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Supplementary material

Appendix 1.

TDRs were deployed on guillemots, razorbills and puffins on the Isle of May National Nature Reserve during the breeding season (Table A1.1). Two sampling rates were used for each species (guillemots: 16 s every 30 days or 32 s every 15 days; razorbills and puffins: 3 s every 10 days or 30 s every day) in order to balance resolution with number of days of data, due to the limited memory size of the loggers. Guillemot data were curtailed within the analysis because of data termination for the other two species.

Table A1.1. Details of TDRs retrieved from common guillemots, razorbills and Atlantic puffins breeding on the Isle of May. Loggers recorded time and depth at a sampling rate of either 16 or 32 s at 30 or 15 day intervals (guillemots), or at a sampling rate of either 3 or 30 s at 10 or 1 day intervals (razorbills and puffins). The sampling period is defined as species-specific population-level fledging date until the TDR stopped functioning or the last sampling date in January. Sex was not determined for two individual birds (Na).

Species	Sampling rate (s)	Sampling interval (days)	Bird ID	Sampling Period		N_{Days}	Sex
Guillemot	16	30	A13193	05/08/05	12/01/06	6	M
			A13195	05/08/05	12/01/06	6	F
			A13196	05/08/05	12/01/06	8	F
			A13199	05/08/05	12/01/06	6	M
			A13200	05/08/05	12/01/06	8	M
			A13202	05/08/05	12/01/06	6	Na
			A13211	05/08/05	12/01/06	6	F
			A13228	05/08/05	12/01/06	8	F
			A13233	05/08/05	12/01/06	5	F
	32	15	A13237	05/08/05	28/01/06	13	M
			A13275	20/07/05	28/01/06	15	F
			A13197	20/07/05	28/01/06	15	M
			A13226	05/08/05	28/01/06	12	F
Razorbill	3	10	A01926	06/07/08	02/01/09	19	M
			A01929	06/07/08	23/11/08	15	F
			A01930	06/07/08	02/01/09	19	F
			A01941	06/07/08	15/08/08	4	M
			A01943	06/07/08	22/01/09	21	F
			A01946	06/07/08	02/01/09	19	F
			A01947	06/07/08	05/08/08	4	M
	30	1	A01935	01/07/08	25/01/09	207	Na
			A01936	01/07/08	13/08/08	44	M
			A01938	01/07/08	09/10/08	100	F
			A01948	01/07/08	03/09/08	65	F
			A01950	01/07/08	11/11/08	141	F

			A01952	01/07/08	06/12/08	159	M
Puffin	3	10	A01959	26/07/08	06/12/08	11	M
			A01976	26/07/08	04/09/08	5	F
			A01977	26/07/08	04/09/08	4	F
			A01980	26/07/08	03/12/08	14	M
			A01991	26/07/08	16/07/08	1	M
			A01993	26/07/08	15/08/08	3	M
	30	1	A01967	19/07/08	22/09/08	66	M
			A01971	19/07/08	21/07/08	4	M
			A01984	19/07/08	24/07/08	7	F
			A01985	19/07/08	13/07/08	4	F
			A01986	19/07/08	04/08/08	18	M
			A01996	19/07/08	02/10/08	76	F

Appendix 2.

The mean population fledging dates of Isle of May guillemots, razorbills and puffins in the years of TDR deployment were 10 July 2005, 30 June 2008 and 18 July 2008, respectively. Dive data recorded prior to these dates were therefore assumed to reflect diving behaviour during the breeding season.

During the breeding season, the mean MDD of razorbills and puffins were 3.5 ± 0.1 and 3.8 ± 0.1 m respectively (Fig. A2.1). The density distributions of guillemot dive depth were bimodal (Fig. A2.1). Shallow dives (< 30 m) had a mean depth of 4.0 ± 0.1 m and deep dives (> 30 m) had a mean depth of 50.5 ± 0.3 m. MDD was similar between the sexes of all species during the breeding season, and dives were generally deeper during this time, compared to those that occurred outside the breeding season.

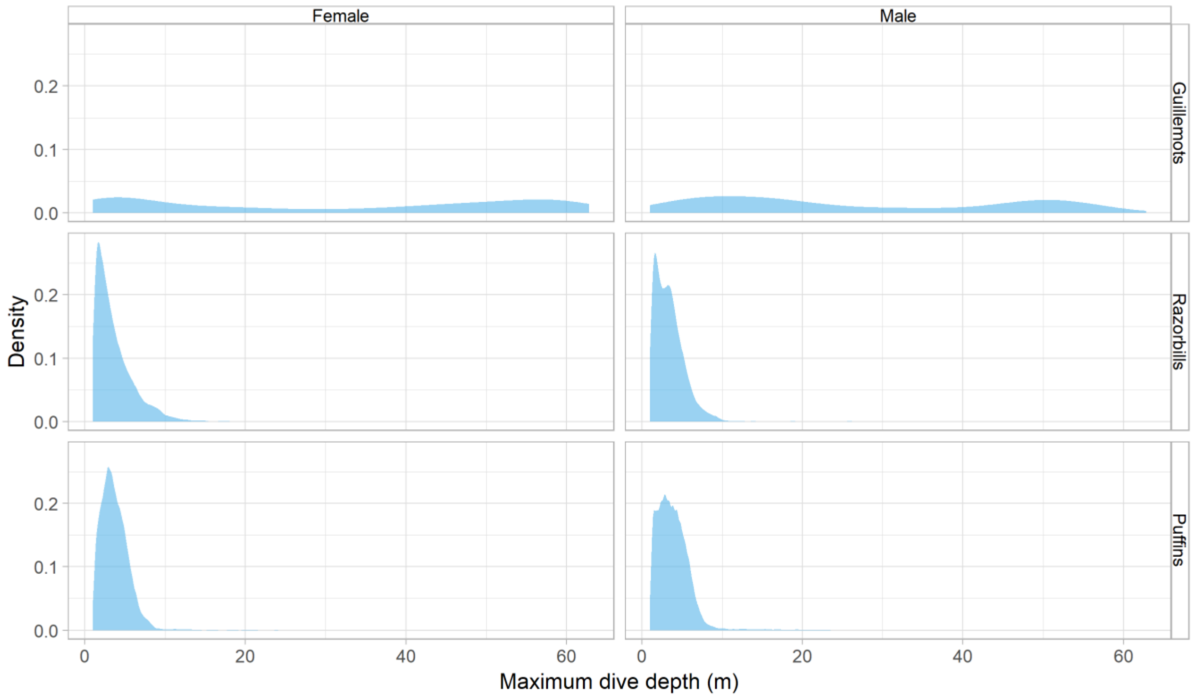


Fig A2.1. Density plots of maximum dive depths (MDD) of male and female common guillemots (N_{birds} = 11, N_{dives} = 1,766), razorbills (N_{birds} = 12, N_{dives} = 5,204) and Atlantic puffins (N_{birds} = 12, N_{dives} = 23,524) during the breeding period, prior to the mean population fledging dates.

Guillemots, razorbills and puffins spent 3.45 ± 0.46, 2.38 ± 0.19 and 4.69 ± 0.21 h submerged respectively per day during the breeding season (Fig. A2.2). DTS was similar across the sexes (razorbills males: 2.80 ± 0.28 h; razorbill females: 2. 60 ± 0.22 h; puffin males: 4.92 ± 0.29 h; puffin females: 4.28 ± 0.29 h), although female guillemots (3.95 ± 0.66 h) had greater DTS than male guillemots (2.56 ± 0.20 h). This result may be reflective of female guillemots feeding their chicks more frequently than males (Wanless and Harris 1986, Thaxter et al. 2009). Breeding season DTS was lower than that recorded outside the breeding season.

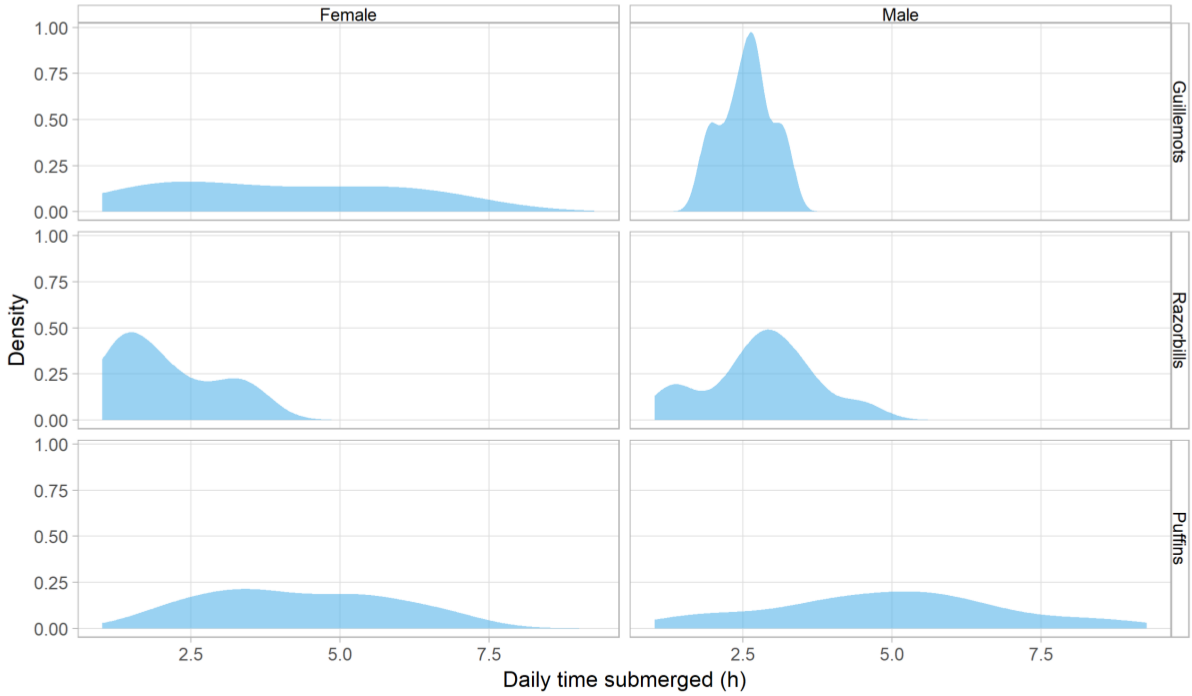


Fig A2.2. Density plots displaying the distribution of daily time submerged (DTS) by male and female common guillemots (N_{birds} = 10, N_{days} = 14), razorbills (N_{birds} = 11, N_{days} = 25) and Atlantic puffins (N_{birds} = 11, N_{days} = 74) during the breeding period, prior to the mean population fledging dates.

Thaxter, C. B., Daunt, F., Hamer, K. C., Watanuki, Y., Harris, M. P., Grémillet, D., Peters, G. and Wanless, S. 2009. Sex-specific food provisioning in a monomorphic seabird, the common guillemot Uria aalge: Nest defence, foraging efficiency or parental effort? - J. Avian Biol. 40: 75–84.

Wanless, S. and Harris, M. P. 1986. Time spent at the colony by male and female guillemots uria aalge and razorbills alca torda. - Bird Study 33: 168–176.

Appendix 3.

In order to identify bimodality in guillemot dive depth, as previously described during the breeding season (Thaxter et al. 2010), we fitted finite mixture models to each month of guillemot maximum dive depth (MDD) data using the Expectation-Maximisation algorithm in the *cutoff* package (Choisy 2015). Whilst these models force bimodality into the distributions, only the model that was fitted for the July data accurately represented the distribution of the data (Figure A3.1). For the remaining months covering the non-breeding period (August – January), distributions of MDD seemed more likely to be multimodal with high densities of shallow dives, precluding simple classifications into shallow and deep dives (Figure A3.1).

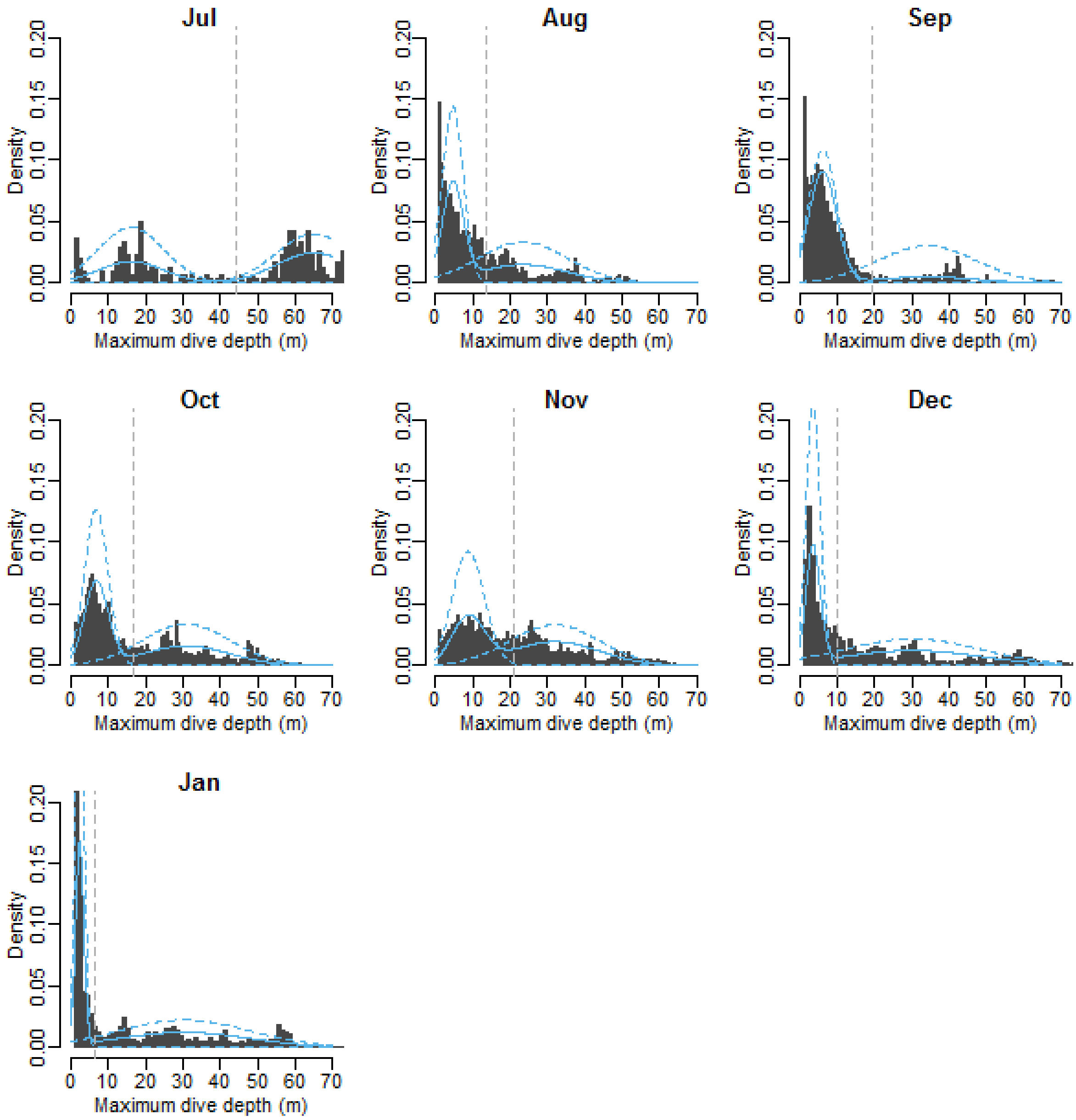


Figure A3.1. Density histograms of the maximum dive depths (MDD) recorded by TDRs attached to common guillemots (N = 13) from the Isle of May over the 2005/06 winter. Grey dashed lines illustrate a cut-off value generated by finite mixture models to identify two peaks within bimodal data. Blue lines illustrate the confidence intervals of the mixture parameter.

Choisy, M. 2015. cutoff: Identify a cutoff value from bimodal data. R package. in press.

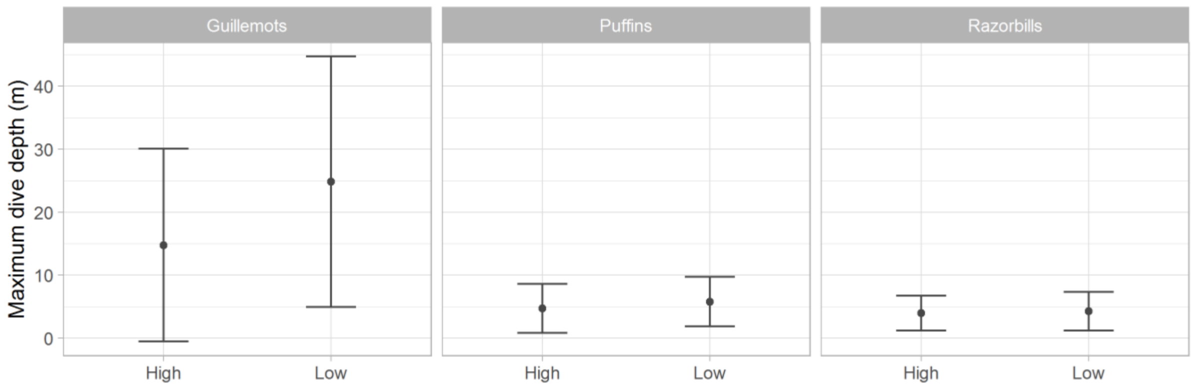
Thaxter, C. B., Wanless, S., Daunt, F., Harris, M. P., Benvenuti, S., Watanuki, Y., Grémillet, D. and Hamer, K. C. 2010. Influence of wing loading on the trade-off between pursuit-diving and flight in Common Guillemots and razorbills. - J. Exp. Biol. 213: 1018–1025.

Appendix 4.

Across all three species, TDRs recorded time and depth at one of two different sampling frequencies: 16 s every 30 days (high frequency) or 32 s every 15 days (low frequency) for guillemots; 3 s every 10 days (high frequency) or 30 s every day (low frequency) for razorbills and puffins. Data loggers that recorded at low sampling intensity may have overestimated maximum dive depth (MDD) and underestimated the measure of Daily Time Submerged (DTS), since they will not have detected all short dives. However, because lower sampling rate loggers are likely to overestimate the duration of individual dives (Wilson et al. 1995), we felt confident that our calculated quantity of DTS would not be affected by sampling frequency (Takahashi et al. 2018).

To test whether sampling rate affected our metrics of dive behaviour, we first compared the empirical estimates of MDD and DTS using the two sampling rates for each species. Second, we conducted a simulation exercise where we compared DTS at different sampling intervals. We could not simulate variation in MDD with sampling rate because of the lack of high resolution dive depth data for guillemots, razorbills and puffins at the Isle of May.

In the comparison of empirical estimates, we found that neither MDD nor DTS differed between the two sampling rates for any of the three species (Fig. A4.1).



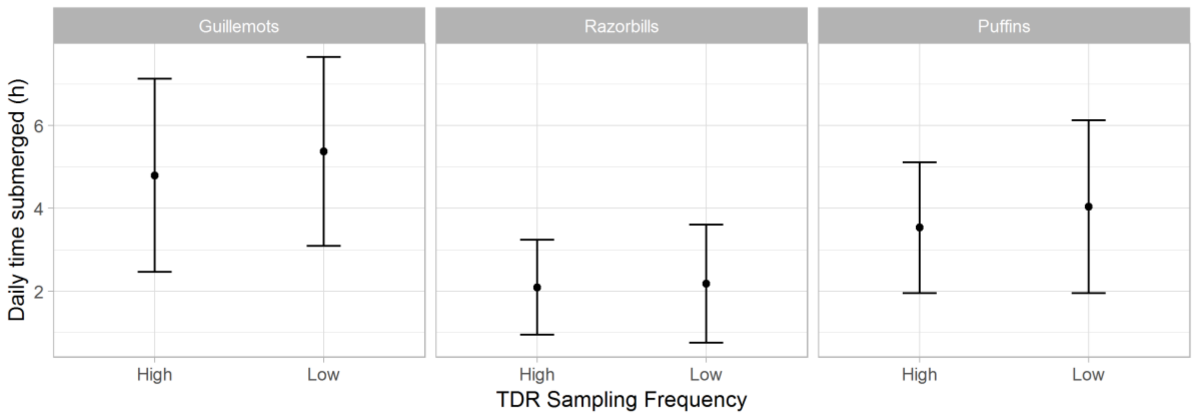


Figure A4.1. Mean maximum dive depth (MDD) and mean daily time submerged (DTS) estimated from TDRs sampling at high and low frequencies during the non-breeding period. Common guillemot (high frequency 16 s, N = 9 birds; low frequency 32 s, N = 4 birds); razorbill (high frequency 3 s, N = 6 birds; low frequency 30 s, N = 6 birds) and Atlantic puffin (high frequency 3 s, N = 7 birds; low frequency 30 s, N = 6 birds). Values are means ± SD.

In the simulation exercise, we randomly generated 100 versions of a four hour period. Birds were modelled as being at the surface at the beginning of this period and then had a 95% likelihood of staying in the same “at-surface” state and a 5% likelihood of switching into a “dive” state. This method allowed us to generate an alternative sequence of surface intervals and dives with realistic durations. To simulate the effect of the different sampling frequencies, we sampled each of the 100 iterations every 1, 2, 4, 8, 16 and 32 s. We then extracted the number of dives recorded, mean dive duration, and daily time submerged for each of the sampling frequencies. Whilst an outcome of the low sampling frequencies (32 and 30 s) was that some dives were missed, resulting in a lower number of recorded dives (Fig. A4.2), this sampling frequency also led to an overestimation of dive duration (Fig. A4.2). The combination of this underestimation of dive number and overestimation of dive duration meant that when the dive durations were summed to calculate daily time submerged (DTS), DTS was consistent between the different sampling frequencies (Fig. A4.2). Unfortunately it was not possible to simulate the effect of sampling rate on MDD in the same way since we did not have the required information on the shape and nature of auk winter dive profiles at an adequately high temporal resolution.

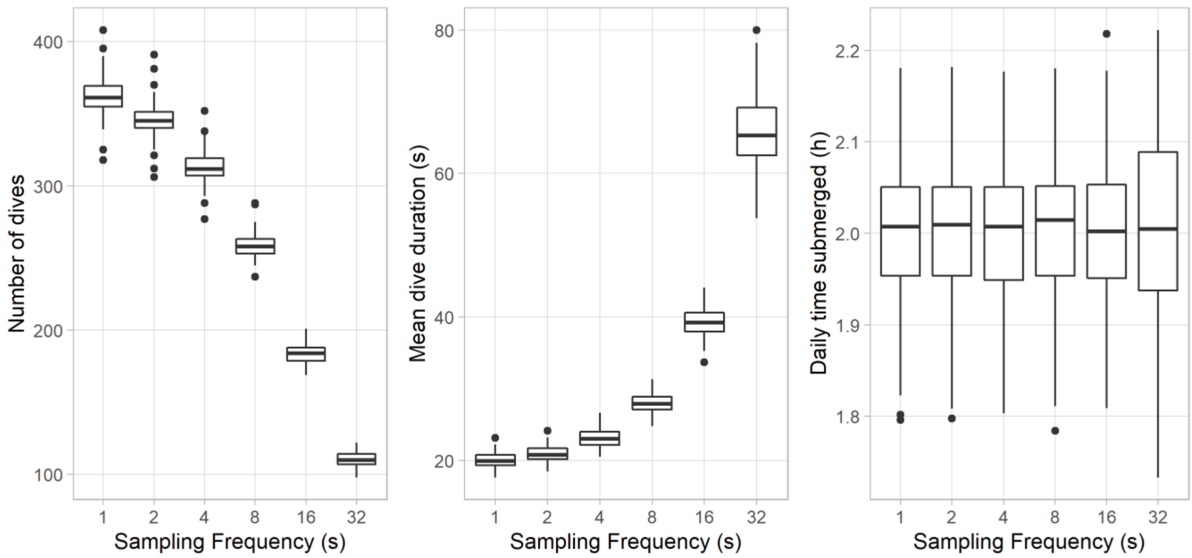


Figure A4.2. Boxplots of the number of dives, mean dive duration and daily time submerged (DTS) generated from 100 random iterations of twenty-four-hour periods comprised of 70% diving and 30% non-diving activity and extracted at sampling rates of 1 s, 3 s, 16 s, 30 s and 32 s.

Takahashi, A., Ito, M., Nagai, K., Thiebot, J. B., Mitamura, H., Noda, T., Trathan, P. N., Tamura, T. and Watanabe, Y. Y. 2018. Migratory movements and winter diving activity of Adélie penguins in East Antarctica. - Mar. Ecol. Prog. Ser. 589: 227–239.

Wilson, R. P., Jean-Benoit, K. P. and Lage, C. J. 1995. Artifacts arising from sampling interval in dive depth studies of marine endotherms. - Polar Biol. 15: 575–581.