Diving activity of Eastern Hudson Bay belugas (*Delphinapterus leucas*) in relation to the diving lactate threshold

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ABSTRACT

Aerobic dive limit (ADL) is defined as the diving duration that results in depletion of oxygen reserves and an increase in blood lactate levels above resting levels. Since it is unlikely that an animal reaches this point, many studies refer instead to diving lactate threshold (DLT). Among pinnipeds and seabirds, most dives are less than DLT. Little is known about DLT in cetaceans, but a similar relationship as in other groups would be predicted. Satellite transmitters were deployed on nine belugas in Eastern Hudson Bay during summers 2003 and 2004. Daily information on location and diving activity were collected for a mean duration of 166 days (range 67-283 d). As expected only a small number (10.5%) of all dives (n = 36 346) exceeded the estimated DLT of 9 minutes. Of those, 93% were from four animals for which tags were still transmitting during winter. In fact, 90% of the dives exceeding the DLT occurred on the winter grounds. A significant ($p<0.002$) positive relationship between dive duration and subsequent surface duration was observed for all dives below DLT ($r_s=0.84$), but the strength of the relationship for dives between DLT and 1.5x DLT was less important though still significant ($r_s=0.74$; $p<0.002$). No correlation was found for dives exceeding 1.5x DLT ($r_s=0.032$). The reasons for this are not clear, but may be related to the pattern of blood lactate accumulation and subsequent reduction. The great proportion of dives exceeding DLT during winter, combined with an observed increase in dive depths from summer to winter habitats, might be related to foraging conditions in deeper waters within this region.

INTRODUCTION

During diving, birds and marine mammals must rely on limited lung, blood and muscle storage to meet metabolic requirements. To maximize efficiency of energy expenditure, the diving metabolic rate (DMR) should be related to the minimum cost of transport for which swimming speed while diving should be held constant. Consequently, the maximal duration for which an animal can stay submerged is directly related to its O_2 storage capability, utilisation rate and its anaerobic capacity (Schreer and Kovacs 1997). The aerobic dive limit (ADL) is defined as the diving duration that results in depletion of O_2 reserves and an increase in blood lactate levels above resting levels. Since it is unlikely that an animal will sustain a dive without any O_2 for its heart and nervous system to function, many studies refer instead to diving lactate threshold (DLT). This illustrates that there is not only an increase in anaerobic metabolism, but also a continuation of aerobic metabolism during the latter portion of dives exceeding the DLT (Butler 2004). In 1997, Shaffer *et al.* determined experimentally a 9-10 min post-dive blood lactate concentration increase, and estimated O_2 stores resulting in an ADL (cADL) of 8-10 minutes for 2 trained adult beluga whales.

OBJECTIVES

- Determine the number of dives below and above DLT (based on Shaffer *et al.* 1997) for nine belugas in Eastern Hudson Bay (EHB);
- Determine if there is a seasonal difference in the number of dives exceeding DLT;
- Study dive behaviour in relation to DLT (correlation between dive and surface duration).

MATERIALS AND METHODS

Satellite transmitters (SRDL 9000, Sea Mammal Research Unit) were deployed at Little Whale River estuary, Eastern Hudson Bay, during summers 2003 and 2004.

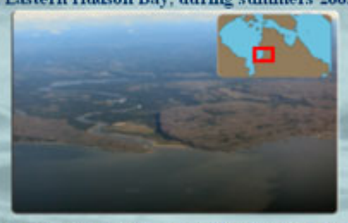

Table 1. Biological and tracking information for nine satellite-tagged EHB belugas during summers 2003 and 2004. Underlined numbers represent individuals followed into winter.

Whale #	Sex	Length (cm)	Weight (kg)[a]	Deployment date	End of tracking	Tracking duration (days)
9365	M	300	356	09-07-04	13-09-04	68
9371	M	281	300	14-07-04	12-10-04	91
9378	M	310	387	04-07-04	22-10-04	111
9392	F	350	529	21-07-04	08-11-04	111
9379	F	348	522	12-07-04	05-12-04	146
3415	F	335	473	22-07-03	29-01-04	190
3022	M	385	677	11-07-03	13-02-04	218
9367	F	361	573	18-07-04	15-04-05	272
9390	M	370	611	17-07-04	26-04-05	283

[a] Estimated from length-weight equation in Doidge (1990)

ADL is calculated from O_2 store values and diving metabolic rate (DMR). We estimated DMR from basal metabolic rate (BMR) and established DLT from two O_2 store values (35 and 51 ml O_2/kg). We then studied diving from a physiological and behavioural standpoint using the calculated ADL, and the DLT value determined experimentally by Shaffer *et al.* (1997).

RESULTS

Table 2. DLT estimation from two O_2 store values and diving metabolic rates (DMR) for dives over DLT (5-10% of all dives), for nine EHB belugas.

O_2 store	35 (ml O_2/kg)[a]	51 (ml O_2/kg)[b]
DMR (ml O_2/kg.min)	1.7-2x BMR	2.5-3x BMR
DLT (min)	8.72[c]	8.58[c]

[a] as reported in Schreer and Kovacs (1997)
[b] as reported in Shaffer *et al.* (1997)
[c] an estimate of 9 minutes is used hereon to define DLT

- The DLT was determined to be approximately 9 minutes for the two O_2 store values. To achieve this 9-minute DLT, the DMR for a 51 ml/kg O_2 store is about 1x BMR higher than for a 35 ml/kg O_2 store.

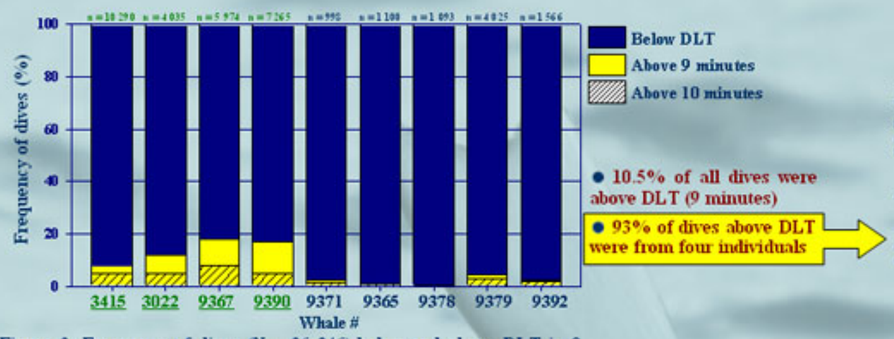

Figure 2. Frequency of dives (N = 36 346) below and above DLT in 9 EHB belugas. Underlined numbers represent individuals followed into winter.

Figure 1. Seasonal movements of an EHB beluga

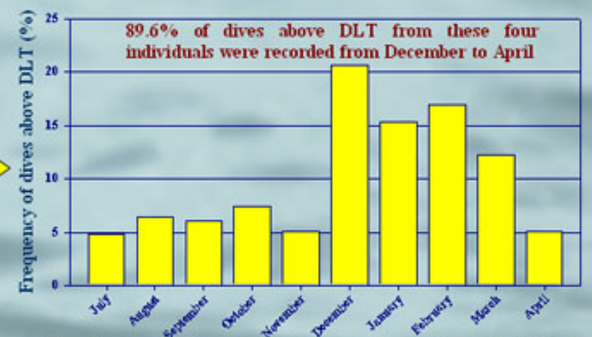

Figure 3. Seasonal distribution of dives above DLT (N = 3 570) in 4 EHB belugas.

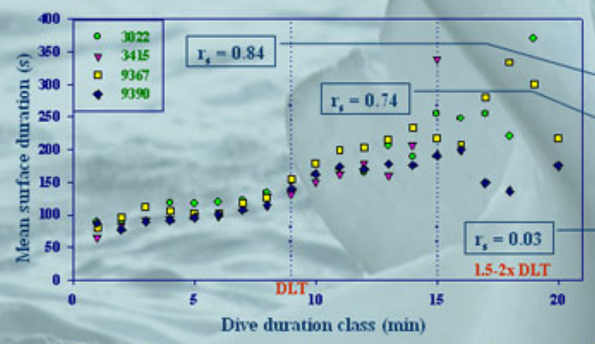

Figure 4. Mean surface duration according to dive duration class in 4 EHB belugas. Spearman correlations (r_s) are indicated for dive durations below DLT, around DLT (1-1.5x DLT), and 1.5-2x DLT.

- Below DLT, correlations are high and significant for all four separate individuals, and all individuals pooled.
- Around DLT (9-14 minutes), correlations are high and significant for three separate individuals, while one displays no correlation. When all individuals are pooled, correlation of surface duration with dive duration is still significant, but less important than below DLT.
- When dive duration is well above DLT (1.5-2x DLT), there are no correlations between surface and dive durations for all separate or pooled individuals.

DISCUSSION AND CONCLUSION

- The greatest proportion of dives exceeding DLT occurred near the end of migration and throughout winter. This, combined with the fact that all dives that were 1.5-2x DLT happened on the wintering grounds, suggest an important change in diving behaviour when reaching the Labrador Sea. This change is possibly due to greater depths in winter habitats which likely provide favourable feeding conditions. The animals might then be more inclined to push their limits and achieve much greater dive durations.
- Shaffer *et al.* (1997) report that lactate levels are elevated for dives longer than 9-10 minutes. When lactate levels are beyond resting levels and accumulate, the variability of surface duration intervals should increase, as it creates an O_2 debt during short surface periods that lengthen when the debt has to be paid back later. This variability was observed in our study animals for winter dives, progressively for 9-14 minute dives, but drastically for dive durations longer than 14 minutes.
- If DMR is close to the 2x BMR value observed in many marine mammal species, our results suggest that O_2 stores in belugas might be between 35 and 51 ml O_2/kg, which would raise the DLT by a few minutes, in agreement with observations by Martin *et al.* (1993). Different results might also originate from the fact that Shaffer *et al.* (1997) experimented on trained animals rather than on migrating or feeding animals. Our study animals could have been using a combination of behavioural and physiological adaptations, which could explain why belugas are able to dive for durations far beyond their estimated aerobic capacities.

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