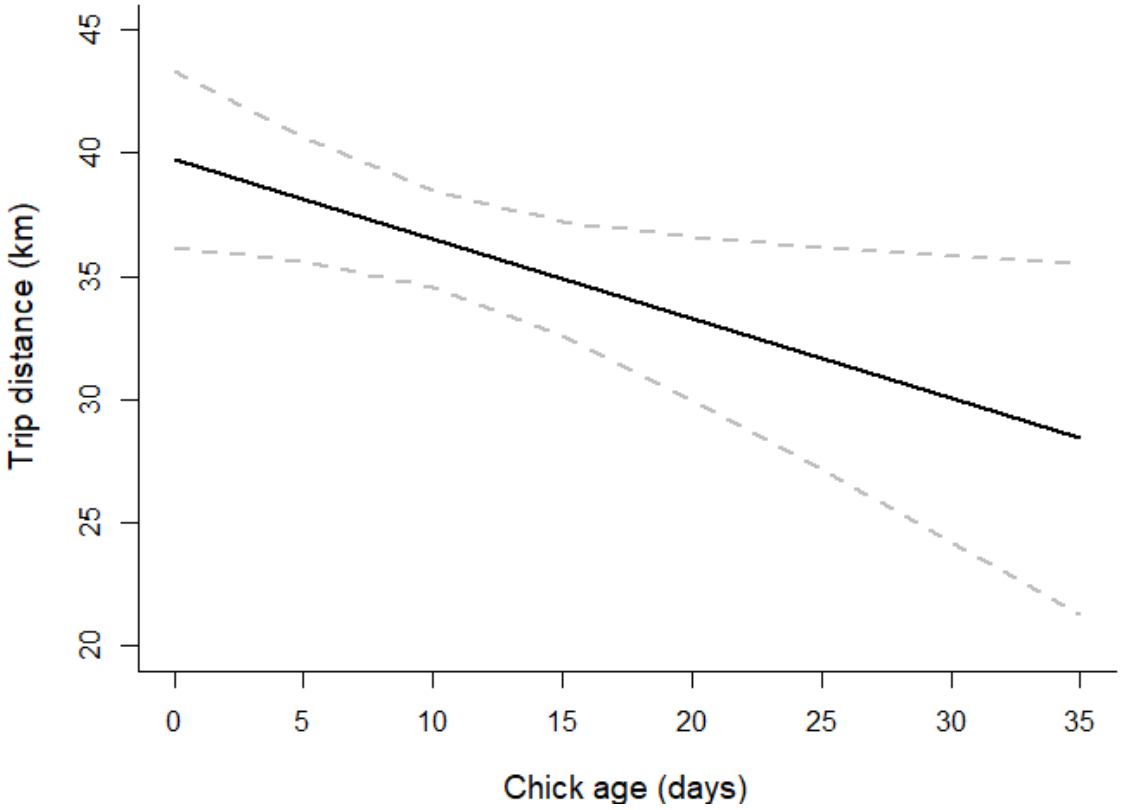

Fig. S4. Distance travelled during foraging trips of shags in relation to the age of the chicks presented as fitted values with confidence interval (grey striped lines).

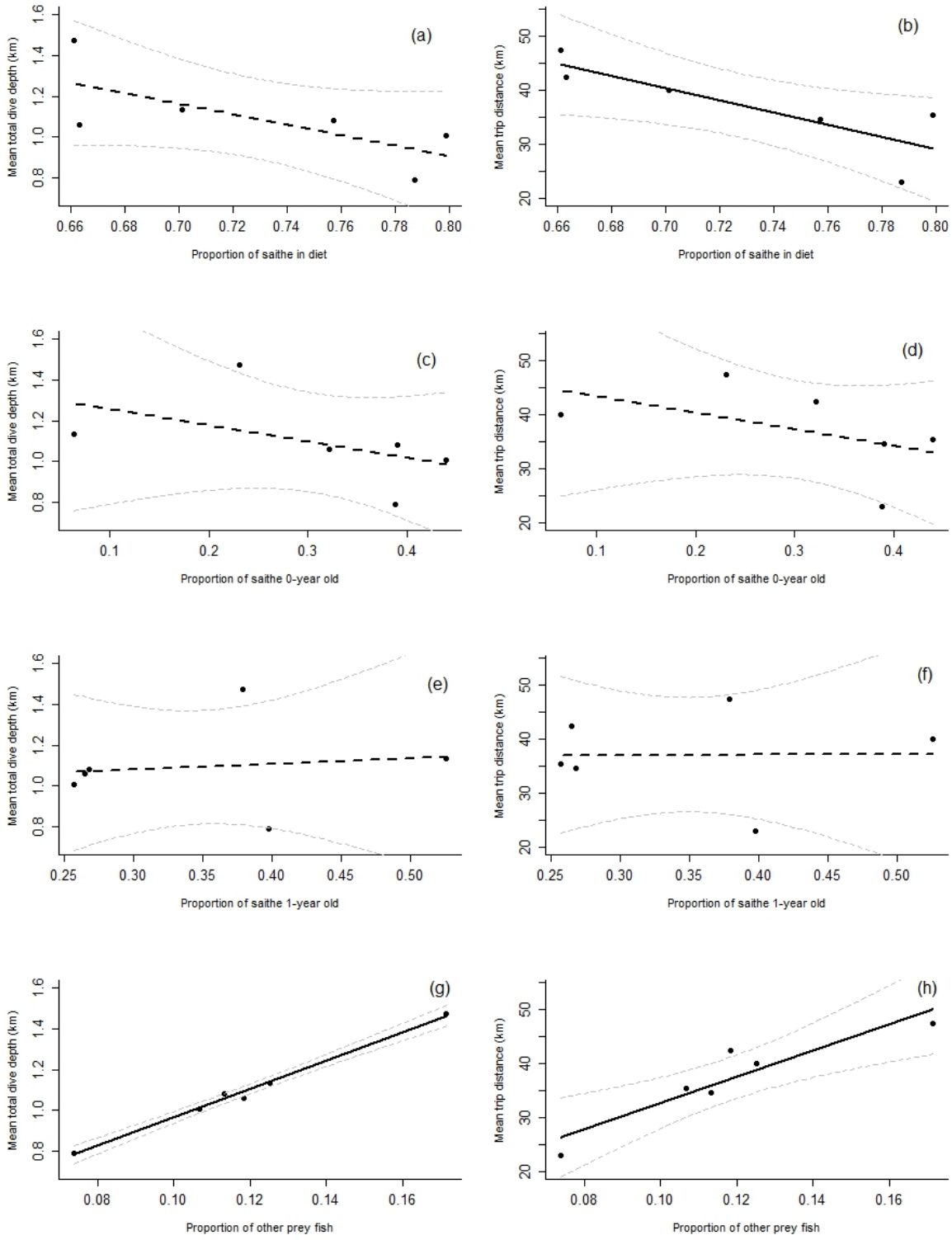

Fig. S5. Annual means of total dive depth (left panel) and of trip distance (right panel) in foraging shags in relation to proportion of different prey classes in the diet: (a, b) all saithe pooled, (c, d) 0-year old saithe, (e, f) 1-year old saithe, and (g, h) other fish prey species. Dots represent raw data and lines fitted values (black) with confidence interval (grey). Significant correlations are represented by solid lines.