Online Supporting information

Title: Dietary studies in prey-carrying birds: testing a non-invasive method using digital photography

Authors: Davide Gaglio, Timothée R. Cook, Maelle Connan, Peter G. Ryan and Richard B. Sherley

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Appendix S1 – Additional methods and results for estimation of prey standard length

Allometric regressions between anchovy morphometric measurements and standard length

Eighty seven anchovy were collected from commercial purse-seine catches obtained through the Department of Agriculture, Forestry and Fisheries. All 87 fish were straightened by hand on a flat surface and measurements of standard length (SL), operculum width (O), head width (H) and eye diameter (E) were taken using Vernier callipers to the nearest 0.1 mm. For 50 of these fish (the training set), we related each of these three morphometric measurements (O, H and E) to the SL of the fish using linear ($y = \alpha + \beta x$), log-linear ($y = \alpha + \beta \cdot ln(x)$), and power ($y = \alpha \cdot x^{\beta}$) regressions fitted with the *lm* and *nls* functions in R. We compared model fits using Akaike's Information Criterion adjusted for small sample size (AICc) and selected the model with the highest AICc weight in each case (Table S1). All three relationships were best represented by log-linear regressions with adjusted-R^2 values between 0.88 and 0.93 (Table S1, Fig. S1).

Assessing accuracy of predicted standard lengths for the training and cross-validation datasets

We used the log-linear model described above and the *predict* function in R to generate three SL estimates ($\widehat{SL}$) for each of the 50 anchovies in the training data set and each of 20 additional anchovies making up the test data set for cross-validation (Fig. S1). In addition, we combined the three estimates by taking their arithmetic mean (combined $\widehat{SL}$). We then compared these model predicted estimates ($\widehat{SL}$) to the known SL (measured with the callipers) of each fish by computing the mean accuracy ($\bar{\gamma}$) of each of the four sets of $\widehat{SL}$ estimates following the approach in eqn 1 in the main text where n = 50 for the training dataset and n = 20 for the cross-validation dataset. We assessed the mean differences between the known SLs and each set of $\widehat{SL}$ values using permutations tests with 10,000 Monte Carlo iterations (see main text). We checked that the accuracy of the combined $\widehat{SL}$ estimates were not influenced by the size of the fish (known SL) using linear models on the logit transformed percentage accuracy (expressed as a proportion) as in eqn 3 in the main text.

For the 50 anchovy in the training set, mean (± SD) accuracy ($\bar{y}$) of ($\widehat{SL}$) was: O = 96.5 (± 2.3)%, H = 97.2 (± 2.2)%, E = 97.2 (± 2.0)% and combined $\widehat{SL}$ = 97.9 (± 1.7)% and none of the means differed significantly from the mean of the known SL (permutations tests: all p-values > 0.05). On average, the combined $\widehat{SL}$ estimates were inaccurate by 2.34 (± 1.89) mm for these 50 anchovy. For the cross-validation set, mean accuracies were E = 96.3 (± 2.8)%, O = 95.6 (± 1.5)%, H = 98.5 (± 1.1)% for the individual morphometric measurements, and combined $\widehat{SL}$,= 97.3 (± 1.8)%. The $\widehat{SL}$ s based on the E and O measurements almost consistently underestimated SL (Fig. S1) and their means differed significantly from the SL of the 20 anchovy (permutations tests: E: p = 0.001; O: p < 0.001). The estimates based on H were more balanced between under and overestimates (Fig. S1) and did not differ significantly from the SL values (p = 0.51). For these 20 anchovy the combined $\widehat{SL}$ estimates were inaccurate by a mean of 2.97 (± 2.17) mm, which was significantly different from their known SLs (permutations tests: p < 0.007). Accuracy was not affected by the known SL of the fish for either the training dataset ($F_{(1,48)}$ = 0.12, p = 0.73) or the cross-validation dataset ($F_{(1,17)}$ = 0.12, p = 0.73).

Assessing accuracy of predicted standard lengths for the 37 photographed anchovy

Based on the above, we used these log-linear regressions to obtain estimates of SL ($\widehat{SL}$) from 37 anchovy photographed in the bill of a greater crested tern carcass (see Fig. S2 and main text). With the culmen length of the carcass (62.1 mm) set as the reference mean (± SD) accuracy ($\bar{y}$) of ($\widehat{SL}$) was: O = 98.3 (± 1.7)%, H = 96.8 (± 2.0)%, E = 97.8 (± 2.1)% and combined $\widehat{SL}$ = 98.3 (± 1.5)% and none of the means differed significantly from the mean of the known SL (permutations tests: all p-values > 0.05). On average, the combined $\widehat{SL}$ estimates were inaccurate by 0.58 (± 2.58) mm for these 37 anchovy. Accuracy was negatively related to SL for the estimates derived from the pixel measurement of eye diameter ($\hat{E}$: $F_{(1,35)}$ = 4.9, p = 0.03), but not for the other three estimates (all p-values > 0.05).

With the species' mean culmen length (61.2 mm) set as the reference length, the mean (± SD) accuracy ($\bar{y}$) decreased slightly to O = 97.7 (± 1.9)%, H = 96.8 (± 2.1)%, E = 96.9 (± 2.6)% and combined $\widehat{SL}$ = 98.1 (± 1.5)%. Again, none of the means differed significantly from the mean of the known SL (permutations tests: all p-values > 0.05) and the mean (± SD) inaccuracy of the combined $\widehat{SL}$ estimates was 0.64 (± 2.75) mm. Accuracy was not affected by the known SL for any of the estimates in this case (all p-values > 0.05).

For the species' minimum culmen length (54.5 mm), the mean (± SD) accuracy ($\bar{y}$) values were O = 87.9 (± 4.0)%, H = 89.6 (± 4.5)%, E = 88.6 (± 4.7)% and combined $\widehat{SL}$ = 88.9 (± 3.3)%. Again, accuracy was negatively related to SL for the estimates derived from the pixel measurement of eye diameter ($\hat{E}$: $F_{(1,35)}$ = 4.5, p = 0.042), but not for the other three estimates (all p-values > 0.05). For the maximum culmen length (67.6 mm), the $\bar{y}$ values were O = 89.2 (±

4.6)%, H = 88.6 (± 3.7)%, E = 92.4 (± 3.8)% and combined $\widehat{SL}$ = 91.3 (± 3.2)%. Accuracy was positively related to SL for the estimates derived from the pixel measurement of eye diameter ($\widehat{H}$: $F_{(1,35)} = 7.96$, $p = 0.008$) and combined $\widehat{SL}$ ($F_{(1,35)} = 5.48$, $p = 0.03$), but not for the other two estimates (p-values > 0.05). For the both minimum and maximum culmen lengths, all $\widehat{SL}$ means differed significantly from the mean of the known SL (permutations tests: all p-values < 0.001); however, these values represent the absolute extremes record for this species (see main text).

Finally, based on the above, we used the combined $\widehat{SL}$ for all further analyses described in this paper.

Table S1: Regression equations and adjusted R^2 values from models regressing anchovy (n = 50) eye diameter, operculum width and head width against standard length (SL) based on morphometric measurements. Models for each morphometric measurement are sorted by AICc weight, with the adjusted R^2 and regression equation given for the best fitting model in each case.

Morphometric measurement	Model type	AICc value	AICc weight	Adjusted R^2 value	Regression equation
Eye diameter	Log-linear	279.5	0.94	0.92	$\widehat{SL} = -68.16 + 91.95 \times \ln(E)$
	Power	285.8	0.04	–	–
	Linear	287.2	0.02	–	–
Operculum width	Log-linear	299.0	0.66	0.88	$\widehat{SL} = -230.44 + 121.60 \times \ln(O)$
	Linear	301.5	0.19	–	–
	Power	301.9	0.15	–	–
Head width	Log-linear	276.7	0.38	0.93	$\widehat{SL} = -168.70 + 112.29 \times \ln(H)$
	Linear	277.1	0.32	–	–
	Power	277.2	0.30	–	–

$\widehat{SL}$ = estimated standard length and ln is the natural logarithm.

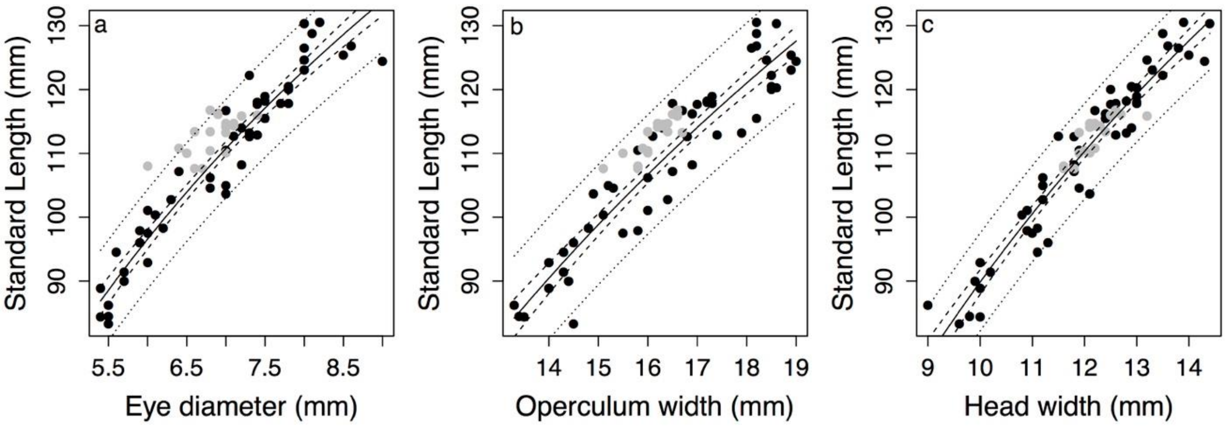

Fig. S1: Log-linear regression fits (solid lines) between measurements of each of (a) the eye diameter, (b) the operculum width, (c) the head width and the standard length (all in mm) of 50 anchovies *Engraulis encrasicolus* (black circles) measured with vernier callipers. Dashed lines show the 95% confidence intervals for the regression fit (solid line) and dotted lines show the 95% prediction intervals. Grey circles show the same measurements for 20 fish from the cross-validation dataset.

Fig. S2: An example of the set up used to validate SL estimates of anchovies *Engraulis encrasicolus* from photographs taken in the field. Here an anchovy of known SL is held in the bill of a carcass of greater crested tern *Thalasseus bergii* with known culmen length.

Table S2: Estimated SLs from operculum width, head diameter and eye diameter from the (N) 37 anchovy photographed in the bill of a greater crested tern carcass and measured in ImageJ. SL = known standard length. Results obtained using as reference: carcass = bill length of the carcass photographed; min = minimum bill length known for the species; mean = mean bill length known for the species; max = maximum bill length known for the species. All results in mm.

		Operculum width ($\hat{O}$)				**Head diameter ($\hat{H}$)**				**Eye diameter ($\hat{E}$)**			
N	**SL**	**Carcass**	**Min.**	**Mean**	**Max.**	**Carcass**	**Min.**	**Mean**	**Max.**	**Carcass**	**Min.**	**Mean**	**Max.**
1	113.3	111.84	97.22	111.18	124.16	110.33	102.88	114.91	122.89	113.87	106.46	109.18	120.48
2	107.6	107.39	95.57	108.37	121.03	113.01	101.58	113.83	124.47	107.42	92.51	99.61	115.38
3	113.4	112.93	95.73	109.93	121.03	117.84	107.68	119.32	127.64	109.84	96.59	107.42	122.12
4	114.1	113.15	97.22	113.51	124.16	110.33	102.88	117.66	122.89	113.87	106.46	110.77	120.48
5	108.0	107.24	95.57	107.31	121.03	113.01	101.58	109.01	124.47	107.42	92.51	107.42	115.38
6	116.0	118.92	104.41	114.86	131.82	117.93	98.81	116.52	127.00	114.88	105.36	113.99	122.47
7	114.6	116.35	106.02	116.21	131.63	123.06	108.44	122.72	130.18	112.33	100.49	110.77	117.11
8	114.3	110.30	88.19	108.29	114.08	117.31	94.26	119.32	127.64	115.00	109.04	113.99	131.60
9	107.6	108.82	99.66	108.44	127.15	111.91	102.18	112.19	122.72	111.68	104.80	110.77	124.19
10	114.7	113.22	101.82	113.15	128.50	119.32	106.72	120.18	130.33	110.77	98.11	110.77	121.77
11	110.0	109.19	94.82	107.54	121.90	111.73	97.76	114.55	121.96	103.10	96.59	105.36	110.77
12	116.1	111.55	95.32	107.46	119.47	119.58	105.36	121.88	134.41	105.63	83.96	99.61	110.77
13	115.9	112.35	100.23	111.48	124.82	118.71	92.08	118.36	127.24	114.12	99.60	112.07	119.53
14	110.8	110.45	98.04	108.97	125.67	113.83	96.61	115.81	124.63	112.07	96.59	109.44	121.54
15	113.4	112.49	104.79	114.08	130.51	117.40	102.58	117.58	122.64	112.97	102.53	113.36	121.54
16	110.4	119.05	110.08	118.99	139.19	115.36	103.48	114.10	124.38	118.21	104.94	112.07	125.32
17	114.7	114.08	98.85	113.00	125.41	122.05	111.35	122.89	136.65	113.74	100.35	106.60	119.05
18	110.1	113.00	104.33	111.62	122.37	117.14	106.33	116.61	132.89	113.87	99.31	113.36	120.60
19	114.3	111.18	98.85	111.77	121.97	117.75	104.57	117.31	125.62	113.74	101.81	112.33	124.53
20	116.8	111.40	102.45	110.82	126.58	122.97	107.97	121.03	136.36	111.03	103.81	112.07	124.87
21	122.3	119.74	106.90	117.53	131.01	127.16	105.55	124.96	128.76	128.62	111.42	126.98	133.05
22	98.3	99.02	82.39	99.26	111.91	92.63	88.38	91.86	109.01	99.75	88.75	100.20	105.91
23	123.0	119.81	106.10	120.15	131.51	123.64	109.39	122.72	131.66	126.76	115.75	126.32	135.60
24	119.5	117.81	104.09	117.53	128.43	109.67	99.32	111.26	121.88	118.45	101.52	116.00	118.93
25	111.0	111.48	96.73	107.84	123.70	110.33	97.56	108.92	120.69	109.31	98.71	107.15	120.36
26	107.9	107.62	97.63	107.77	121.03	110.52	98.81	109.30	122.64	109.31	96.74	108.77	118.57
27	99.1	100.55	82.57	98.53	108.59	98.91	82.07	97.03	113.10	98.86	84.83	96.28	107.56
28	129.1	129.26	112.64	129.07	144.10	128.92	111.08	126.67	136.65	125.76	107.83	123.50	133.36
29	117.7	111.70	99.26	112.06	126.25	121.29	108.82	119.40	130.18	119.17	106.19	118.69	127.31
30	116.0	116.63	100.55	115.57	127.48	118.01	101.27	114.73	125.78	116.74	104.52	114.37	125.43
31	108.1	108.52	93.30	107.09	122.51	105.36	93.39	107.10	121.96	109.44	95.35	106.19	115.50
32	124.8	127.92	113.07	126.32	139.54	127.24	116.34	128.20	137.90	126.10	108.91	128.73	133.87
33	118.1	118.85	104.79	117.19	135.17	119.32	106.81	118.54	129.78	119.65	104.94	117.23	127.20
34	116.4	113.29	98.69	111.40	124.89	119.66	101.07	118.80	130.65	114.75	101.08	113.10	122.00
35	117.2	117.05	104.17	119.94	133.11	118.45	109.20	115.99	128.76	113.61	95.97	114.37	120.36
36	113.8	113.94	102.37	111.62	130.76	111.17	96.92	111.35	122.80	118.57	104.23	113.10	131.91
37	96.6	94.23	80.98	92.53	100.31	94.47	77.52	91.19	107.20	96.89	95.04	103.10	110.77