The following supplements accompany the article

Success comes with consistency in hard times: foraging repeatability relates to sex and breeding output in African penguins

Gwendoline Traisnel*, Lorien Pichegru

*Corresponding author: traisnel.gwendoline@gmail.com

Marine Ecology Progress Series 608: 279–289 (2019)

Supplement 1. Chick growth and body size

During the first months of the life of an African penguin *Spheniscus demersus*, body parts (e.g. flippers, tarsus), grow proportionally to the mass but both parts stop growing during the pre-fledging phase (Lubbe et al. 2014). Head length is the only attribute which continues to grow linearly with the mass after fledging. However, as described in different species (e.g. sterns, Veen et al. 2003), the relation between mass and head length is not linear throughout the chick's growth. On Robben Island (South Africa), this relation only becomes linear for African penguin chicks with a head length >75mm (Lubbe et al. 2014). Because the environmental conditions might contrast between colonies, the threshold applied by Lubbe et al. (2014) may not be applicable on Bird Island, Algoa Bay (South Africa).

Here, we gathered growth data over three consecutive years (2015 – 2017) and determined a head length threshold from which the relation between head length and mass was linear on Bird Island, Algoa Bay. We measured chicks every 5 days over three to five weeks. Using a Vernier Calliper (± 0.1mm) we measured total head length, i.e. from the tip of the beak to the back of the skull. In addition, we recorded the mass using a spring scale (± 10g) and a bag. Overall, we collected a total of 1913 measurements for 438 chicks over three years of monitoring. By inspecting the relation between mass and head length (Figure S1a) we visually determined a threshold of 65mm from which the relation became linear. We tested this linearity using a Generalised Linear Mixed Model with head length (>65mm) as a fixed effect and chick ID as a random effect to control for repeated measurements.

The relationship between mass and total head length was significantly linear and positive ($z = 87.88$, $p < 0.001$, see Figure S1b). We therefore estimated chick growth rates from offspring with a head length >65mm to avoid any bias related to difference in growth between small (head length <65mm) and big chicks (head length >65mm).

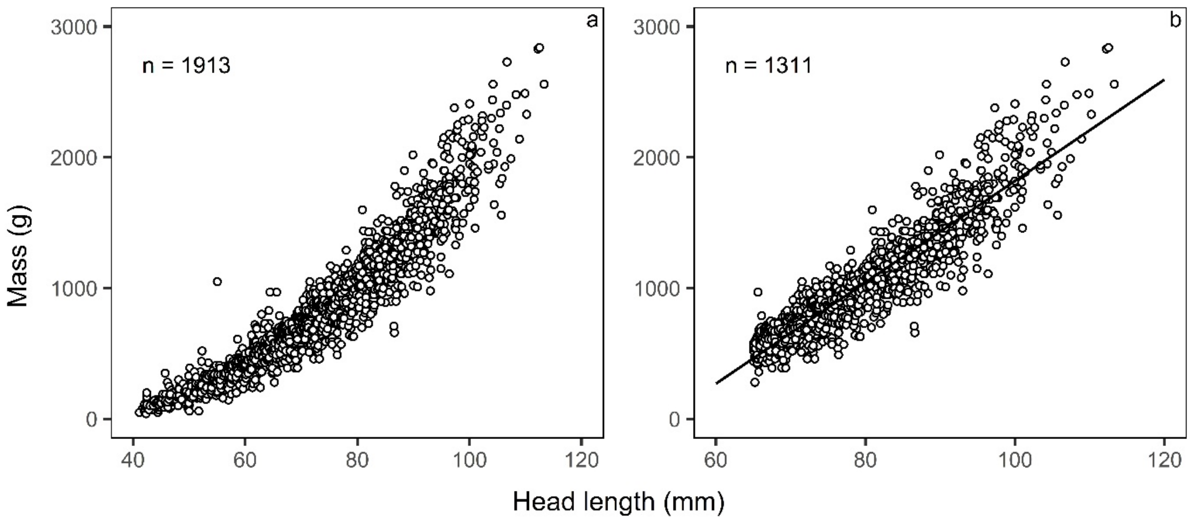


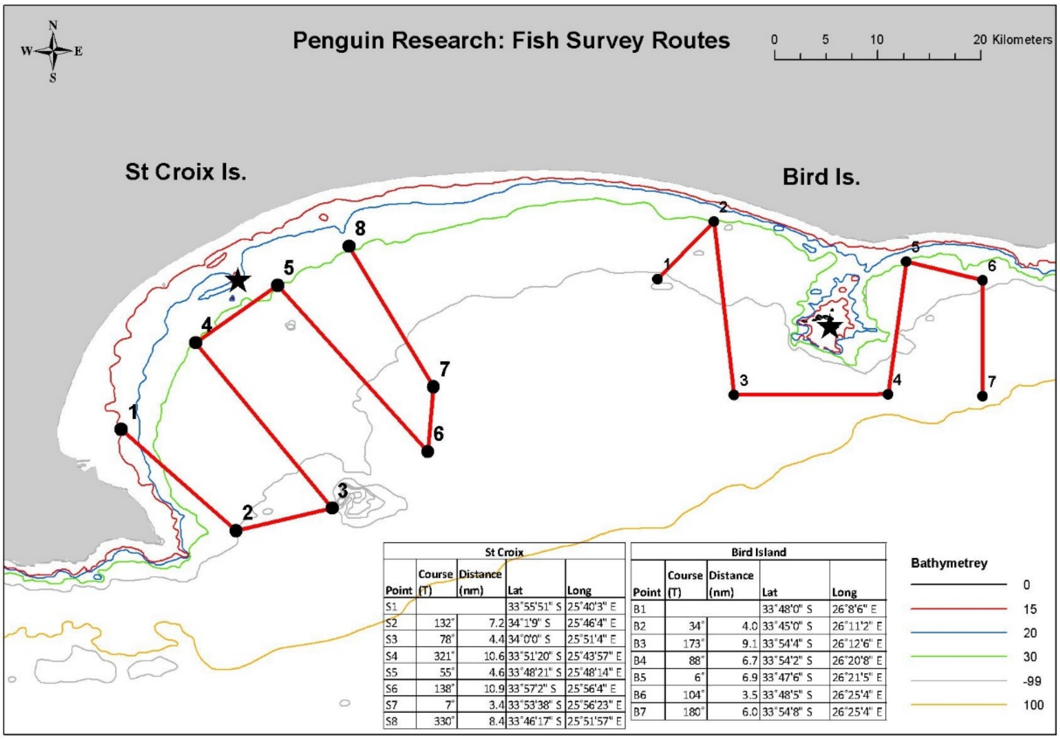
Figure S1. Relation between mass and total head length for African penguin chicks between 2015 and 2017 on Bird Island, Algoa Bay. (a) including all measurements and (b) from chicks with head length >65mm only. Regression line (b) was fitted using the results of a GLMM.

References

Lubbe A, Underhill LG, Waller LJ, Veen J (2014) A condition index for African penguin Spheniscus demersus chicks. Afr J Mar Sci 36:143-154. https://doi.org/10.2989/1814232X.2014.915232

Supplement 2. Relative prey abundance around Bird Island, Algoa Bay (South Africa) between 2015 and 2017

Fish surveys were performed around two main African penguin *Spheniscus demersus* colonies in Algoa Bay (South Africa), Bird and St Croix islands. These surveys estimated the relative distribution and abundance of small pelagic fish around the two breeding sites at regular intervals during the breeding season (McInnes et al. 2015). Small pelagic fish, sardines *Sardinops sagax* and anchovies *Engraulis encrasicolus* are the main prey species targeted by African penguins during their breeding season in Algoa Bay, South Africa (Crawford et al. 2011). The transects have been designed to cross the foraging range of the penguins around the two locations (McInnes et al. 2017, see Figure S2).



St Croix				
Point	Course (T)	Distance (nm)	Lat	Long
S1			33°55'51" S	25°40'3" E
S2	132°	7.2	34°1'9" S	25°46'4" E
S3	78°	4.4	34°0'0" S	25°51'4" E
S4	321°	10.6	33°51'20" S	25°43'57" E
S5	55°	4.6	33°48'21" S	25°48'14" E
S6	138°	10.9	33°57'2" S	25°56'4" E
S7	7°	3.4	33°53'38" S	25°56'23" E
S8	330°	8.4	33°46'17" S	25°51'57" E

Bird Island				
Point	Course (T)	Distance (nm)	Lat	Long
B1			33°48'0" S	26°8'6" E
B2	34°	4.0	33°45'0" S	26°11'2" E
B3	173°	9.1	33°54'4" S	26°12'6" E
B4	88°	6.7	33°54'2" S	26°20'8" E
B5	6°	6.9	33°47'6" S	26°21'5" E
B6	104°	3.5	33°48'5" S	26°25'4" E
B7	180°	6.0	33°54'8" S	26°25'4" E

Figure S2. Route design of the two fish surveys conducted monthly in Algoa Bay (South Africa). The location of the two breeding grounds of African penguins are symbolised by a star. The bathymetry of the bay is also presented by lines of different colour.

We used a recreational fish-finder (Furuno DFF3) placed at the back of a small boat (<10m long). After controlling that the weather conditions would not affect the signal (i.e. swell), we travelled and maintained a speed of 7 knots following a pre-defined transects (McInnes et al. 2015, Figure S2). Data were recorded every 30s. School characteristics were then extracted using a Fish-finder Image Segmentation Helper (FISH) software developed by McInnes et al. (2015) and R Studio (see McInnes et al. 2017 for more details). The parameters were set to fit the school characteristics of anchovies and sardines as they are the main prey of the penguins. This technic has been validated by comparing the data extracted to the data obtained from a scientific echo-sounder (McInnes et al. 2015). The relative abundance (tonnes) and the number of schools encountered during the surveys are presented here but only the data related to the peak of breeding are described (Table S1).

Table S1. Summary of the number of schools and relative abundance of prey encountered during fish surveys conducted around Bird Island, Algoa Bay (South Africa) following a predefined transect. The data were collected in 2015, 2016 and 2017.

Year	Month	Survey date	Schools encountered	Relative abundance (tonnes)
2015	May	2015/05/29	284	20777.26
2016	March	2016/03/03	107	13631.27
2016	April	2016/04/15	4	40.73
2016	June	2016/06/17	38	15579.40
2017	March	2017/03/07	26	3213.69
2017	April	2017/04/12	17	3788.55
2017	May	2017/05/10	87	5668.51
2017	June	2017/06/01	251	33725.44

The highest prey abundances were recorded in May 2015 and June 2017 whereas the lowest was reported in April 2016 (Figure S3). Overall, the number of schools encountered was low between April 2016 and April 2017. Indeed, at the exception of June 2016 and 2017, prey relative abundance was low in both years (<5668.51tonnes of fish per survey) compared to 2015 (20777.26tonnes of fish per survey).

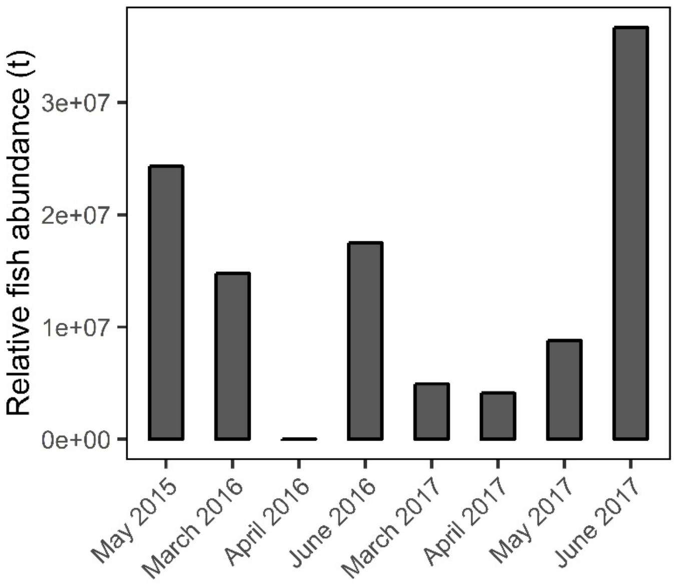


Figure S3. Relative fish abundance (in tonnes) estimated during fish surveys conducted around Bird Island, Algoa Bay between 2015 and 2017 African penguins' breeding season.

Although we only have one month of data in 2015, these results tend to indicate prey availability and distribution fluctuated between months and years during the study period. Overall, prey abundance and distribution were low during most of the peak of the breeding season in 2016 and 2017 whereas it appeared to be high in May 2015.

References

Crawford RJM, Altwegg R, Barham BJ, Barham PJ, Durant JM, Dyer BM, Geldenhuys D, Makhado AB, Pichegru L, Ryan PG, Underhill LG (2011) Collapse of South Africa's penguins in the early 21st century. Afr J Mar Sci 33:139-156. http://dx.doi.org/10.2989/1814232X.2011.572377

McInnes AM, Khoosal A, Murrell B, Merkle D, Lacerda M, Nyengera R, Coetzee JC, Edwards LC, Ryan PG, Rademan J, van der Westhuizen JJ (2015) Recreational fish-finders—An inexpensive alternative to scientific echo-sounders for unravelling the links between marine top predators and their prey. PloS One 10:p.e0140936. https://doi.org/10.1371/journal.pone.0140936

McInnes AM, Ryan PG, Lacerda M, Deshayes J, Goschen WS, Pichegru L (2017) Small pelagic fish responses to fine-scale oceanographic conditions: implications for the endangered African penguin. Mar Ecol Prog Ser 569:187-203. https://doi.org/10.3354/meps12089

Supplement 3. Influence of the number of trips recorded on individual consistency in foraging behaviours

One may argue the number of trips recorded may influence individual consistency in foraging behaviours especially when several birds have only been tracked over two consecutive trips. Here, we tested whether the number of foraging trips recorded for African penguins *Spheniscus demersus* did influence individual consistency of four parameters: maximum distance, trip duration, path length and straightness index. We recorded between two to six consecutive trips per individual and performed Kruskal-Wallis tests for each parameter as the residuals were not normally distributed. Because we recorded six trips for only one bird we removed the data from the analyses. All analyses have been conducted in R cran version 3.3.2. We summarized the statistical results in Table S2.

Table S2. Results obtained conducting Kruskal-Wallis tests assessing the influence of the number of trips recorded from African penguins on their individual consistency for four foraging behaviour on Bird island, Algoa Bay. Mean ± sd associated to the year are also provided for each parameter.

Indices of consistency (R_{ind})	**2015**	**2016**	**2017**	**Chi-squared**	df	p
R_{ind} maximum distance	**0.72 ± 0.21**	**0.69 ± 0.25**	**0.78 ± 0.23**	2.61	3	**0.456**
R_{ind} trip duration	**0.62 ± 0.21**	**0.72 ± 0.22**	**0.76 ± 0.23**	6.25	3	**0.100**
R_{ind} path length	**0.69 ± 0.26**	**0.70 ± 0.26**	**0.74 ± 0.26**	3.74	3	**0.291**
R_{ind} straightness index	**0.61 ± 0.25**	**0.59 ± 0.18**	**0.76 ± 0.19**	0.06	3	**0.996**

None of the index of consistency was affected by the number of trips recorded (all $p \geq 0.100$, Table S2).

Supplement 4. Collinearity: indices of individual consistency

Here we analysed individual consistency (R_{ind}) in four foraging parameters in chick-rearing African penguins *Spheniscus demersus*: maximum distance, trip duration, path length and straightness index. We tested whether collinearity occurred between these variables to apply appropriate tests when analysing the influence of individual consistency on chick growth rates. We created a correlation matrix and tested whether the correlations were significant using Spearman's method as the variables were not normally distributed. The results are summarised in the following table (Table S3).

Table S3. Correlation matrix between all four indices of individual consistency (R_{ind}) using Spearman's methods. The second part of the table reveals the p-value associated to the different correlation coefficients.

Correlation coefficient				
Parameters	R_{ind} maximum distance	R_{ind} trip duration	R_{ind} path length	R_{ind} straightness index
R_{ind} maximum distance	X	X	X	X
R_{ind} trip duration	0.48	X	X	X
R_{ind} path length	0.52	0.73	X	X
R_{ind} straightness index	0.34	0.30	0.29	X

P-value associated				
Parameters	R_{ind} maximum distance	R_{ind} trip duration	R_{ind} path length	R_{ind} straightness index
R_{ind} maximum distance	X	X	X	X
R_{ind} trip duration	**< 0.001**	X	X	X
R_{ind} path length	**< 0.001**	**< 0.001**	X	X
R_{ind} straightness index	**0.008**	**0.021**	**0.024**	X

All four indices are significantly and positively correlated to each other, but the degree of correlation varies between 0.29 and 0.73.