# Energetic consequences of behavioural responses to sonar in killer whales

Marjoleine M.H. Roos and Patrick J.O. Miller

## Introduction

Measuring cetaceans' energetics costs triggered by human stressors suspected to cause behavioural disturbance, such as sonar, is important to evaluate its significance in both short- and long-term effects on individual survival. However, measuring energetics in large free-ranging cetaceans remains a challenge.

In general, breathing rates (BR) (multiplied with a fixed $O_2$ uptake) are used as a metric for energetics, though breaths do not account for breath-by-breath variation in gas exchange. Here we implemented a innovative method to produce more realistic energetic estimations from longitudinal continuous DTAG data records, including breath times, from fee-ranging killer whales (*Orcinus orca*), which were exposed to experimental sonar, in combination with theoretical data. This new method allows $O_2$ uptake to vary per breath depending on the estimated $O_2$ saturation within the animal at the time of the breath.

## Methods

We used DTAG data from 3 adult North Atlantic killer whales (1 ♀, 2 ♂) which were exposed to sonar, including breathing times and underwater behaviour. For the 2 males three sonar experiments were conducted, while for the female just one.

**Methods**:

- Establishing a theoretical $O_2$ exchange model, with as key feature the $O_2$ uptake curve, so that $O_2$ uptake can vary per breath according to estimated $O_2$ store at time of the breath. Data on physiological aspects from other studies (tidal lung volume, (basal) metabolic rates, average $O_2$ uptake, $O_2$ store capacities) were implemented in the model
- Calculating fluking rate from pitch in the DTAG data per 15 min
- Calculating BR from depth sensor DTAG data per 15 min
- Estimating the $O_2$ uptake through the theoretical model per 15 min

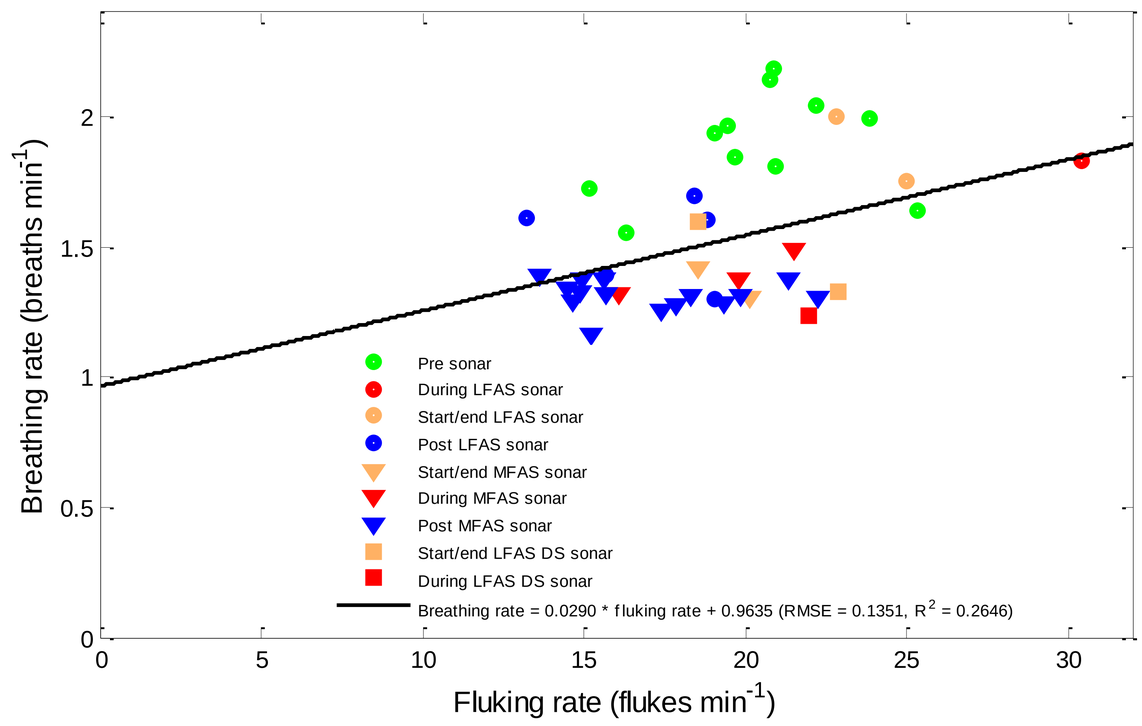


**Figure 1.** Scatter plot of the fluking rate versus breathing rate for one of the adult male killer whales (09_144b) with symbols representing the different phases of the tagging record.

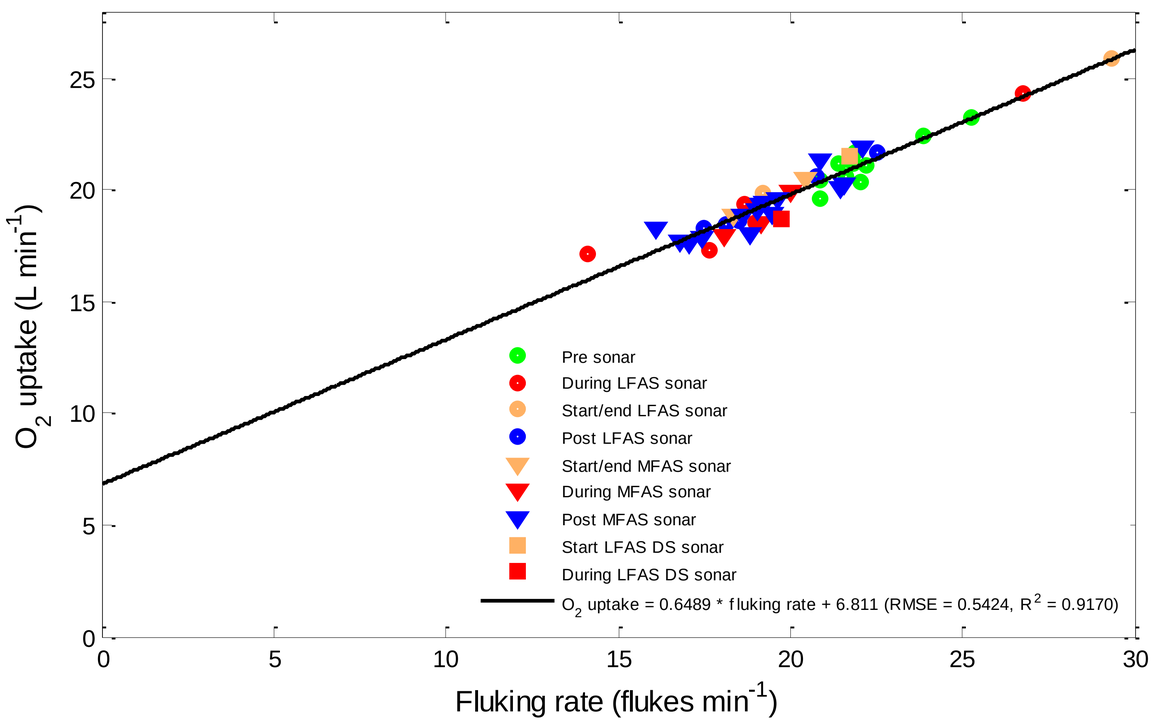


**Figure 2.** Scatter plot of the fluking rate versus estimated $O_2$ uptake for one of the adult male killer whales (09_144b) with symbols representing the different phases of the tagging record.

## First results

1. BR as metric for energetics: results in a estimation of unlimited increasing $O_2$ store over the tag record instead of a balance between $O_2$ uptake and $O_2$ use represented by a rather weak correlation (Fig. 1).

2. Theoretical $O_2$ model including $O_2$ uptake curve: stronger correlation or balance between $O_2$ use (depending on fluking rate and breath interval) and $O_2$ uptake (Fig. 2).

3. BR pre-sonar of one of the males were overall somewhat higher than during and post-sonar, irrespective of level of activity (Fig. 1). For the other male this observation was less prominent, while for the female it was not prominent at all.

4. For all whales activity level increased significantly during the first sonar exposure compared to activity level pre-sonar, accompanied by an increase in $O_2$ uptake (Fig. 1). For consecutive exposures no behavioural disturbance was observed.

5. Nevertheless, no elevated metabolic rates were observed other than those induced by increased activity level (Fig. 2).

## Conclusions

1. Relatively weak correlation exists between BR and level of activity for all whales.

2. Including fluctuating $O_2$ uptake per breath improved fit of model to data significantly for all whales: **timing of breaths is important in making accurate energetic estimations!**

3. For all whales behavioural disturbance was present after the first sonar exposure, however caused by different sonars: MFAS for female and LFAS for males.

4. This study shows no indication of elevated metabolic rates caused by sonar in free-ranging killer whales, other than those induced by activity level.

## Future work

- Examine the underlying physiological effect of the stress response to $O_2$ use and respiration
- Evaluate whether the type of sonar induces an increase in level of activity or any sonar exposure which is the first disturbance of the experiment

Sea Mammal Research Unit

University of St Andrews

**Contact details:**
mmhr@st-andrews.ac.uk