Nurse shark acceleration and oxygen consumption in cold and warm water (Shark Metabolic Rate project)

Website: https://www.bco-dmo.org/dataset/670902
Data Type: experimental
Version: 1
Version Date: 2016-12-21

Project
» Determining the Field Metabolic Rate of Marine Predators: Integrating Accelerometry and Respirometry to Bridge the Gap Between the Laboratory and the Field (Shark Metabolic Rate)

Contributors	Affiliation	Role
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Abstract
Nurse shark acceleration and oxygen consumption in cold and warm water.

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Coverage

Spatial Extent: **N**:28.457 **E**:-80.29 **S**:24.54 **W**:-82.83
Temporal Extent: 2012 - 2016

Methods & Sampling

These methods describe all those associated with the project.

Capture and maintenance:

Respirometry experiments were conducted on juvenile nurse, lemon, and blacktip sharks. Nurse sharks (n=8, 53-132 cm TL) were captured via rod and reel from the Florida Keys, USA. Lemon sharks (n= 30, 69-100 cm TL) were captured with cast nets from Cape Canaveral, FL, and the Florida Keys, USA. Blacktip sharks (n = 8, 53-64 cm TL) were captured with rod and reel from Terra Ceia Bay, FL, USA. All animals were transported to Mote Marine Laboratory in Sarasota, FL, and held in a 150,000 liter indoor, recirculating tank for the duration of experiments. Sharks were fed a diet consisting of herring, squid, and shrimp every other day to satiation, but were fasted prior to the beginning of trials to achieve a post-absorptive state. Nurse sharks were fasted for at least 72 h prior to trials, and lemon and blacktip sharks were fasted for at least 48 h prior to trials. All sharks were kept on a constant 12 h light:dark cycle.

Respirometry trials were run at two temperature groups representing the low (~20°C) and high (~30°C) end of the temperature range these species are likely to experience in the wild. Sharks were acclimated to trial temperatures in the holding tank for at least a week prior to experimentation. Trials with lemon and blacktip sharks were all run within 1 –2 months of initial capture. Nurse shark trials were run with individuals that had been maintained in captivity for at least one year.

Accelerometry:

During trials, sharks were equipped with Cefas G6A+ acceleration data loggers (Cefas, Inc., Lowestoft, UK), which recorded triaxial acceleration at 25 Hz. Tags were attached to the first dorsal fin of sharks at two points using monofilament (Fig. 4) at least 24 h in advance of the start of a trial. Since sharks tagged in the field would also need to be tracked acoustically in order to retrieve the data loggers, the loggers used in captive trials were paired with a mock acoustic tag (Vemco Inc., Nova Scotia, model V9) in order to maintain the same weight and drag as tags used in field studies (see Fig. 4). The paired tag package measured 37 x 36 x 15 mm and weighed 23 g in air, representing 0.02-0.002% of the body mass of the study animals.

Respirometry:

Trials were conducted in a circular, closed respirometer constructed from a modified fiberglass holding tank, as described in Whitney et al. (2016). Briefly, the respirometer was sealed using a lid constructed from a PVC frame with translucent plastic sheeting stretched across it, and dissolved oxygen (DO) and temperature were measured using a handheld YSI (model Pro 2030, Yellow Springs, OH). In order to ensure even water mixing in the respirometer and create water flow past the YSI probe for accurate DO measurements, a pump was set up in the centre of the tank facing into a T-shaped pipe made of PVC which housed the YSI probe, providing sufficient water movement to mix water throughout the system without creating a current in the tank. The pump and YSI were enclosed in a circular cage made of PVC and rigid plastic mesh during lemon and nurse shark trials to encourage the sharks to swim in full circles around the outer edge of the tank. This mesh cage was not used during blacktip trials because it appeared to induce stress in blacktip sharks. See Fig. 4 for a picture of the respirometer set-up.

Lemon and nurse sharks were placed into the respirometry system at least 12 h prior to the start of trials to allow them to acclimate to the system overnight. Blacktip sharks appeared to fatigue after extended periods in the smaller tank system, and were acclimated to the respirometer for 1 h prior to the start of trials rather than overnight. After the acclimation period, the respirometer tank was isolated from its flow-through system and sealed off with the lid. The tank was surrounded by a curtain to limit extraneous disturbances, and the trials monitored remotely using a live digital video feed. DO and water temperature were recorded every five minutes, and behavior monitored constantly throughout the trials. Trials began with the DO near 100% saturation and were run until the DO reached 80% saturation. To assess background respiration, a blank respirometer (without an animal) was measured for 4 h during each group of trials.

Data analysis:

Periods of the trials where sharks displayed consistent behavior (either constant swimming or resting) for at least 20 min, were used to analyze metabolic rate. Oxygen consumption rate (MO2, mgO2 kg-1 h-1) was calculated for each one of these periods using equation 1:

(3) MO2 = (S-b)(60 min)(V)/(W)

Where S is the slope of the oxygen degradation curve (in min), b is the slope of the background respiration curve, V is the volume of the respirometer in liters, and W is the weight of the shark in kg. The volume of the shark (<10 l) was considered to be negligible relative to the respirometer volume (2494 l), representing an error of <0.5%, and was thus not incorporated into our model.

Accelerometer data were analyzed using Igor Pro (Wavemetrics, Lake Oswego, OR). Static acceleration (indicating animal body position) was separated from dynamic acceleration (indicating animal movement) using a 3 s box smoother (Shepard, 2008), and ODBA calculated as the sum of the three dynamic acceleration axes. A mean ODBA value was calculated for each time interval where MO2 was analyzed during respirometry trials, to provide paired ODBA-MO2 points for analyses.

SMR's (Standard Metabolic Rate) were calculated for lemon and nurse sharks at each experimental temperature by averaging metabolic rates during all resting intervals recorded. Since blacktip sharks are a ram-ventilating species, SMR was not directly calculated, but was estimated using the intercept of the ODBA-MO2 relationship. RMRs were calculated for each species and temperature grouping as the mean metabolic rate of all periods where the study animal showed consistent swimming activity. Rest periods for lemon and nurse sharks were not included in RMR calculations.

Due to difficulties in keeping blacktip sharks in captivity for extended periods, a full ODBA -MO2 calibration was not conducted at temperatures near 20°C. However, a pair of trials was run at 21.6°C on one individual, allowing for the calculation of a preliminary Q10 value. Since there were insufficient data at the low temperatures to extrapolate an SMR for blacktip sharks, this Q10 value was calculated based on differences in RMR. Only RMR data that overlapped in ODBA levels between the two temperatures were used in the Q10 calculation to ensure the comparison was made between metabolic rates from similar activity levels. Q10 values for nurse and lemon sharks were calculated using SMR data. Q10 values were calculated according to the Van't Hoff equation

(4) $Q10 = (R2/R1)^{10/T2-T1}$

Where R1 is the metabolic rate at temperature T1, and R2 the metabolic rate at temperature T2.

Error estimation and modeling:

Error estimation and modeling were performed in R (R Core Team, 2010), using the lme4 (Bates et al. 2015) and MuMIn (Barton, 2016) packages. Linear mixed models were constructed to describe the relationship between ODBA and oxygen consumption for each species, with ODBA, activity state (resting or swimming), and temperature group as predictor variables, and individual included as a random effect. All combinations of variables and interaction effects were assessed using a comprehensive model selection table produced by the MuMIn package. Models were compared against each other using a corrected Akaikes Information Criterion (AICc), residuals, log likelihood, and R2 of the models. Using the regression line produced by the best-fit model, the predicted MO2 for each analysis interval was calculated, and compared against the measured MO2 to calculate the standard error of the estimate for each species [(predicted MO2 – observed MO2) / predicted MO2 x 100], which was examined as a percentage of the measured MO2. Normality of the residuals of the optimal models was tested using an Anderson-Darling test (Wright et al., 2014).]

Data Processing Description

BCO-DMO Processing notes:
- added conventional header with dataset name, PI name, version date
- modified parameter names to conform with BCO-DMO naming conventions
- combined cold and warm data tables
- converted formulae to values
- nd (no data) was entered into all blank cells
- changed #DIV/0! in 'cost_transport' column
- re-formatted date from m/d/yyyy to yyyy-mm-dd

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Data Files

File
nurse_respiration.csv (Comma Separated Values (.csv), 22.65 KB) MD5:c82645d7472807841ac2366f64a76ab5 Primary data file for dataset ID 670902

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Related Publications

Bates, D., Maechler, M., & Bolker, B. (2013). lme4: Linear mixed-effects models using S4 classes. R package version 0.999999-2.
Software

Lear, K. O., Whitney, N. M., Brewster, L. R., Morris, J. J., Hueter, R. E., & Gleiss, A. C. (2016). Correlations of metabolic rate and body acceleration in three species of coastal sharks under contrasting temperature regimes. The Journal of Experimental Biology, 220(3), 397–407. doi:10.1242/jeb.146993

Results

MuMIn, Barton, K. (2018). multi-model inference. R package version 1.15. 6. 2016. https://CRAN.R-project.org/package=MuMIn
Methods

Shepard, E., Wilson, R., Halsey, L., Quintana, F., Gómez Laich, A., Gleiss, A., … Norman, B. (2008). Derivation of body motion via appropriate smoothing of acceleration data. Aquatic Biology, 4, 235–241. doi:10.3354/ab00104
Methods

Whitney, N. M., Lear, K. O., Gaskins, L. C., & Gleiss, A. C. (2016). The effects of temperature and swimming speed on the metabolic rate of the nurse shark (Ginglymostoma cirratum, Bonaterre). Journal of Experimental Marine Biology and Ecology, 477, 40–46. doi:10.1016/j.jembe.2015.12.009
Results

Wright, S., Metcalfe, J., Hetherington, S., & Wilson, R. (2014). Estimating activity-specific energy expenditure in a teleost fish, using accelerometer loggers. Marine Ecology Progress Series, 496, 19–32. doi:10.3354/meps10528
Methods

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Related Datasets

IsRelatedTo

Whitney, N., Hueter, R. (2016) **Shark acceleration and oxygen consumption trials summary (Shark Metabolic Rate project).** Biological and Chemical Oceanography Data Management Office (BCO-DMO). (Version 1) Version Date 2016-12-21 http://lod.bco-dmo.org/id/dataset/670880 [view at BCO-DMO]

IsSupplementedBy

Whitney, N., Hueter, R. (2016) **Shark respirometry temperature corrections from other studies (Shark Metabolic Rate project).** Biological and Chemical Oceanography Data Management Office (BCO-DMO). (Version 1) Version Date 2016-12-21 http://lod.bco-dmo.org/id/dataset/670974 [view at BCO-DMO]

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Parameters

Parameter	Description	Units
expt_descrip	whether trial took place in warm or cold water	unitless
date	trial date formatted as YYYY-MM-DD	unitless
shark_id	individual shark identifier	unitless
weight_kg	shark weight	kilograms
flume_static	whether trial was in flume or static water	unitless
day_night	whether trial took place during the day or at neight	unitless

time_start	trial start time formatted as HH:MM	unitless
time_stop	trial stop time	unitless
duration_min	trial duration	minutes
min_elapsed	minutes elapsed since start of trial	minutes
temp	tank temperature	degrees Celsius
behavior	shark behavior during trial	unitless
slope	?what are the two variables?	unitless
slope_corr	corrected slope: the slope minus 0.0004 for cold and minus 0.0006 for warm trials	unitless
VO2	Oxygen consumption of animal during experiment	milligrams oxygen/kiligram/hour (mgO2/kg/h)
MR_cal_kg_h	metabolic rate	calories/kilogram/hour (cal/kg/h)
MR_kJ_day	metabolic rate	kilojoules/day (kJ/day)
ODBA_start	Overall dynamic body acceleration at start of trial	gravity (g)
ODBA_end	Overall dynamic body acceleration at end of trial	gravity (g)
ODBA_mean	Overall dynamic body acceleration as measured by an acceleration data logger tag	gravity (g)
ODBA_bin	Overall dynamic body acceleration bins	gravity (g)
time_circle_avg	average time to swim circle once	?
speed_swim_2m_circle	swimming speed around a 2 meter diameter circle	centimeters/second (cm/s)
speed_swim_cm_s	swimming speed bins	centimeters/second (cm/s)

speed_swim_km_h	swimming speed	kilometers/hour (km/h)
length_total	total body? length	centimeters
speed_swim_BL	swimming speed	body lengths/second
BL_s_bin	swimming speed bins	body lengths/second
cost_transport	Cost of transport	calories/kilogram/kilometer (cal/kg/km)
accelmeter_flag	whether accelerometer was attached to specimen or not	unitless
MO2_ODBA	?ratio of warm acclimated? Oxygen consumption rate (MO2) to ODBA	milligrams oxygen/kiligram/hour/gravity (mgO2/kg/h/g)
VO2_ODBA	?ratio of cold acclimated? Oxygen consumption rate (VO2) to ODBA	milligrams oxygen/kiligram/hour/gravity (mgO2/kg/h/g)

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Instruments

Dataset-specific Instrument Name	Cefas G6A+ acceleration data loggers (Cefas, Inc., Lowestoft, UK),
Generic Instrument Name	Accelerometer
Dataset-specific Description	Recorded triaxial acceleration at 25 Hz of shark; attached to first dorsal fin.
Generic Instrument Description	An instrument for measuring acceleration, typically that of an automobile, ship, aircraft, or spacecraft, or that involved in the vibration of a machine, building, or other structure.

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Deployments

Whitney_2012-16

Website	https://www.bco-dmo.org/deployment/670842
Platform	Mote Marine Lab
Start Date	2012-04-01
End Date	2016-03-31
Description	shark studies

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Project Information

Determining the Field Metabolic Rate of Marine Predators: Integrating Accelerometry and Respirometry to Bridge the Gap Between the Laboratory and the Field (Shark Metabolic Rate)

Coverage: Gulf Coast of South Florida and Bimini, Bahamas

Description from NSF award abstract:
Energetics is a central theme in ecology, and metabolism may be the primary factor determining the structure of biological systems as a whole. Despite the importance of top level predators in marine ecosystems and the need to understand the impact of their global population declines, surprisingly little is known about energy flow in upper trophic levels. This gap in knowledge is due to the difficulty of assessing the metabolic rate of marine predators and the inability to link experimentally derived metabolic rates to those of free-ranging animals in their natural habitat. Novel accelerometry technology is now making this link possible for the first time. Because Overall Dynamic Body Acceleration (ODBA) has been shown to correlate closely with oxygen consumption in numerous vertebrate taxa, this potentially transformational technique can be used to derive time-energy budgets for free-ranging marine predators.

This study will integrate the use of respirometry and accelerometry technology to bridge the gap between laboratory- and field-based metabolic rates for three species of sharks with different behaviors. The PIs will conduct respirometry experiments on accelerometer-equipped animals in the laboratory to determine the relationship between metabolic rate and ODBA for each species over a range of swim speeds and water temperatures. Using these relationships, the PIs will then conduct field experiments using accelerometry to calculate the absolute energetic expenditure of sharks in their natural habitat over several days. Because accelerometers also provide data with which specific shark behaviors can be quantified, the PIs will be able to partition between standard and active metabolic rate and determine how the relationship changes at varying temperatures. This aspect will have implications for predicting how seasonal or long-term changes in sea surface temperatures are likely to affect the impact of ectothermic predators on their prey.

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Funding

Funding Source	Award
NSF Division of Ocean Sciences (NSF OCE)	OCE-1156141
NSF Division of Ocean Sciences (NSF OCE)	OCE-1156145

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