Body condition influences ontogeny of foraging behaviour in juvenile southern elephant seals

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Appendix

A1. Bathymetry

Bathymetry data were obtained from the ETOPO1 bathymetric dataset, freely downloadable from NOAA at a one degree resolution. For each dive, the spatially matched bathymetry was extracted. Dives registered at or deeper than their spatially matched bathymetry were considered benthic dives, whilst dives with maximum depths that occurred above 90% of the bathymetry were considered as epi-benthic dives (Table A1 and Figure 1). Dives performed within the 2000 m depth contour line were considered to be on the Kerguelen plateau (O'Toole, Hindell, Charrassin, & Guinet, 2014) but were not necessarily benthic or epi-benthic (Figure 1).

A2. Body Mass Index at departure

Between 2011 and 2016, 630 juveniles were measured and weighed at weaning at Kerguelen Island. Assuming that their length would not change between weaning and departure to sea, and using a mean fasting duration of 6 weeks (42 days) prior to departure (McConnell, Fedak, Burton, Engelhard, & Reijnders, 2002) we calculated a predicted mass at departure following (Guinet, 1992):

$$M_d = M_w - (0.0048 * M_w + 0.3031) * 42 \qquad \text{(Eq. 1)}$$

where M_d is the mass at departure (to be estimated) and M_w is the mass at weaning. We then applied a linear regression to body mass at departure and length at weaning and took the residual values from that regression as the Body Mass Index (BMI, Fig. A1). The relationship between BMI and length could then be considered as independent and thus comparable between individuals (Guinet, Roux, Bonnet, & Mison, 1998, Fig. A1). The departure dates of individuals equipped with a tag were taken as the day when they did not return to land and began to perform dives deeper than 50 m. We then calculated mass and BMI at departure following the methods as mentioned above (Table A1).

A3. Extended Surface Intervals

Juveniles performed extended surface intervals (ESI > 3.5 min) in 1.3% (n=211) of all dives. The mean duration of these surface intervals was 8.1 ± 2.5 min with a maximum of 31.9 min. We did not find any relationship between extended surface duration and other diving parameters such as depth, dive duration, PrCA rates, swimming effort or time since departure. However, the frequency of extended surface intervals per individual increased slightly at night (6.8 ± 4.6 ESI at night vs 2.9 ± 2.2 ESI during the day, LME: $z = 4.7$ $p < 0.01$).

Other studies have described similar durations of extended surface intervals (e.g. (Mark A Hindell et al., 1999; Irvine, Hindell, van den Hoff, & Burton, 2000; Le Boeuf, Morris, Blackwell, Crocker, & Costa, 1996), even in adults (Hindell, Slip, & Burton, 1991). These surfaces intervals may be related to the maintenance of some organs that turn off during diving (e.g. kidney or liver, see Hindell et al., 1991).

A4. Haul outs

Over the entire transmission period of the SPOT tags, juveniles performed several trips to sea. Individuals made several mid-winter haul outs (Table A6), usually between June and August when they fasted on land for few days before returning to sea. The individuals who made foraging trips to the Kerguelen plateau hauled out more often than those that remained offshore in oceanic environments (Kruskall-Wallis, KW, $X^2 = 3.9$, $p = 0.049$, 2.9 ± 3.1 haul outs for neritic individuals versus 1.1 ± 0.3 for oceanic). One individual (#140066) performed as many as 10 haul outs, most of them on Heard Island, which was very close to its foraging grounds at the southern part of the Kerguelen plateau. Individuals who foraged on the Kerguelen plateau remained negatively buoyant (Figure 7), and the opposite was true of individuals performing oceanic trips. Haul out periods were also shorter for neritic individuals than oceanic individuals (2.9 ± 2.59 days *vs* 8.7 ± 4.4 days, KW: $X^2 = 11.6$, $p < 0.01$).

A5. Nycthemeral Dives

We used the *maptools* R package, (Bivand et al., 2017) to associate each dive location to its associated solar azimuth and time of day (day or night) according to the nautical twilight definition (i.e. when the sun is geometrically 12 degrees below the horizon). A mean depth was calculated for each day since departure and used to assess differences in behaviour between night and day (nycthemeral behaviour).

As soon as they left their natal colony, juvenile seals exhibited a nycthemeral diving pattern, performing deeper dives during the day. The differences between daytime and nighttime diving depths increased over time, most markedly after 100 days at sea (i.e. ~2 months after departure which corresponds to the beginning of the Austral winter). This nycthemeral behaviour was less obvious, but still present for juveniles foraging on the Kerguelen plateau (Fig. A8).

<u>Seasonal effect on nycthemeral behaviour</u>

Juvenile seals started exhibiting a nycthemeral diving pattern soon after leaving their natal colony, with differences between day and night diving depths increasing over time, most markedly after c. 100 days i.e. the beginning of the austral winter (Fig. A8).

Figures

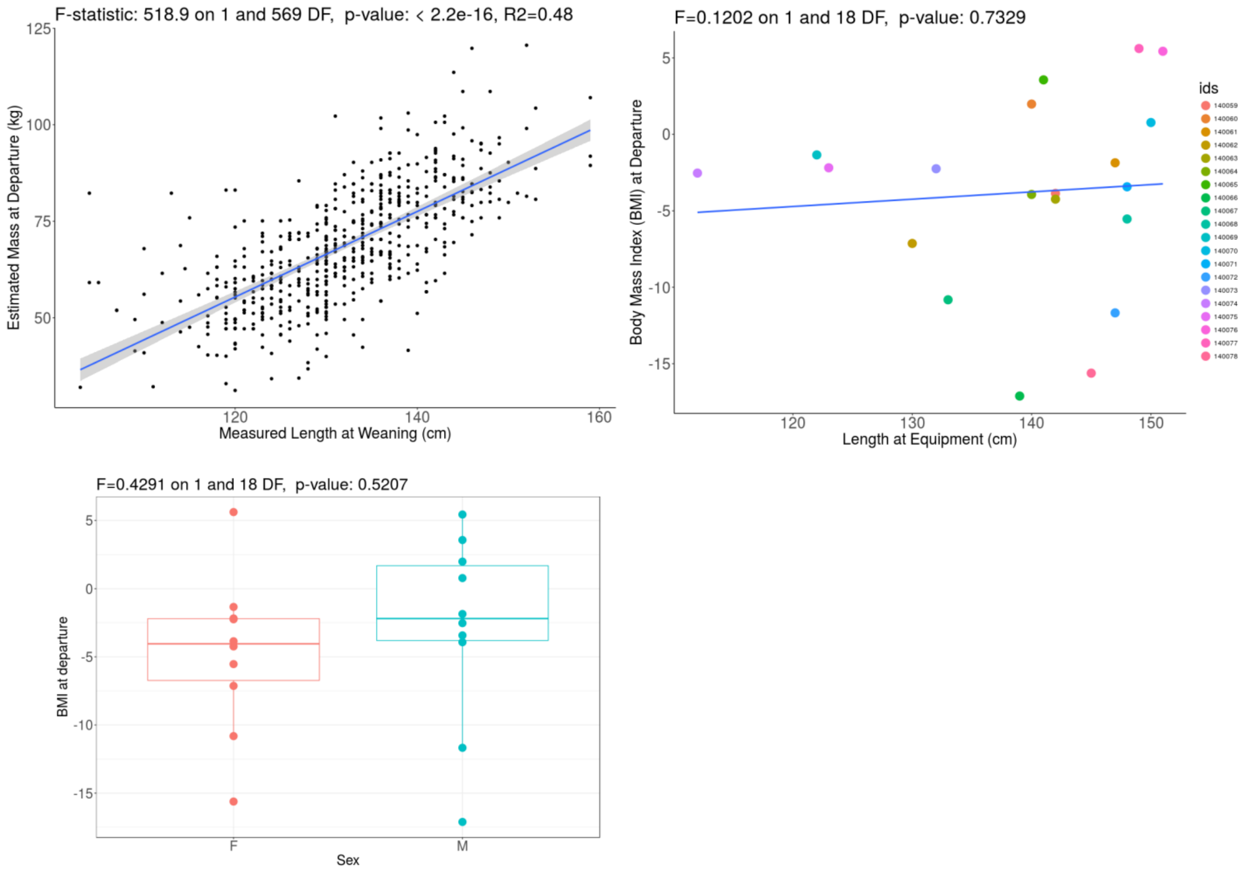

Figure A1: Top left is the linear regression allowing extraction of residuals (Body Mass Index, BMI) for each individual. The top right figure shows the relationship between the BMI and length at departure, the relationship was not significant. The boxplot of BMI, on the lower lower left, shows no significant difference between juvenile females and juvenile males.

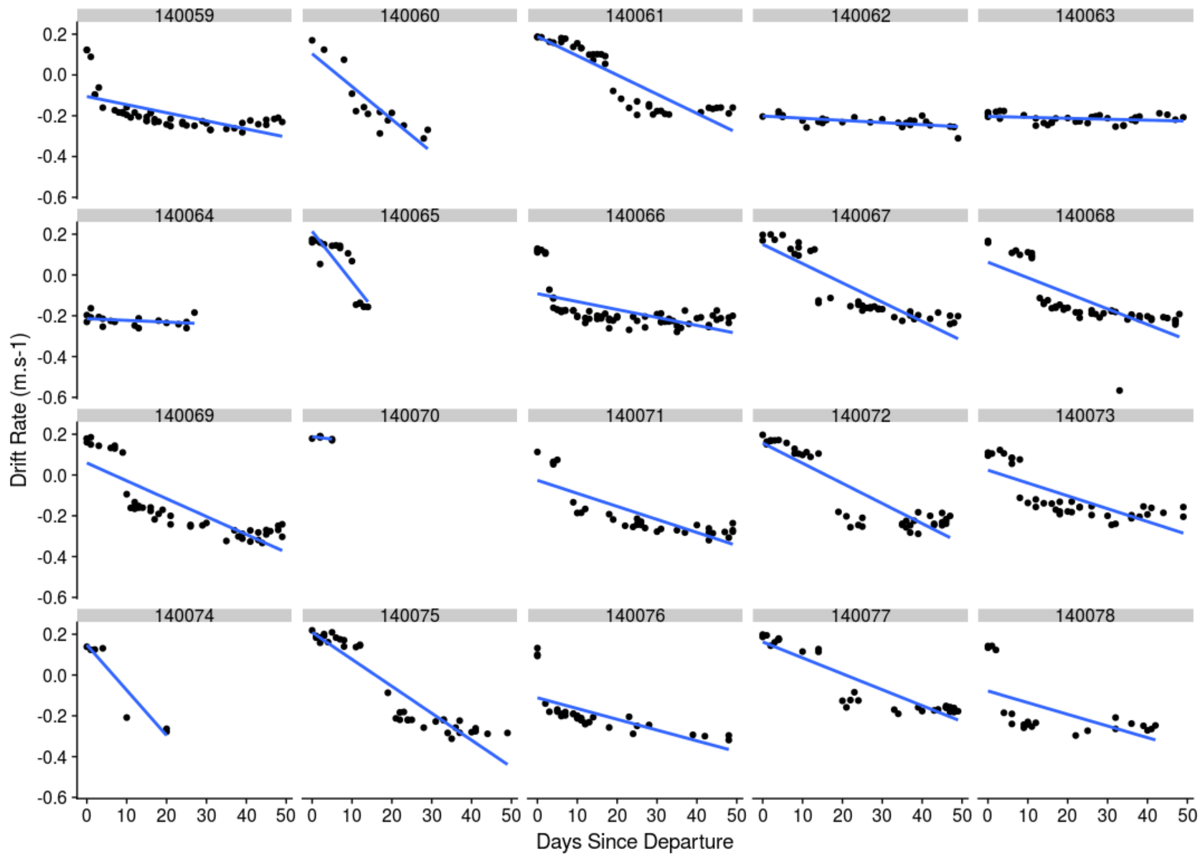

Figure A2: Random slope/intercepts linear mixed models outputs for the changes in drift rates during the first 50 days at sea for each juvenile. Black points are the raw data. See Figure A7 for the complete time series.

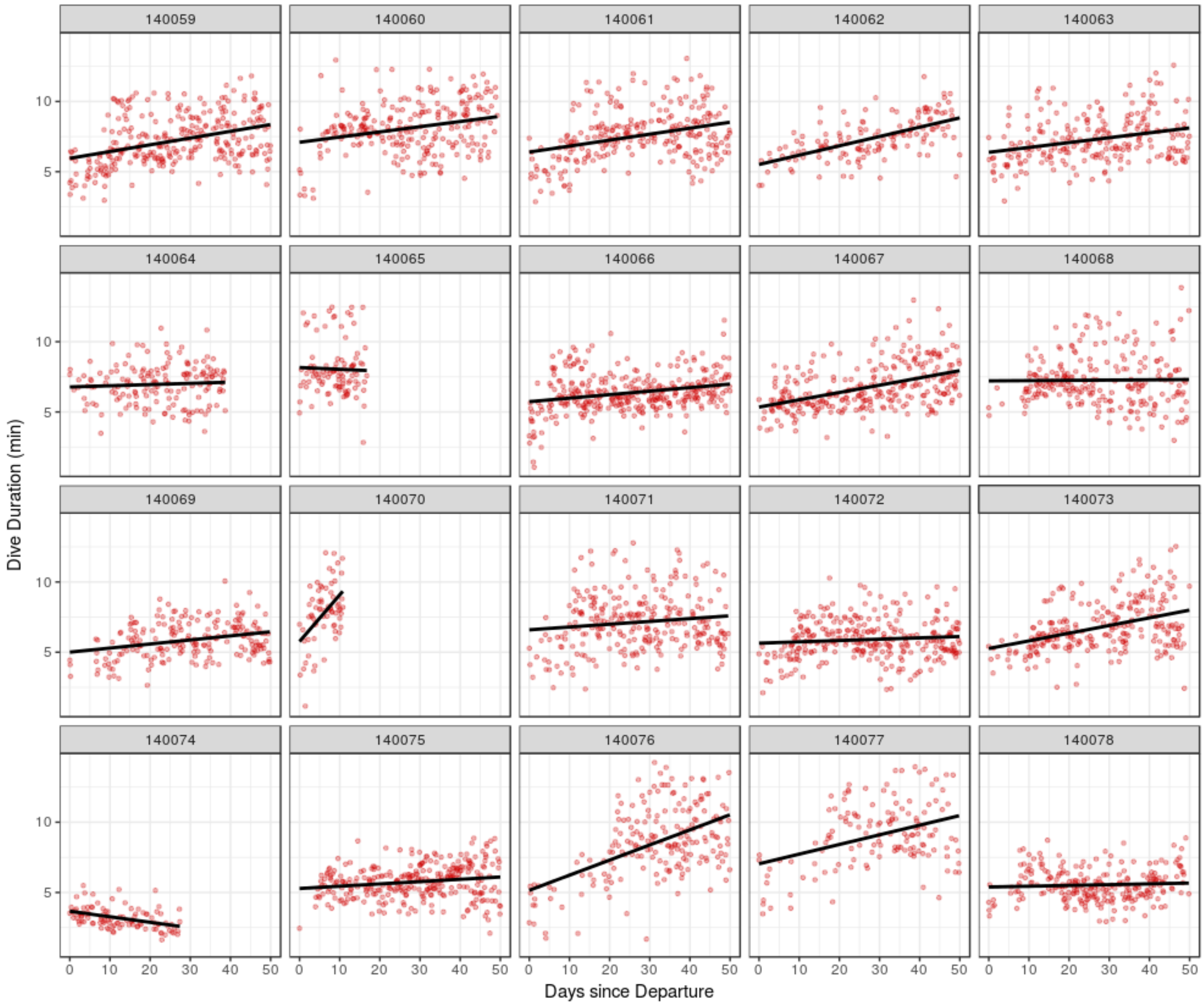

Figure A3: Random slopes/intercepts linear mixed models outputs for the changes in dive durations during the first 50 days at sea for each juvenile. Red dots are the raw data.

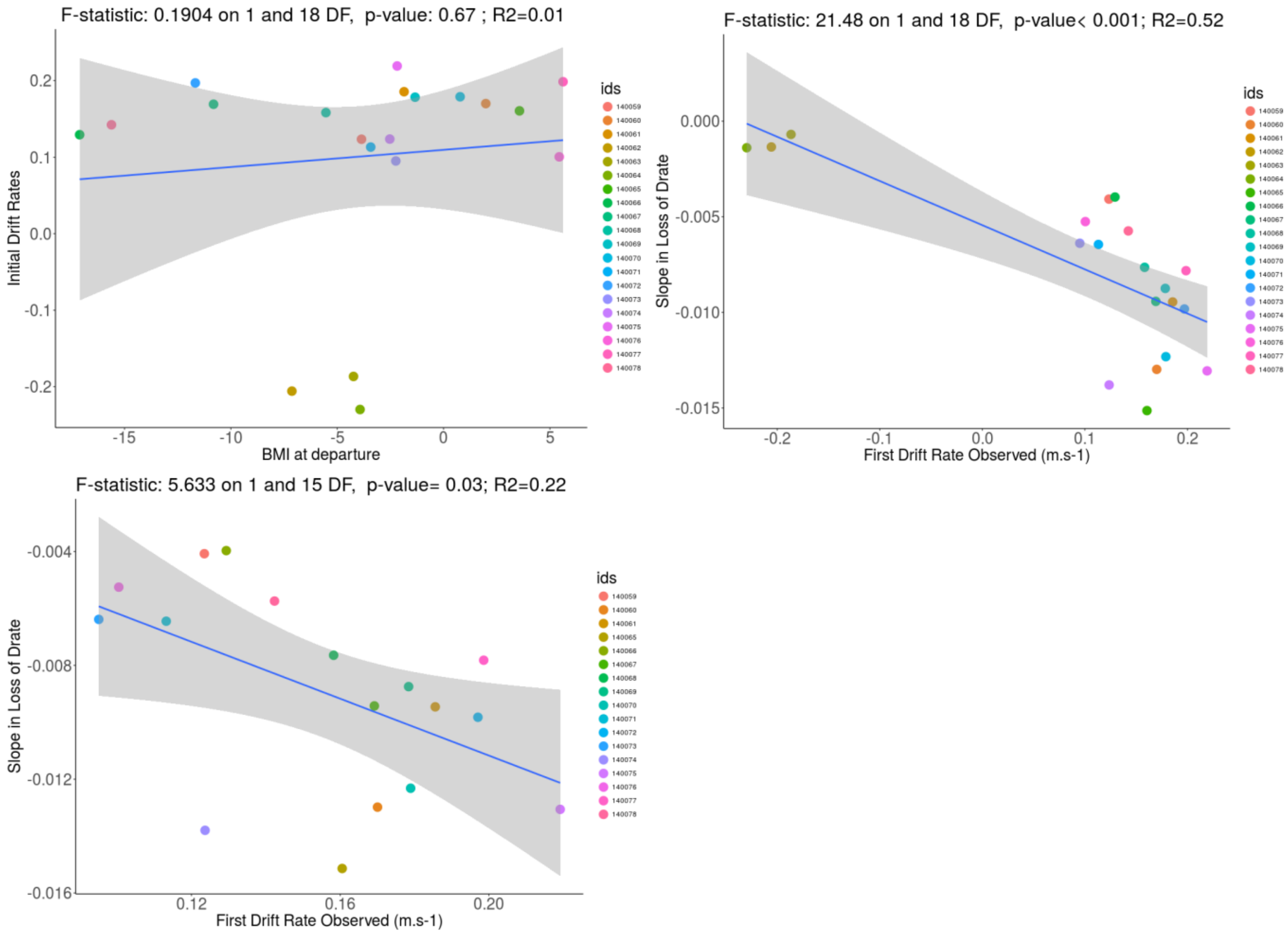

Figure A4: Initial drift rates BMI do not have a strong correlation (top left), however the slope of the changes in drift rate during the first 50 days correlates to the inital drift rate values observed per individual (top right). This correlation is stronger if the three outliers (#140062, #140063 and #140064) with negative the initial drift rates are removed (lower left). No differences were found between males and females when comparing drift rates slopes (F=1.9, p=0.189) and initial observed drift rate values (F=0.1422, p=0.710)

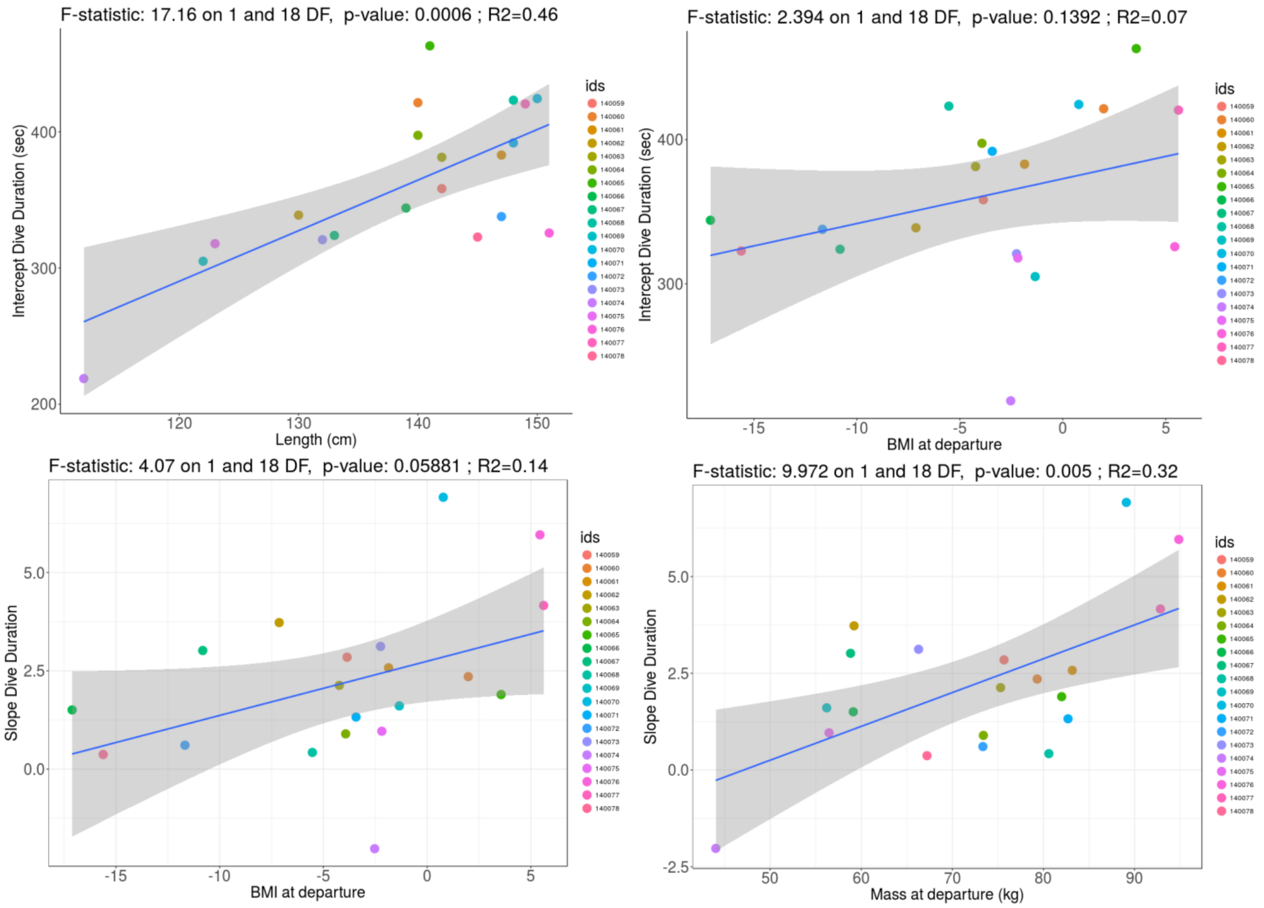

Figure A5: The duration of the first dive observed per juvenile is correlated to the body length (top left) but not to their BMI (top right). The changes in dive duration during the first 50 days is not correlated to the BMI (lower left) but is correlated to the body mass estimated at departure (lower right).

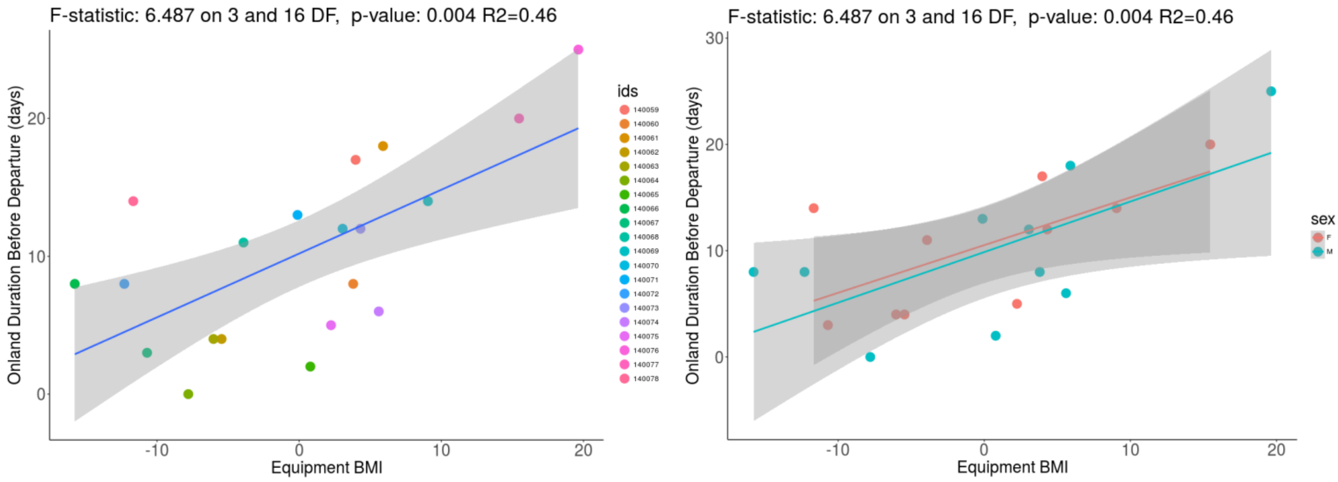

Figure A6: The relationship between time spent on land before departure and BMI estimated at equipment is significant (right) but there is no difference between male and female juveniles (left, intercept: t = -0.196, p = 0.847; slope: t = -0.042, p = 0.967).

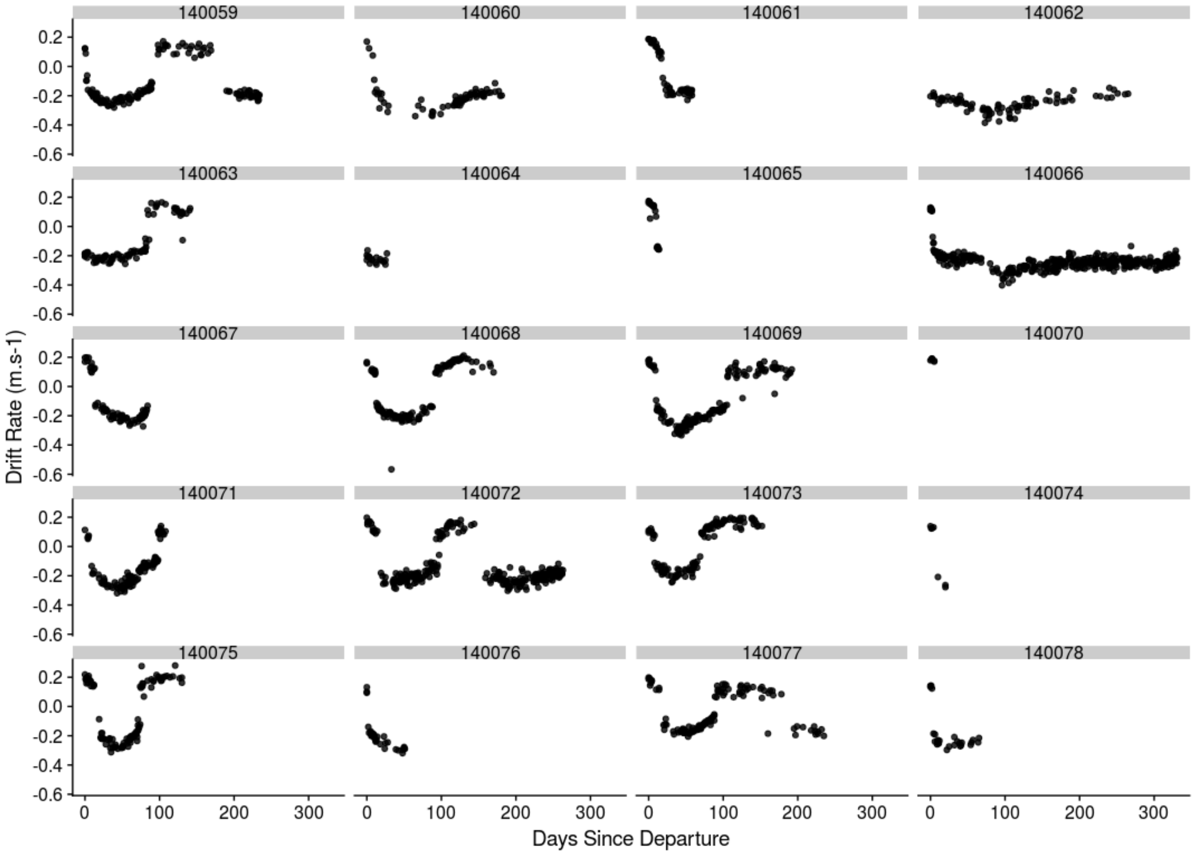

Figure A7: Drift rates time series for each juvenile estimated from the vertical speed during drift dives.

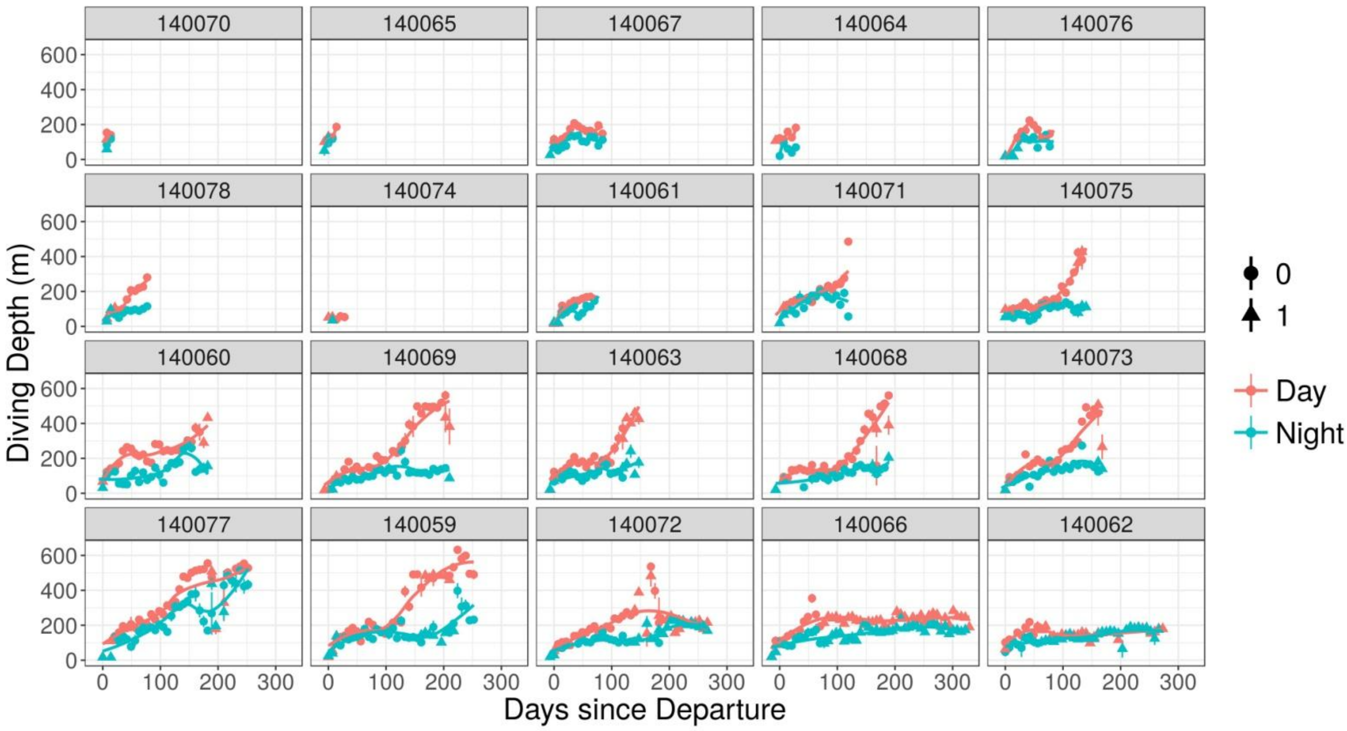

Figure A8: Nycthemeral differences between average day and night diving depths over time for each juvenile. Individuals that foraged in the Kerguelen plateau at the end of their trips are 140072, 140066 and 140062. These individuals did not perform demonstrate a strong nycthemeral behaviour as the differences between day and night depths are small.

Tables

Table A1: Deployment summaries for the 20 juvenile elephant seals. **BMI:** Body Mass Index at departure (see supplementary material) **On land**: the duration spent on land before departure. **Epi/Benthic Dives:** the proportion of benthic or epi-benthic dives performed on the Kerguelen plateau.

Ids	**Sex**	**Departure Date**	**Departure Mass (kg)**	**Departure Length (cm)**	**BMI**	**Dive Monitoring (days)**	**On-land (days)**	**Number of Dives**	**Epi/benthic Dives (%)**
140065	M	02/12/2014	83.4	141	3.6	19.6	2	105	21
140070	M	17/12/2014	98.4	150	0.8	20.8	12	74	41
140074	M	12/12/2014	47.2	112	-2.5	27.9	6	109	33
140064	M	04/12/2014	73.4	140	-3.9	38.8	0	165	3
140061	M	21/12/2014	97	147	-1.9	72.1	18	399	13
140076	M	31/12/2014	116.4	151	5.4	82.7	25	391	12
140078	F	20/12/2014	76.6	145	-15.6	82.7	14	378	14
140067	F	08/12/2014	60.6	133	-10.8	88.2	3	539	6
140071	M	18/12/2014	92.4	148	-3.4	122.1	13	708	7
140075	F	11/12/2014	59.4	123	-2.2	142.4	5	979	8
140063	F	08/12/2014	78	142	-4.2	157.3	4	808	20
140073	F	17/12/2014	74.2	132	-2.2	173.9	12	968	9
140060	M	11/12/2014	85	140	2.0	192.1	8	1201	9
140068	F	16/12/2014	88.6	148	-5.5	196.9	11	1211	9
140069	F	19/12/2014	64.8	122	-1.3	214.3	14	1120	6
140059	F	20/12/2014	88	142	-3.9	250.9	17	1379	19
140077	F	26/12/2014	109.4	149	5.6	253.1	20	1030	10
140072	M	14/12/2014	78.8	147	-11.7	274.1	8	1662	40
140062	F	08/12/2014	61.6	130	-7.1	275.3	4	913	78
140066	M	04/12/2014	64	139	-17.1	338.1	8	1895	72
		Mean±sd	79.9±17.7	139±11	-3.8±6.2	151.2±96.5	10.2±6.6	802±529	22±21

Table A2: Generalised additive mixed models (GAMMs) outputs corresponded with the time series of Figure 2 of the main manuscript (juveniles). The response variables depth, descent (Desc) and ascent (Asc), swimming effort (Sweff), and drift rates (DRs) are related to days since departure (daysdep). Individuals (ids) are in random effect.

Depth	Parametric coefficients:	Estimate	SE	t	p-value		Dev.Expl
	(Intercept)	10.587	0.243	43.56	<2e-16	***	31.20%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep)	3.992	4	1097.25	<2e-16	***	
	s(ids)	18.81	19	78.81	<2e-16	***	

Desc Sweff	Parametric coefficients:	Estimate	SE	t	p-value		Dev.Expl
	(Intercept)	6.7186	0.1994	33.69	<2e-16	***	28.30%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep)	3.992	4	440.4	<2e-16	***	
	s(ids)	18.34	19	51.48	<2e-16	***	

Asc Sweff	Parametric coefficients:	Estimate	SE	t	p-value		Dev.Expl
	(Intercept)	10.3776	0.4552	22.8	<2e-16	***	52.10%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep)	3.998	4	784.5	<2e-16	***	
	s(ids)	18.762	19	189.8	<2e-16	***	

DRs	Parametric coefficients:	Estimate	SE	t	p-value		Dev.Expl
	(Intercept)	-0.0576	0.02298	-2.507	0.0123	*	59.90%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep)	3.967	3.999	39.284	<2e-16	***	
	s(ids)	14.212	19	4.587	1.61E-14	***	

Table A3: Generalised additive mixed models outputs correspond with the time series of Figure 3 of the main manuscript (adults). Depth, descending swimming effort (Desc Sweff), ascending swimming effort (Asc Sweff), and drift rates (DRs) are related to days since departure (daysdep). Individuals (ids) are in random effect.

Depth	Parametric coefficients:	Estimate	SE	t	p-value		Dev.Expl
	(Intercept)	116.361	4.863	23.93	<2e-16	***	14.90%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep)	3.98	4	164.7	<2e-16	***	
	s(ids)	7.99	8	850.7	<2e-16	***	
Desc Sweff	**Parametric coefficients:**	**Estimate**	**SE**	**t**	**p-value**		**Dev.Expl**
	(Intercept)	2.473	0.376	6.575	4.92E-11	***	81.40%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep)	3.986	4	286.9	<2e-16	***	
	s(ids)	7.999	8	7440.8	<2e-16	***	
Asc Sweff	**Parametric coefficients:**	**Estimate**	**SE**	**t**	**p-value**		**Dev.Expl**
	(Intercept)	8.8791	0.9608	9.241	<2e-16	***	92.20%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep)	3.953	3.999	3796	<2e-16	***	
	s(ids)	8	8	21524	<2e-16	***	
DRs	**Parametric coefficients:**	**Estimate**	**SE**	**t**	**p-value**		**Dev.Expl**
	(Intercept)	-0.33933	0.00864	-39.26	<2e-16	***	55.60%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep)	3.356	3.774	206.58	<2e-16	***	
	s(ids)	7.633	8	27.43	<2e-16	***	

Table A4: Generalised additive mixed models outputs corresponded with the time series of Figure 5 of the main manuscript. Prey catch attempt rates (PrCA) are related to days since departure (daysdep). A comparison of the two life stages is included: adult post-breeding females (stadads_pb) and juveniles (stadjuvs). Individuals (ids) are in random effect.

PrCA	**Parametric coefficients:**	**Estimate**	**SE**	**t**	**p-value**		**Dev.Expl**
	(Intercept)	-1.38018	0.01	-143.5	<2e-16	***	12%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(daysdep):stadads_pb	3.872	3.945	379.25	<2e-16	***	
	s(daysdep):stadjuvs	3.984	4	433.75	<2e-16	***	
	s(ids)	26.186	28	57.54	<2e-16	***	

Table A5: GAMMs outputs corresponded to Figure 6 of the main manuscript. The response variable is surface interval in relation to dive duration (div.dur), total swimming effort (tot.sweff), depth, and prey catch attempts (bott.tipca).

Dive Duration	**Parametric coefficients:**	**Estimate**	**SE**	**t**	**p-value**		**Dev.Expl**
	(Intercept)	44.631	1.232	36.23	<2e-16	***	67.30%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(div.dur):stadads_pb	1.997	2	2162.7	<2e-16	***	
	s(div.dur):stadjuvs	1.998	2	2136.3	<2e-16	***	
	s(ids)	27.822	28	408.7	<2e-16	***	
Tot Sweff	**Parametric coefficients:**	**Estimate**	**SE**	**t**	**p-value**		**Dev.Expl**
	(Intercept)	54.076	1.685	32.09	<2e-16	***	66.10%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(tot.sweff):stadads_pb	1.985	2	2776	<2e-16	***	
	s(tot.sweff):stadjuvs	1.998	2	1286.2	<2e-16	***	
	s(ids)	27.823	28	379.5	<2e-16	***	
Depth	**Parametric coefficients:**	**Estimate**	**SE**	**t**	**p-value**		**Dev.Expl**
	(Intercept)	67.754	1.962	34.53	<2e-16	***	70.90%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(depth):stadads_pb	1.995	2	4811.2	<2e-16	***	
	s(depth):stadjuvs	1.983	2	2645.9	<2e-16	***	
	s(ids)	27.841	28	259.3	<2e-16	***	
Bottom PrCA	**Parametric coefficients:**	**Estimate**	**SE**	**t**	**p-value**		**Dev.Expl**
	(Intercept)	50.031	2.591	19.31	<2e-16	***	58.30%
	Approximate significance of smooth terms:	**edf**	**Ref.df**	**F**	**p-value**		
	s(bott.tipca):stadads_pb	1.902	1.99	68.91	<2e-16	***	
	s(bott.tipca):stadjuvs	1.986	2	68.66	<2e-16	***	
	s(ids)	27.889	28	826.53	<2e-16	***	

Table A6: Summary of parameters measured for each individual (ids): initial mass (mi, in kg), departure mass (md, in kg), length at weaning (lg, in cm), time spent onland before departure (onland, in days), scaled mass index (smi), body mass index (bmi), changes in drift rate the first 50 days (slope.dr, in m.s-^{1}.day^{-1}), first drift rate observed (first.dr, in m.s-1), changes in dive duration the first 50 days (slope.dur, in sec.day-1) and first dive duration (inter.dur, in sec)

ids	mi	md	lg	onland	sex	smi	bmi.departure	bmi.equipment	slope.dr	first.dr	slope.dur	inter.dur
140059	88.0	75.7	142.0	17.0	F	59.8	-3.9	4.0	0.0	0.1	2.8	358.3
140060	85.0	79.3	140.0	8.0	M	65.6	2.0	3.8	0.0	0.2	2.4	421.5
140061	97.0	83.2	147.0	18.0	M	59.0	-1.9	5.9	0.0	0.2	2.6	383.0
140062	61.6	59.2	130.0	4.0	F	61.8	-7.1	-5.5	0.0	-0.2	3.7	338.9
140063	78.0	75.3	142.0	4.0	F	59.5	-4.2	-6.0	0.0	-0.2	2.1	381.4
140064	73.4	73.4	140.0	0.0	M	60.7	-3.9	-7.8	0.0	-0.2	0.9	397.5
140065	83.4	82.0	141.0	2.0	M	66.3	3.6	0.8	0.0	0.2	1.9	463.2
140066	64.0	59.1	139.0	8.0	M	50.0	-17.1	-15.8	0.0	0.1	1.5	344.1
140067	60.6	58.8	133.0	3.0	F	57.2	-10.8	-10.7	0.0	0.2	3.0	324.0
140068	88.6	80.6	148.0	11.0	F	55.9	-5.5	-3.9	0.0	0.2	0.4	423.3
140069	64.8	56.2	122.0	14.0	F	71.7	-1.3	9.1	0.0	0.2	1.6	305.0
140070	98.4	89.1	150.0	12.0	M	59.3	0.8	3.1	0.0	0.2	6.9	424.5
140071	92.4	82.7	148.0	13.0	M	57.4	-3.4	-0.1	0.0	0.1	1.3	391.9
140072	78.8	73.3	147.0	8.0	M	52.0	-11.7	-12.3	0.0	0.2	0.6	337.8
140073	74.2	66.3	132.0	12.0	F	66.0	-2.2	4.3	0.0	0.1	3.1	320.8
140074	47.2	44.0	112.0	6.0	M	73.5	-2.5	5.6	0.0	0.1	-2.0	218.8
140075	59.4	56.5	123.0	5.0	F	70.2	-2.2	2.2	0.0	0.2	1.0	317.9
140076	116.4	94.9	151.0	25.0	M	61.8	5.4	19.6	0.0	0.1	6.0	325.8
140077	109.4	92.8	149.0	20.0	F	63.1	5.6	15.5	0.0	0.2	4.2	420.5
140078	76.6	67.2	145.0	14.0	F	49.7	-15.6	-11.7	0.0	0.1	0.4	322.8

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