EXTRACTING SWIMMING KINEMATICS FROM HIGH-RESOLUTION DATA

Practical Lesson

REDUCE

Movement Ecology Group

BIOPOLIS

cibio

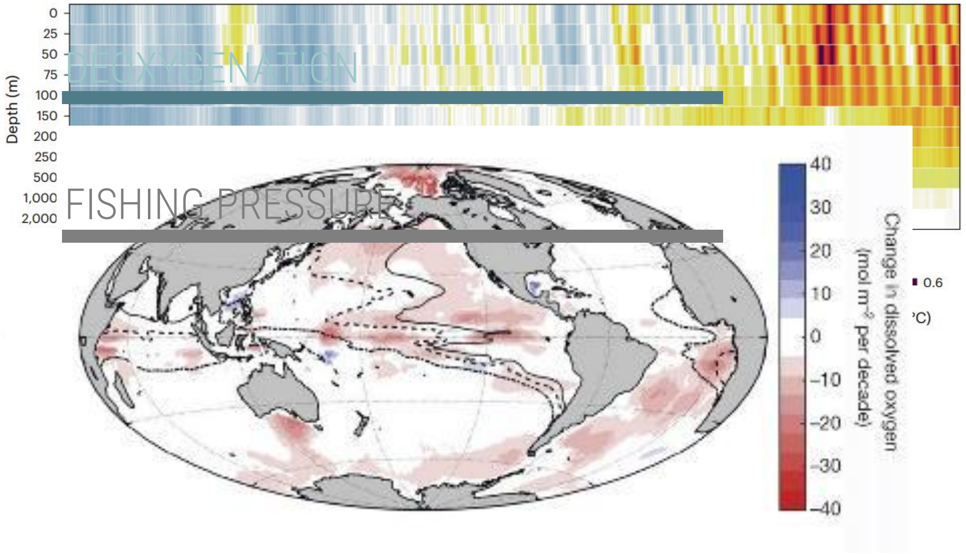
ivodacosta11@gmail.com

LARGE PELAGIC FISH

OCEAN WARMING

DEOXYGENATION

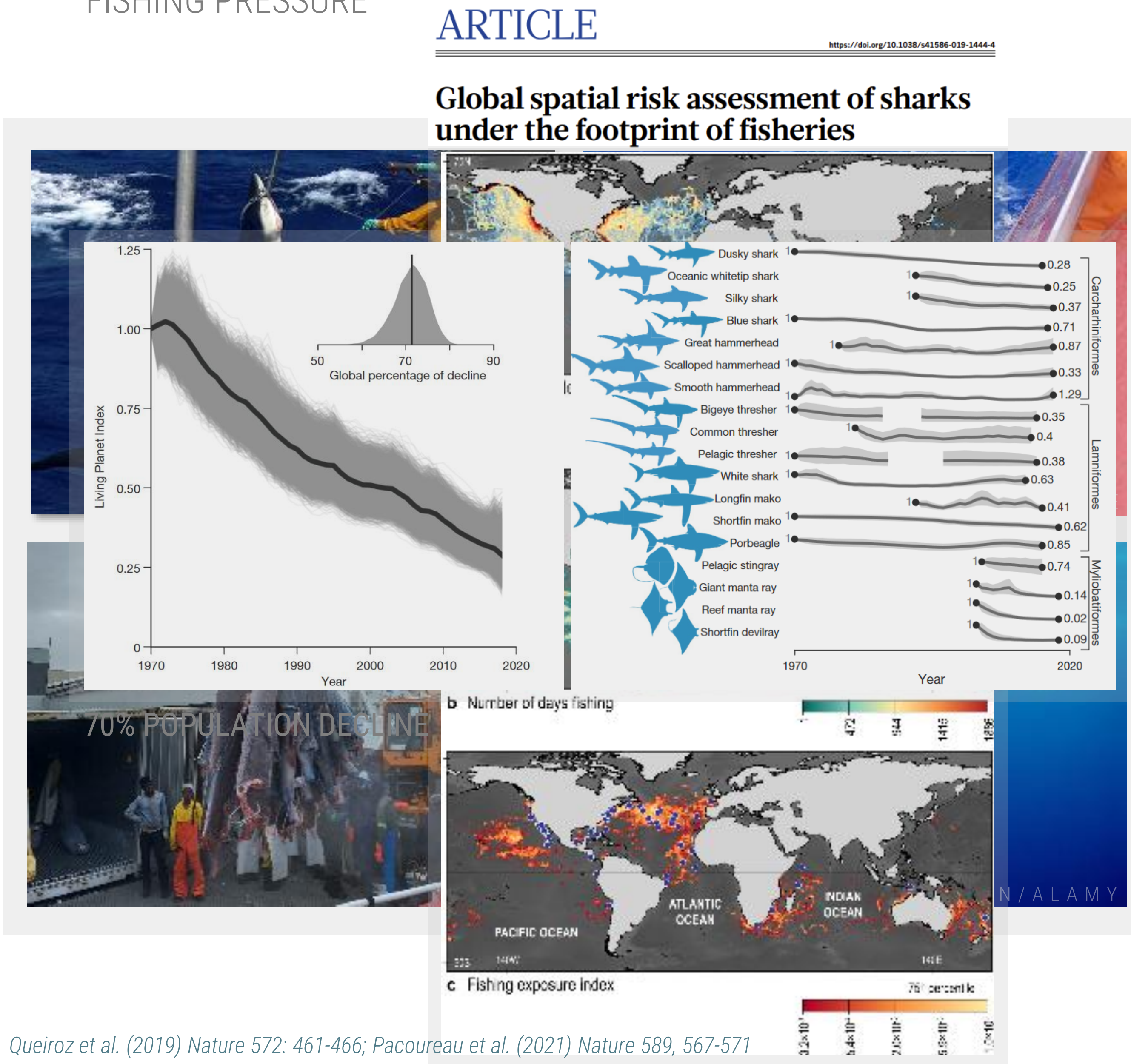
FISHING PRESSURE

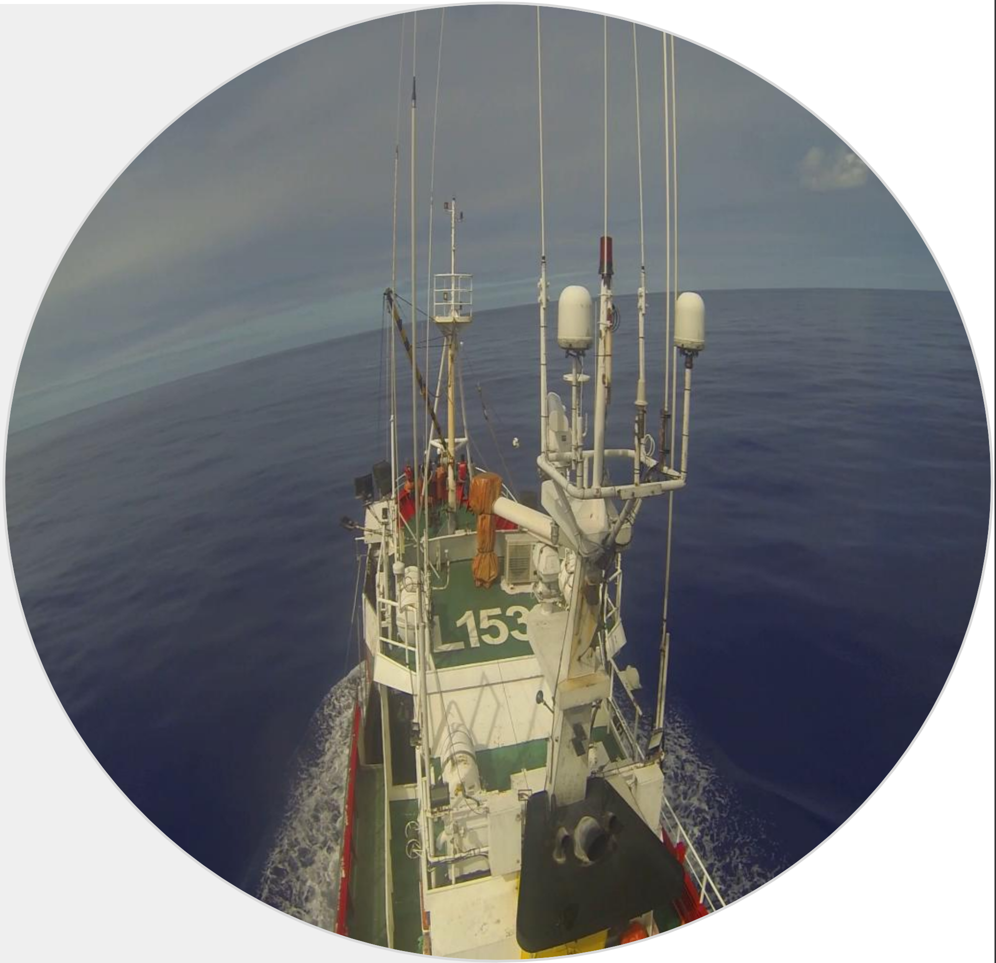


Fragkopoulou et al. (2023) Nature Climate Change 13, 1114–1121; Breitburg et al. (2019) Science 359: eaam7240;

LARGE PELAGIC FISH

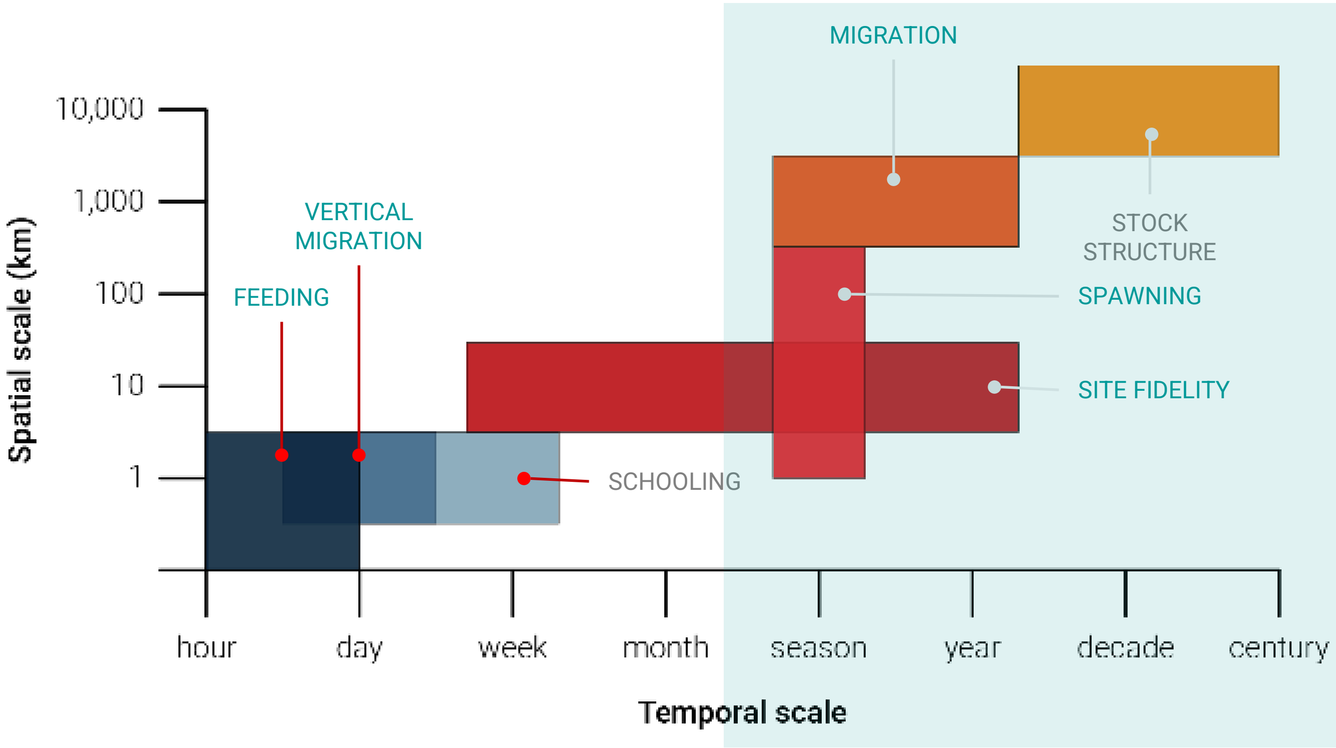
FISHING PRESSURE

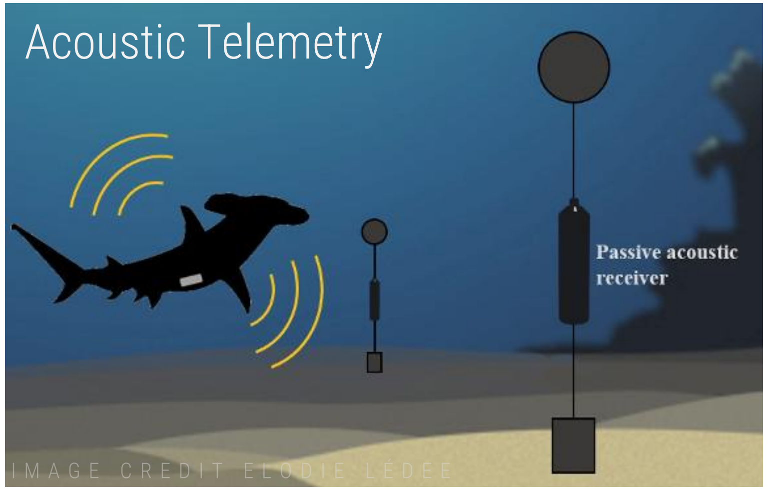




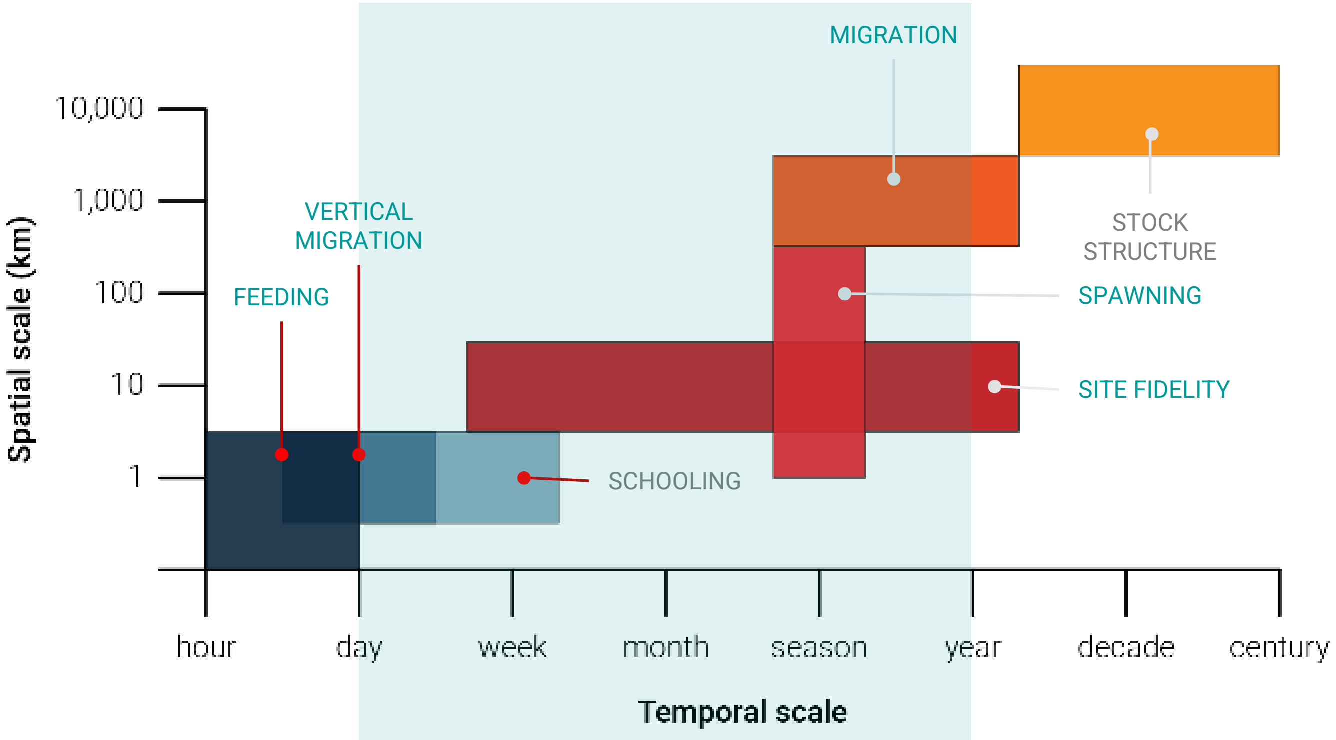
Queiroz et al. (2019) Nature 572: 461-466; Pacoureau et al. (2021) Nature 589, 567-571

SCALES OF BEHAVIOUR

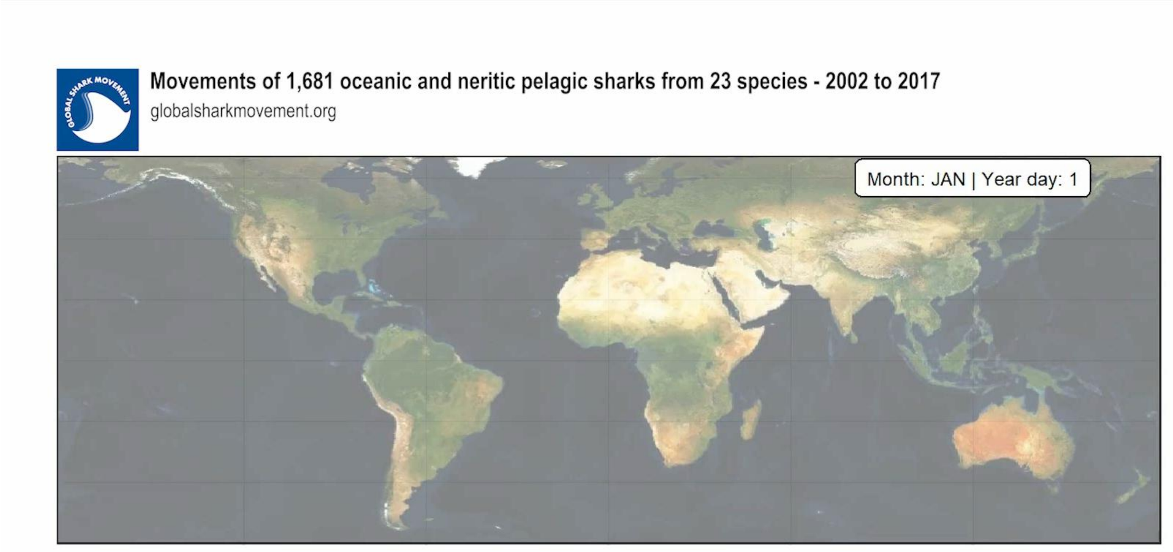


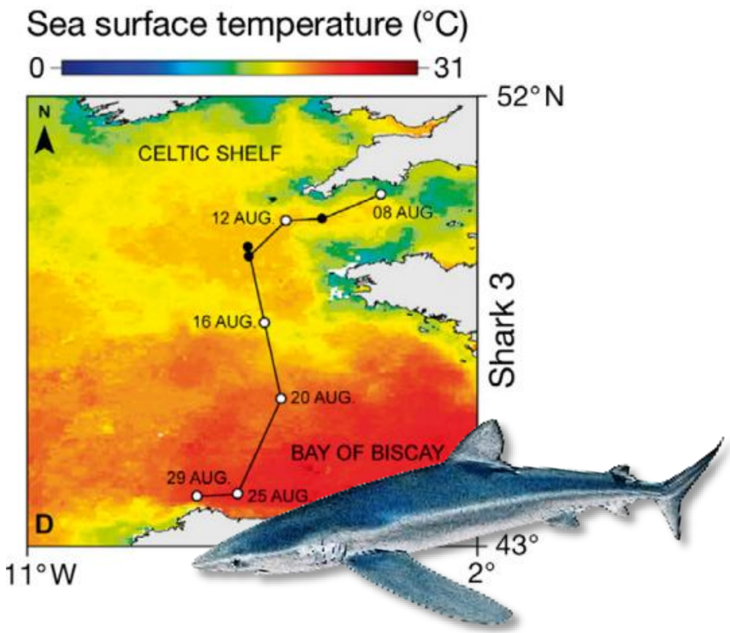


SCALES OF BEHAVIOUR

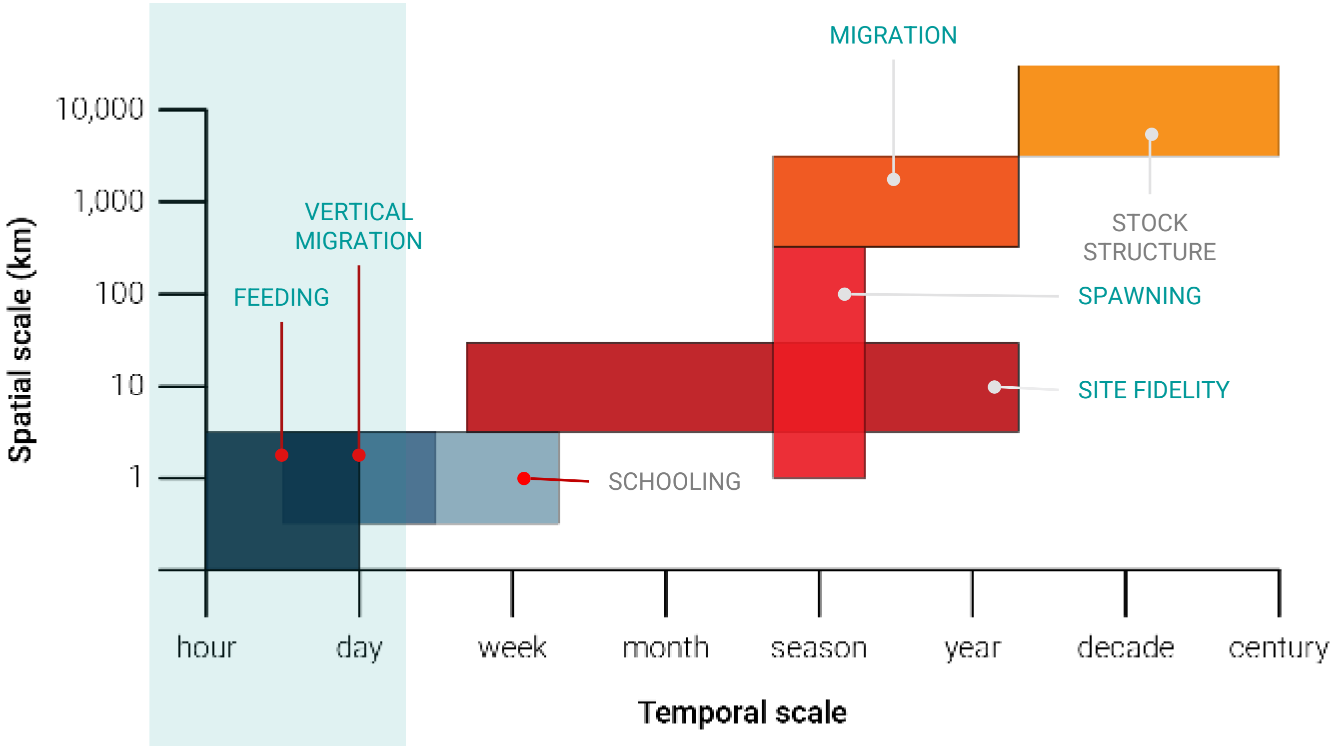


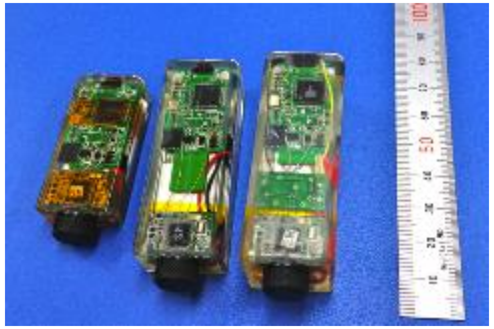
Satellite Tags



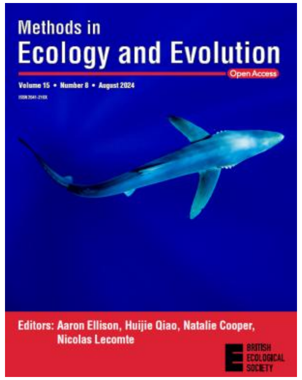


SCALES OF BEHAVIOUR

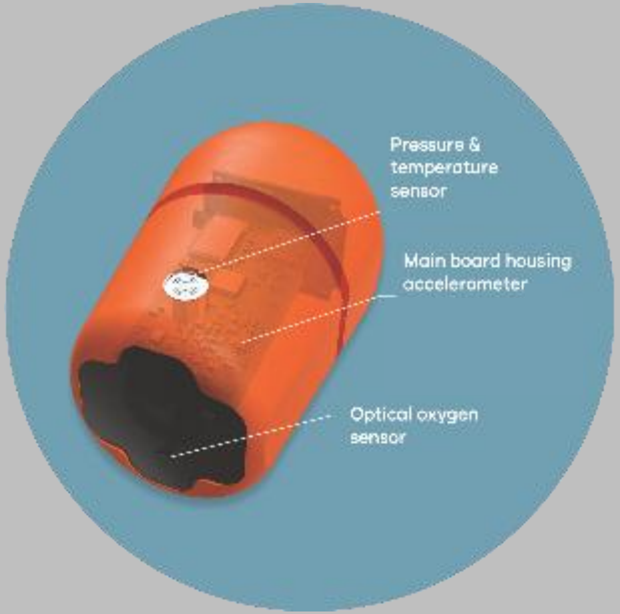




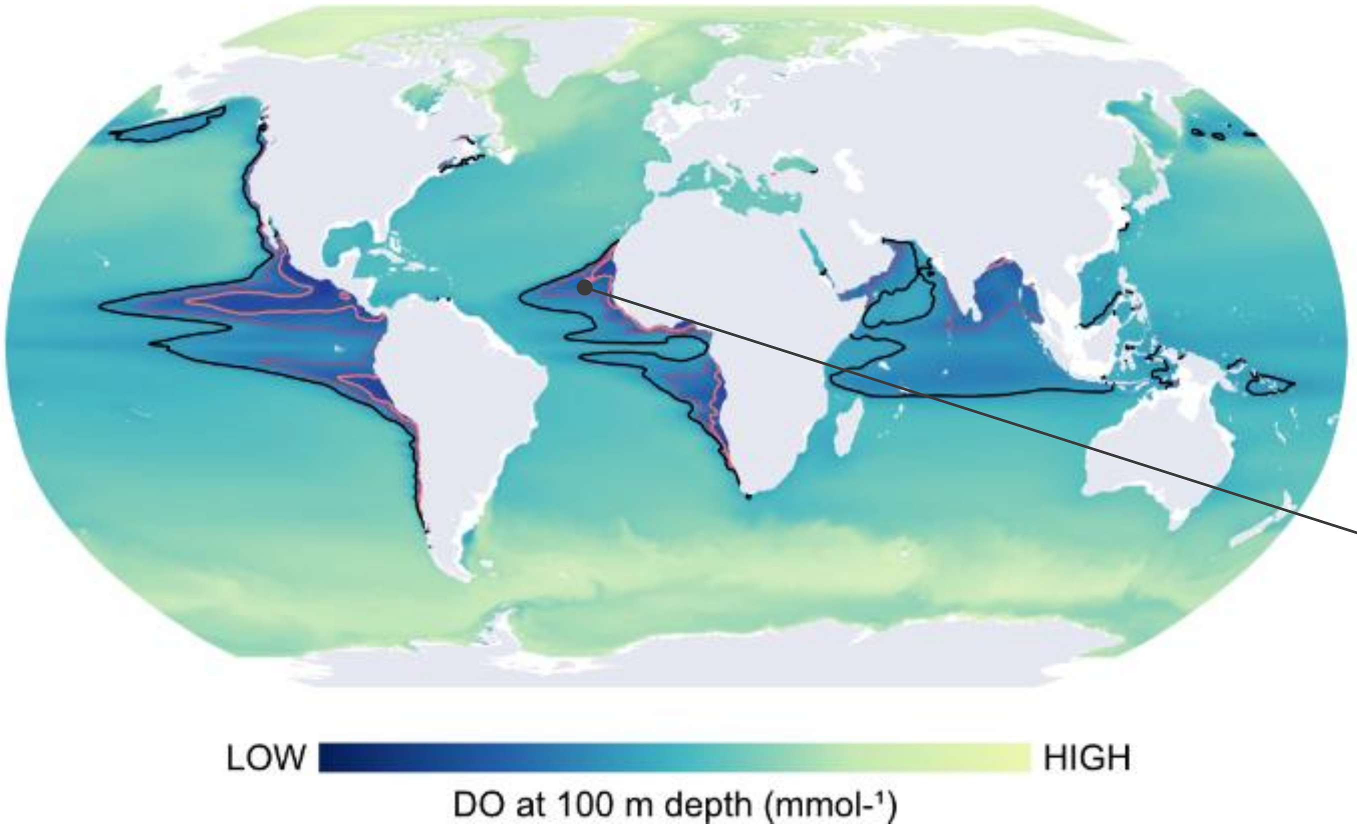
Measuring deoxygenation effects on marine predators:
A new animal-attached archival tag recording *in situ* dissolved oxygen, temperature, fine-scale movements and behaviour

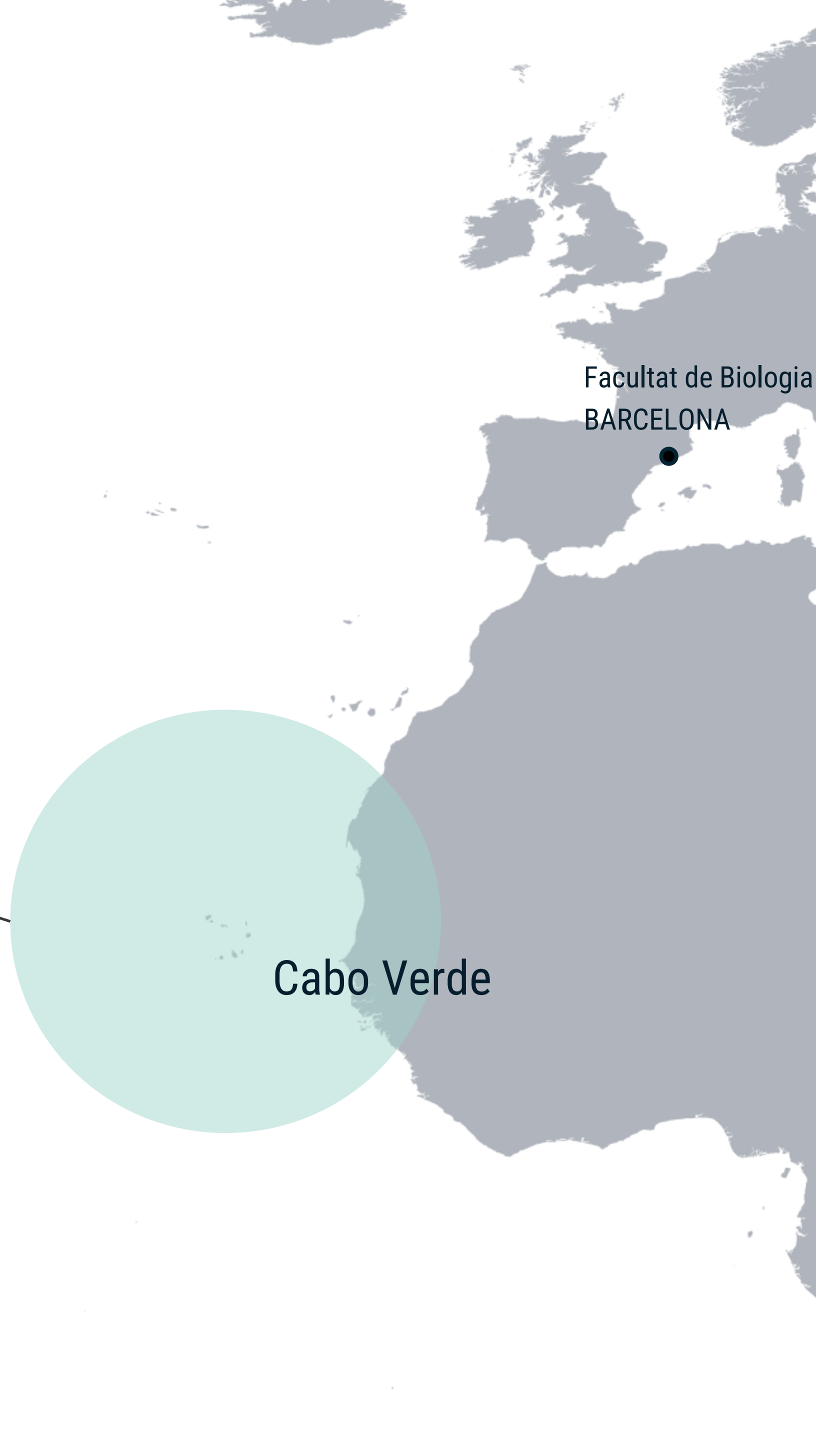


da Costa et al. (2024) Methods in Ecology and Evolution
doi:10.1111/2041-210X.14360



Sharks and deoxygenation





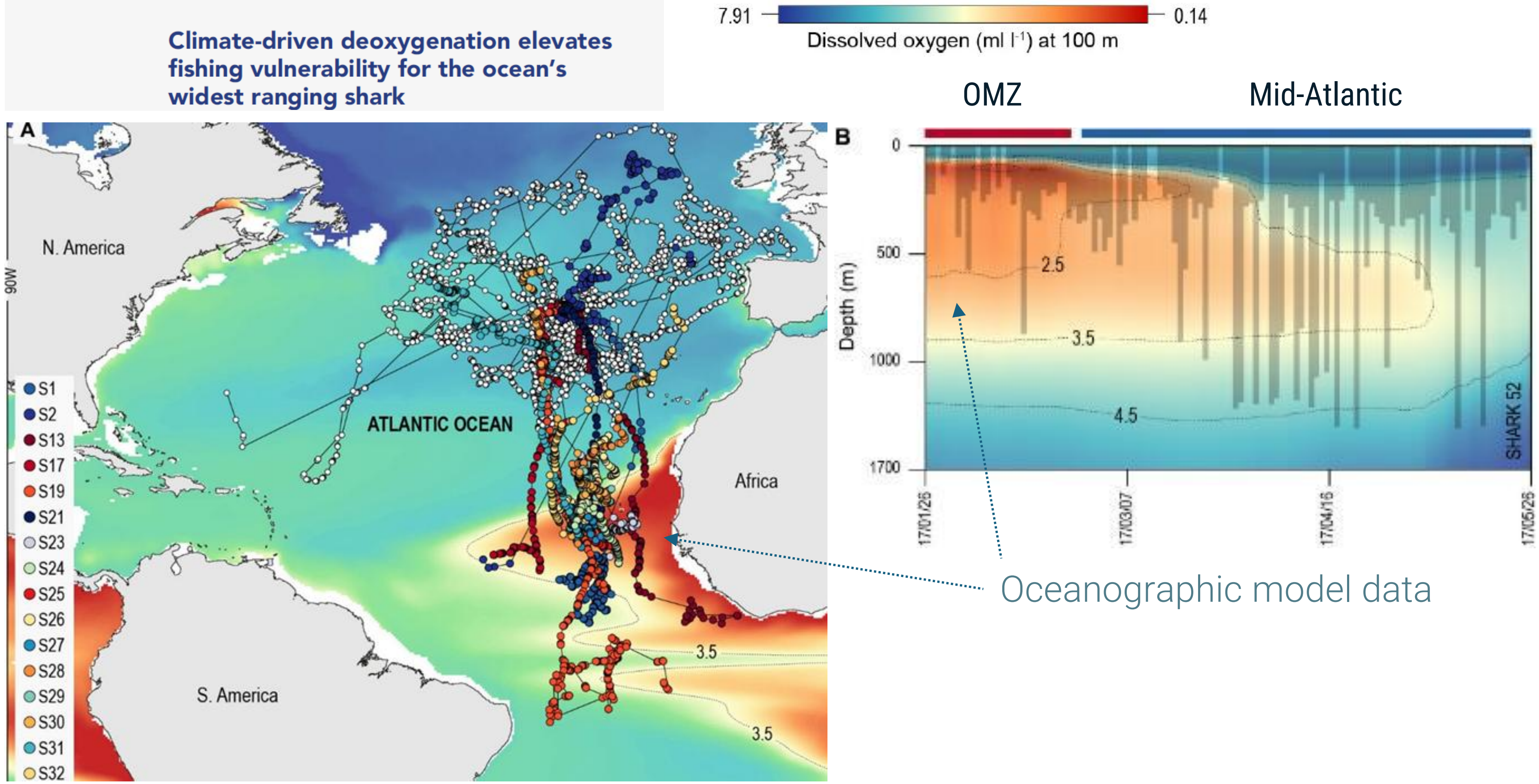
Waller et al. (2024) J Fish Biol. 2024;105:482–511

Sharks and deoxygenation

eLife

RESEARCH ARTICLE

Climate-driven deoxygenation elevates fishing vulnerability for the ocean's widest ranging shark



Oceanographic model data

LIMITATIONS

- Most have relied on modelled DO data extracted from large, ocean-environmental databases (e.g., CMEMS; World Ocean Atlas)
- Long term information (days, monthly)
- Direct oxygen tolerances in environments impacted with climate change

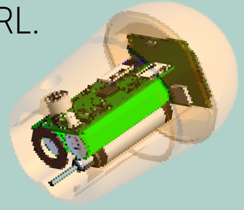
DOME ARCHIVAL TAG

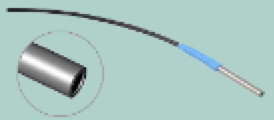
Vedor et al.(2021) eLife. 10 e62508

DOME ARCHIVAL TAG

Methods

1 DOME development conducted at BIOPOLIS CIBIO – Electric Blue CRL.

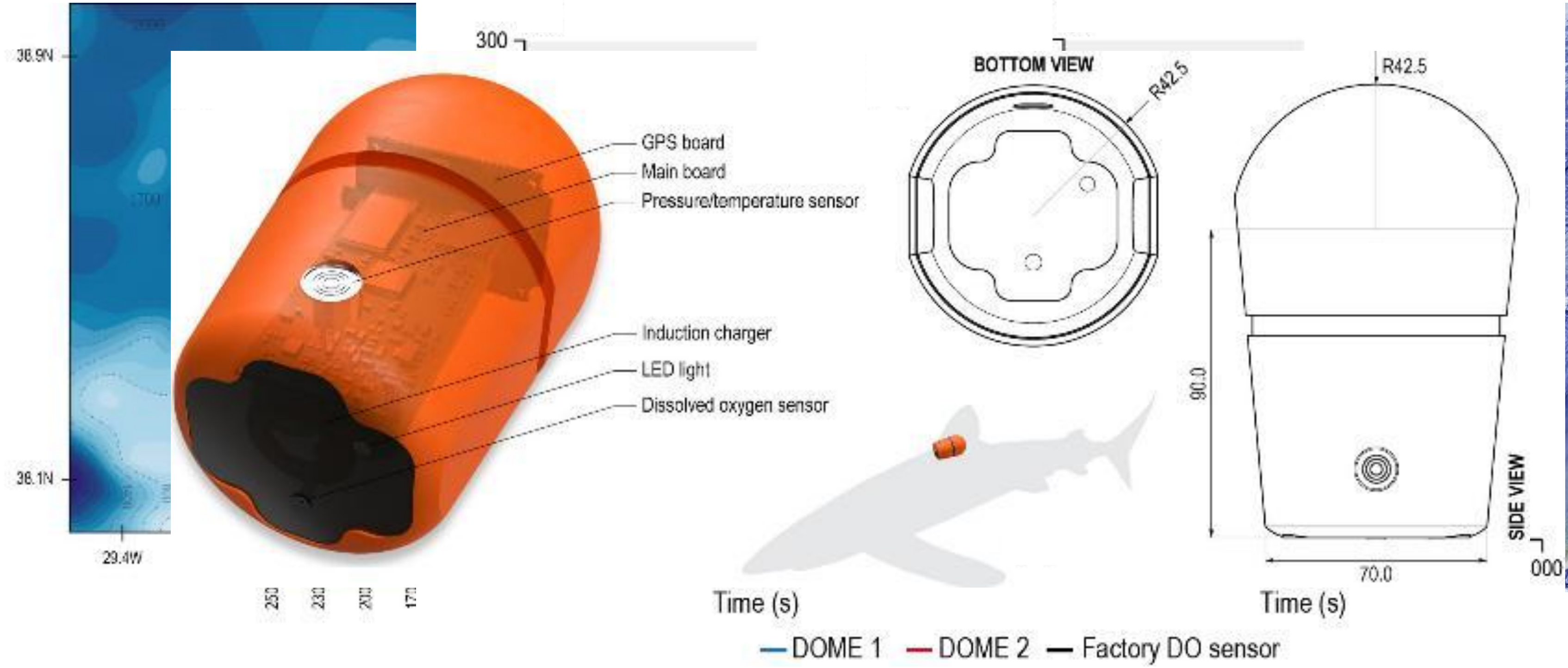




2 Calibration and standardisation of the DO measurements of each DOME tag. Pressure and drift tests.

3 Field tests were conducted off Faial islands in Azores.

Dissolved **O**xygen **ME**asuring (DOME) archival tag



BIOPOLIS

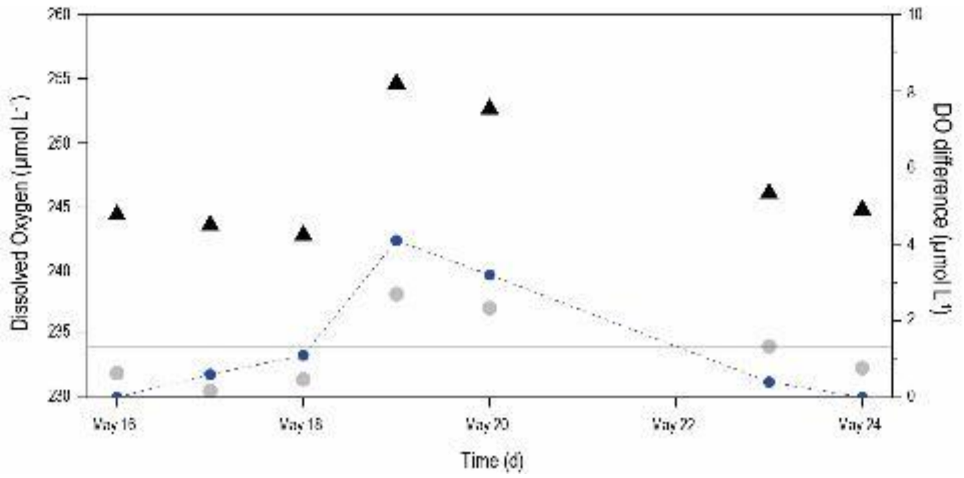
cibio

ElectricBlue

tools for environmental monitoring and biologging

Oxygen calibrations and pressure tests

DRIFT TESTS

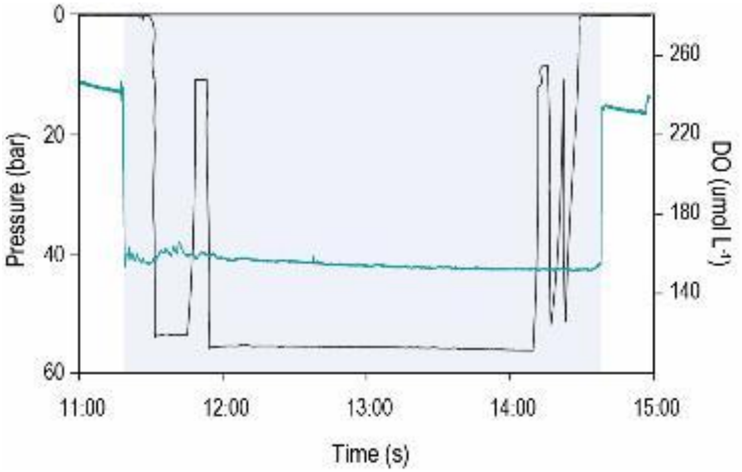


Daily DO measurements

Optical DO sensor

DO difference

PRESSURE TESTS



Pressure in the chamber

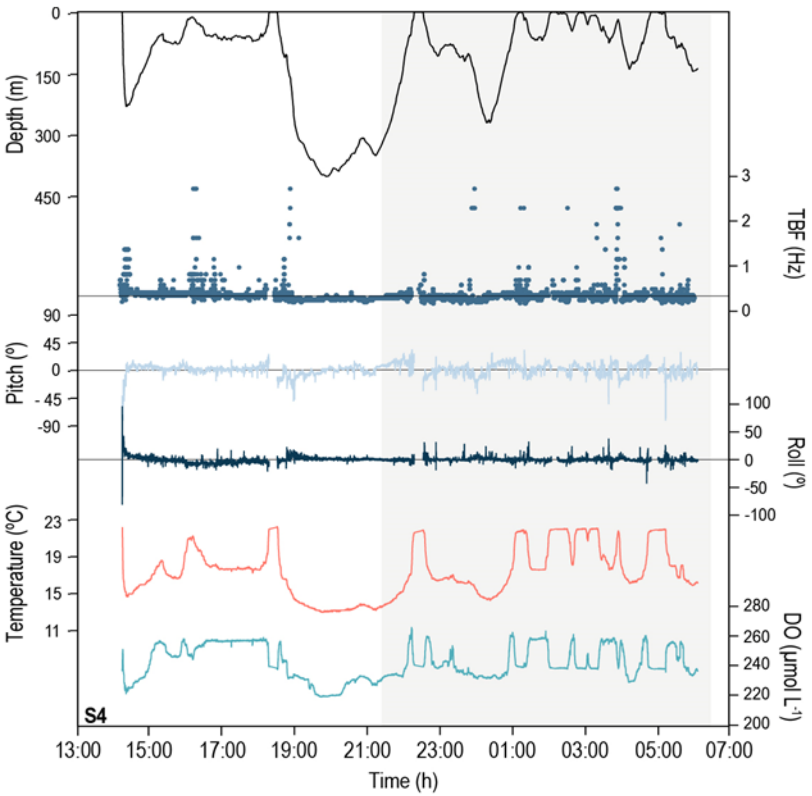
DO values

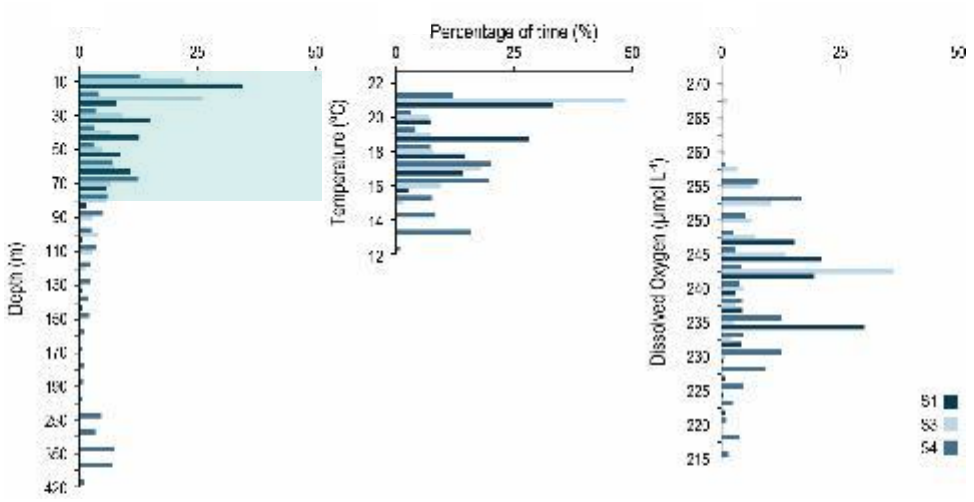
ACCURATE MEASUREMENTS

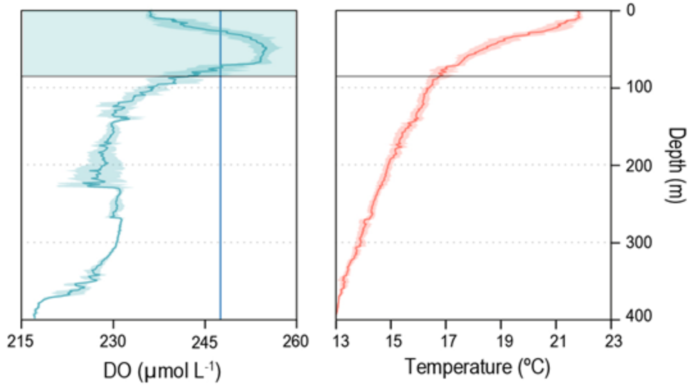
- Small mean difference between DOME tag and factory-calibrated DO sensors (mean relative error of 5%).
- No temporal drift was observed over the 9-day test period.
- Dissolved oxygen measurements showed no variation with changes in pressure.

Relating fine-scale behaviour to environmental gradients

VERTICAL BEHAVIOUR







AMBIENT DESCRIPTION

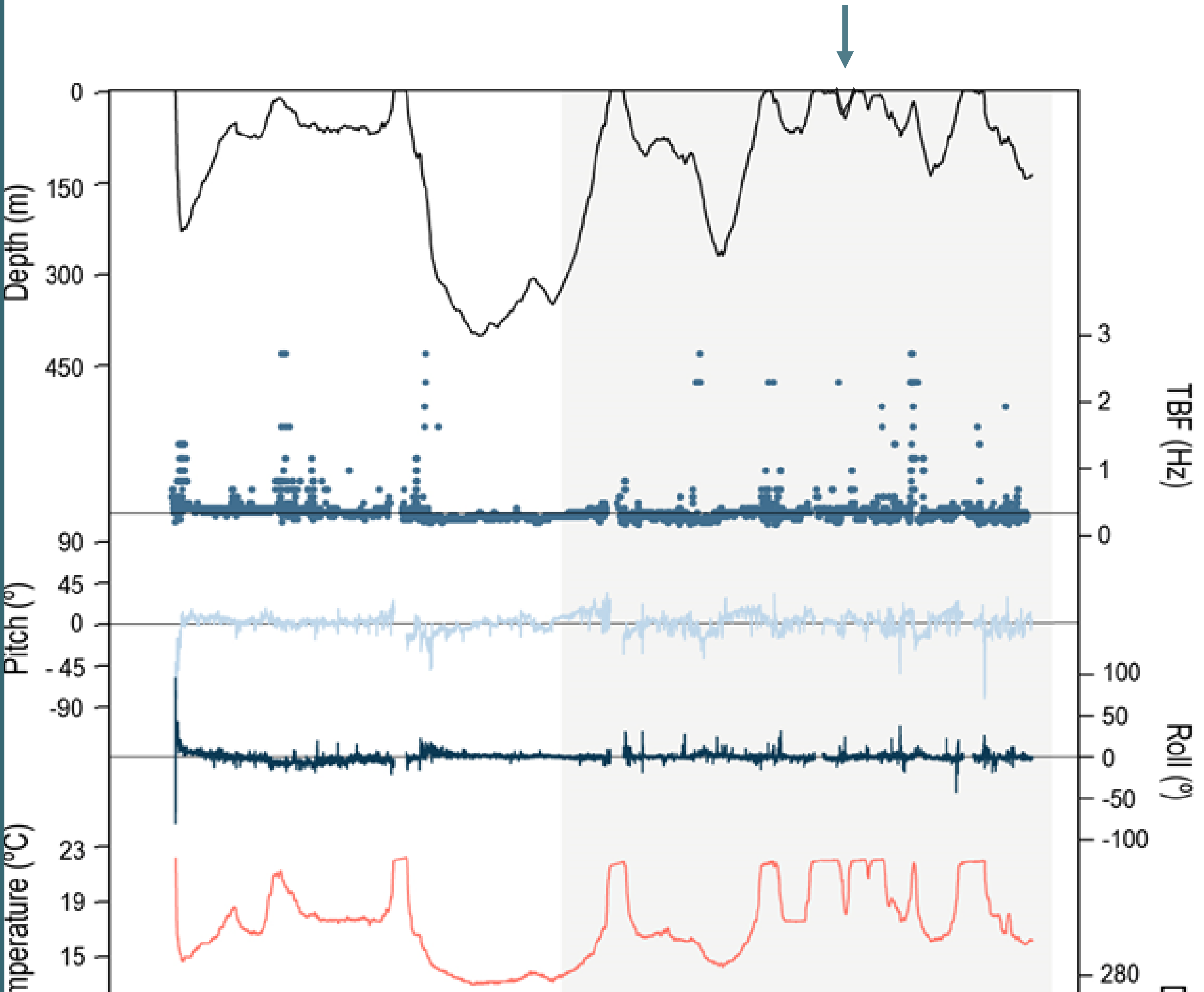
- DO concentrations ranging from 217 to 272 µmol L^{-1}; maximum at ~ 45 m
- Temperatures between 13°C and 23°C

BEHAVIOUR DESCRIPTION

- Vertical oscillations from surface to 404 meters depth
- 30 % of their time spent in high DO region

DOME ARCHIVAL TAG

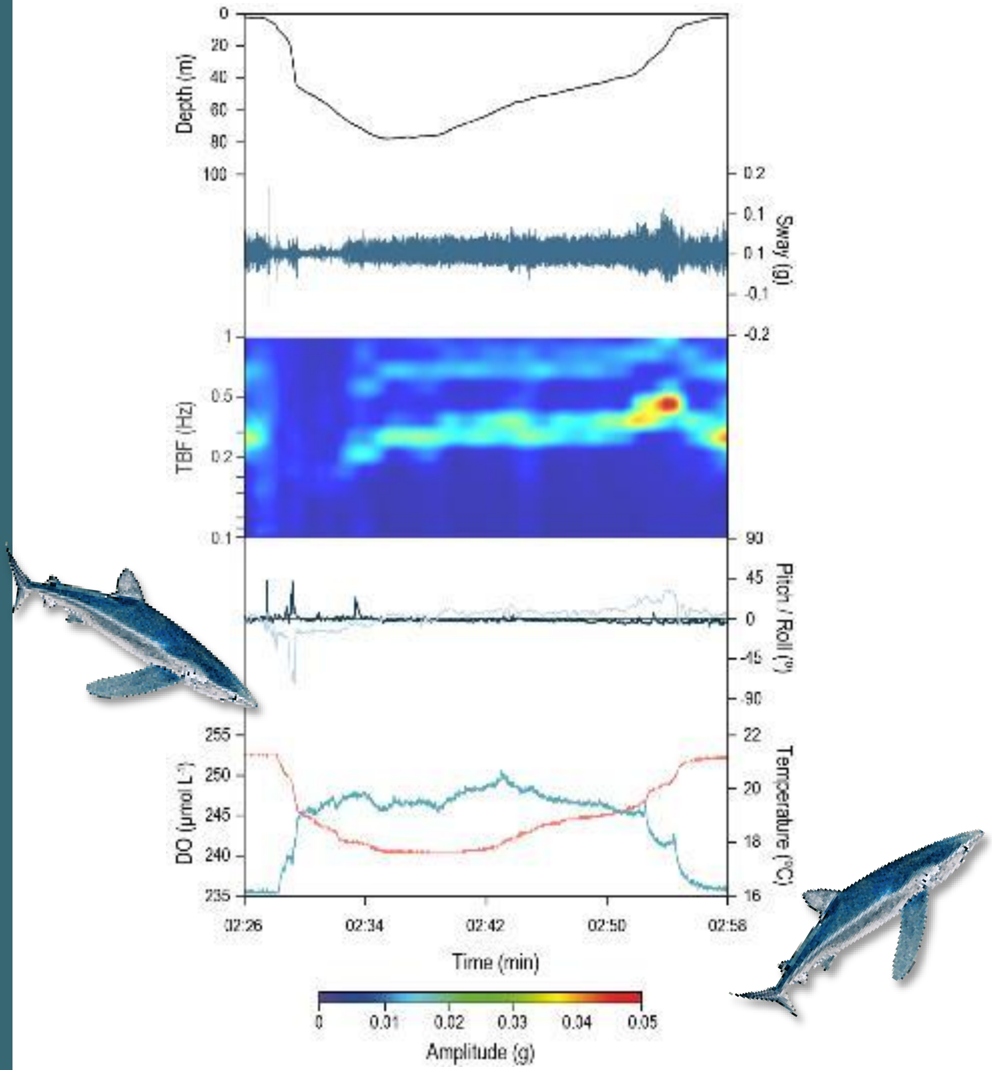
Relating fine-scale behaviour to environmental gradients

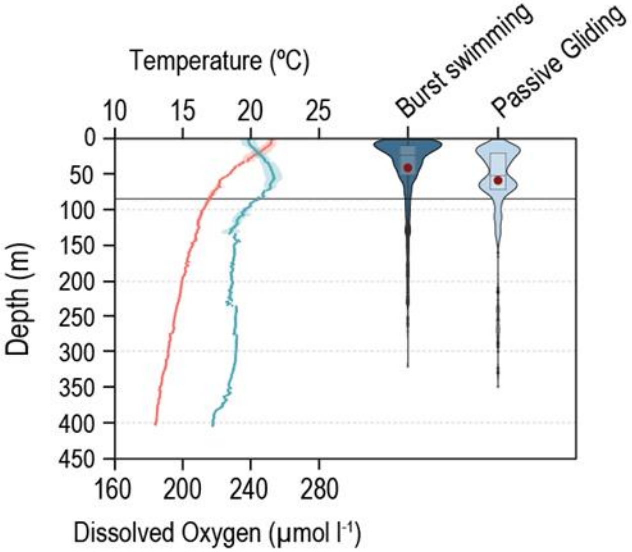


DOME ARCHIVAL TAG

Relating fine-scale behaviour to environmental gradients

TAILBEAT FREQUENCY AND ACTIVITY LEVELS





COST-EFFECTIVE SWIMMING

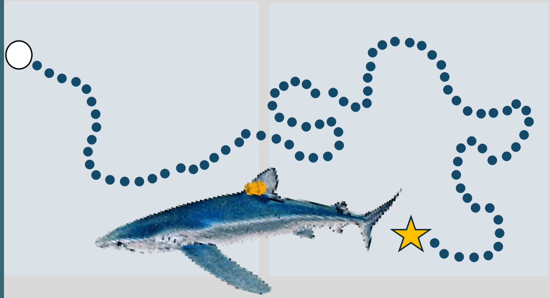
- Blue sharks displayed vertical oscillations with faster tailbeats and increased activity during ascents when compared with descents
- Greater proportion of gliding during descents (but only ~20% of the time)

FORAGING STRATEGY

- High DO region: Maximum tailbeats and activity levels and higher proportion of burst swimming

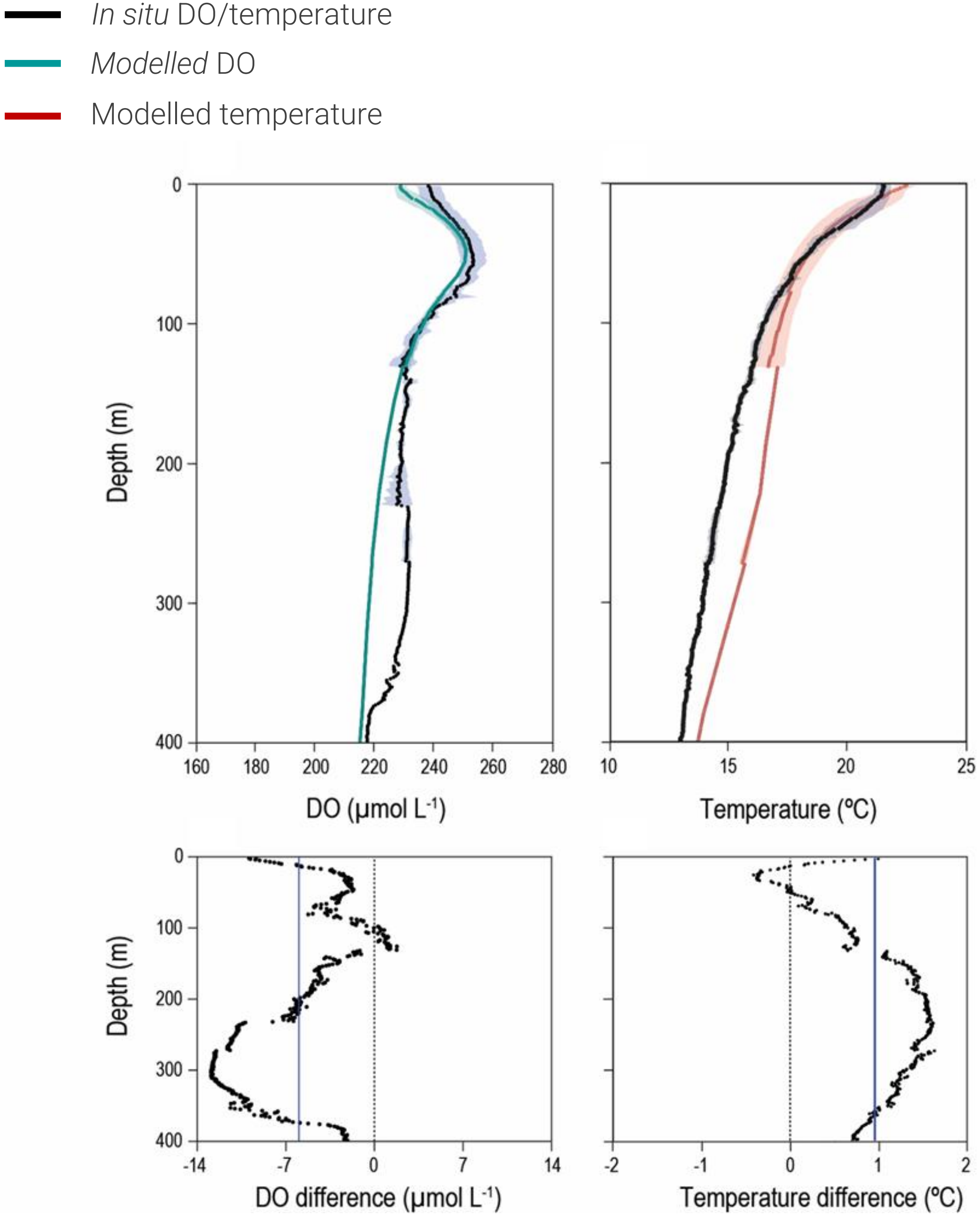
Modelled vs in situ measurements

DOME ARCHIVAL TAG



Mean *in situ* DO profiles by averaging daily oxygen measurements for both tagging and pop-off days.

Modelled DO profiles extracted from the grid cell (0.25° × 0.25°) corresponding to the day and location of tagging/pop-off.



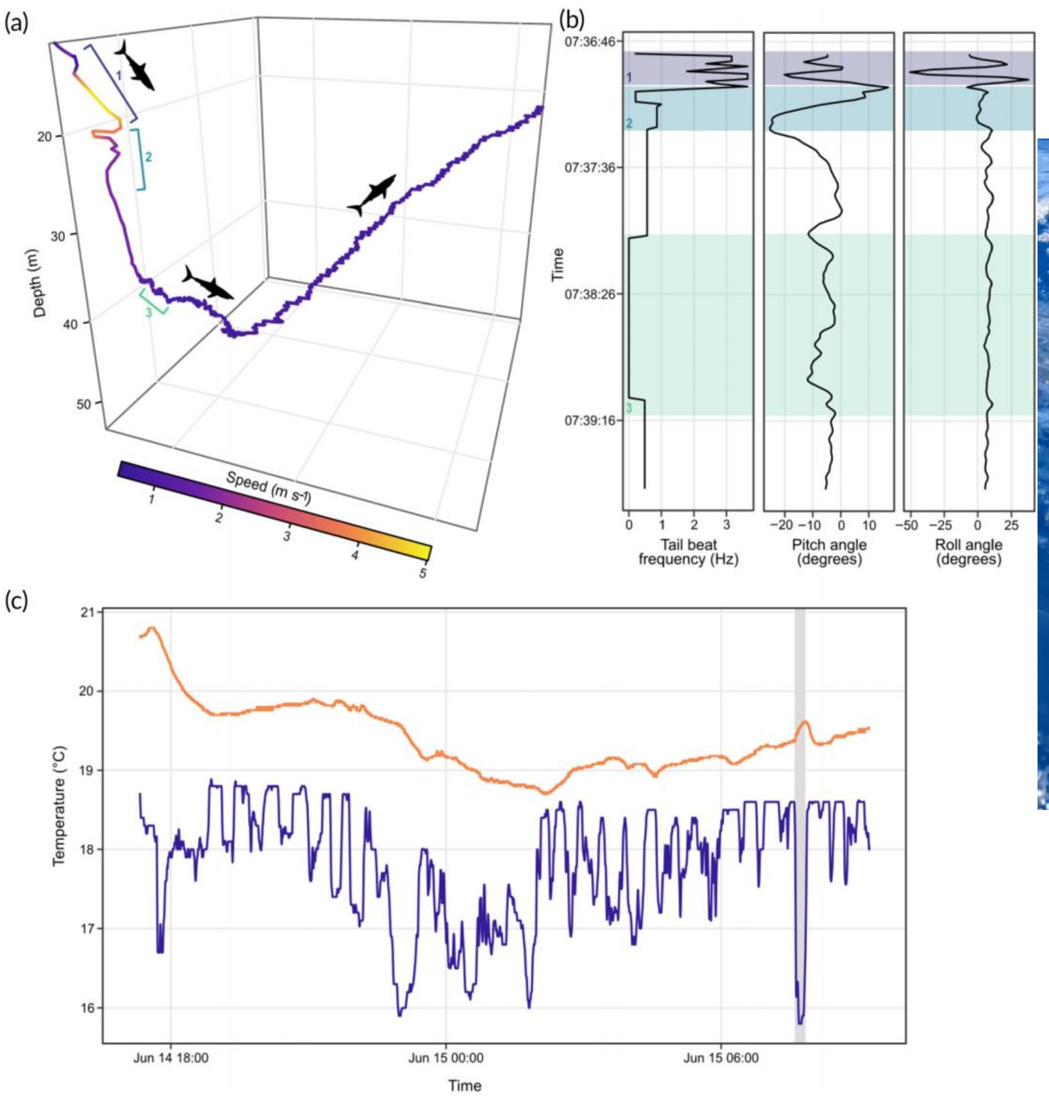
IMPROVE OCEAN MODELS

- CMEMS data generally underestimated *in situ* DO data by about 3% at deeper depths and by about 2% above 85 m.
- 'Animal oceanographers' to improve limited availability of *in situ* DO data

Watanabe & Papastamatiou (2023) Annu. Rev. Anim. Biosci.11:247–67

MULTISENSOR TAG

FINE-SCALE BEHAVIOUR AND METABOLIC RATES



Little Leonardo TOKYO JAPAN

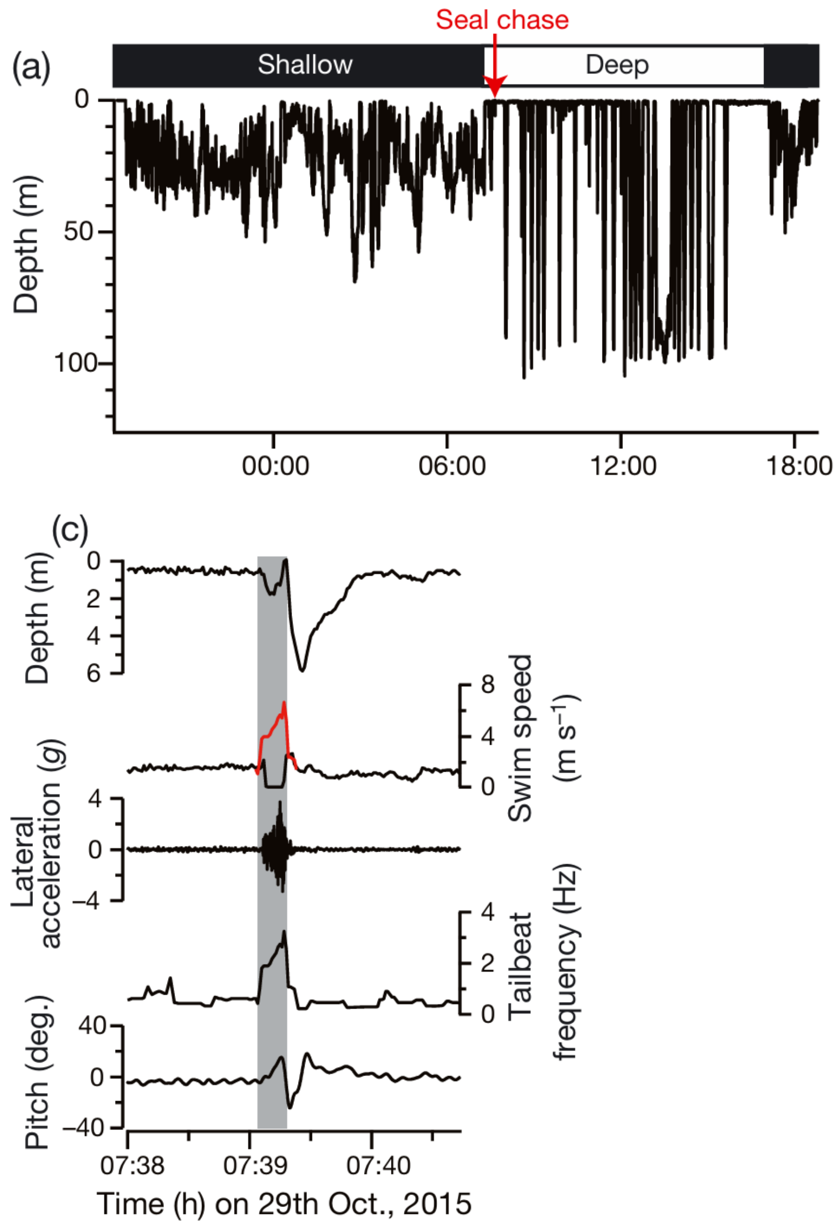
ElectricBlue

TOOLS FOR ENVIRONMENTAL MONITORING AND BIOLOGGING

Waller et al., (2023) Fish. Biol. 2023: 1–20

MULTISENSOR TAG

FORAGING BEHAVIOUR



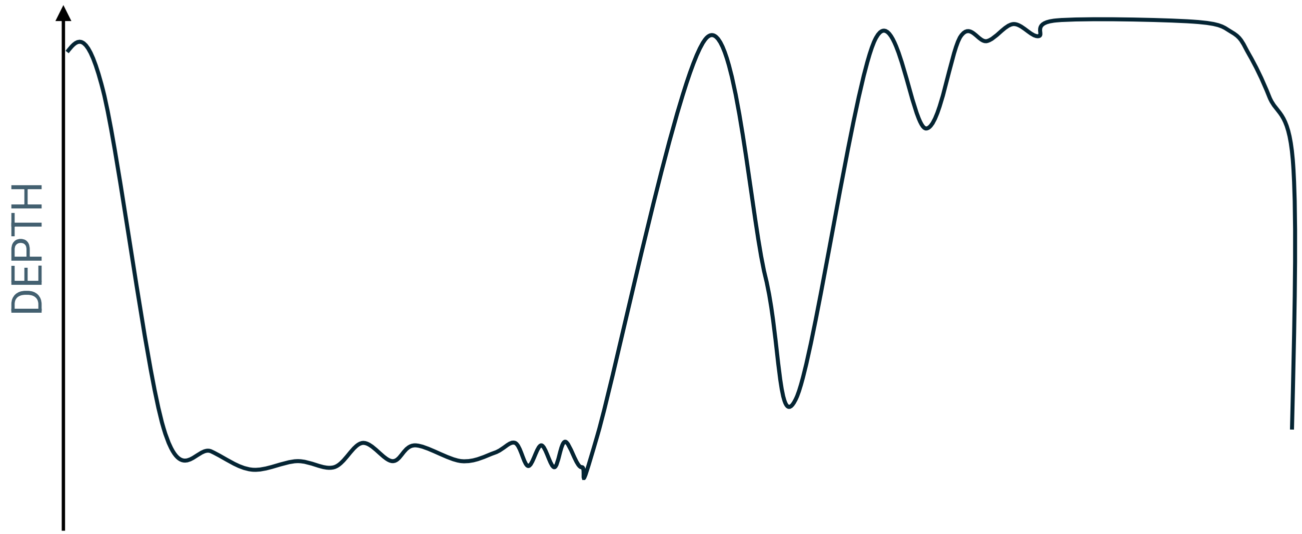
Watanabe et al. (2019). Mar. Ecol. Prog. Ser. 621:221-227

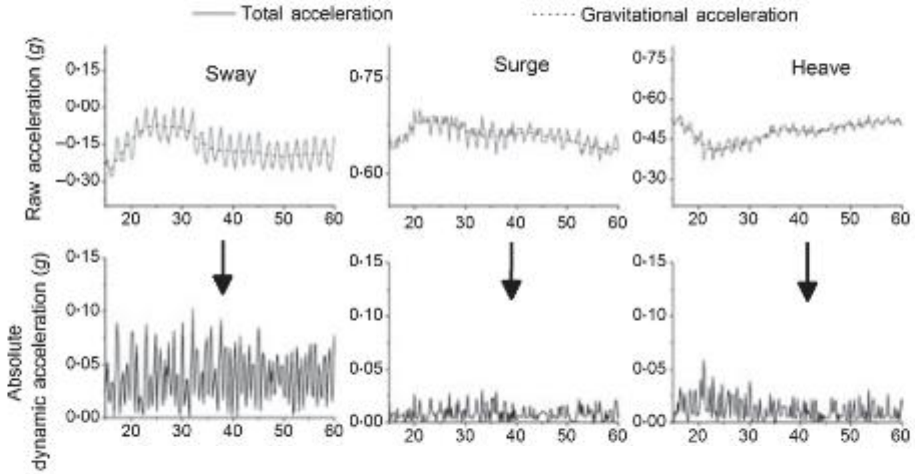
EXTRACTING SWIMMING KINEMATICS FROM HIGH-RESOLUTION DATA

ACCELERATION DATA

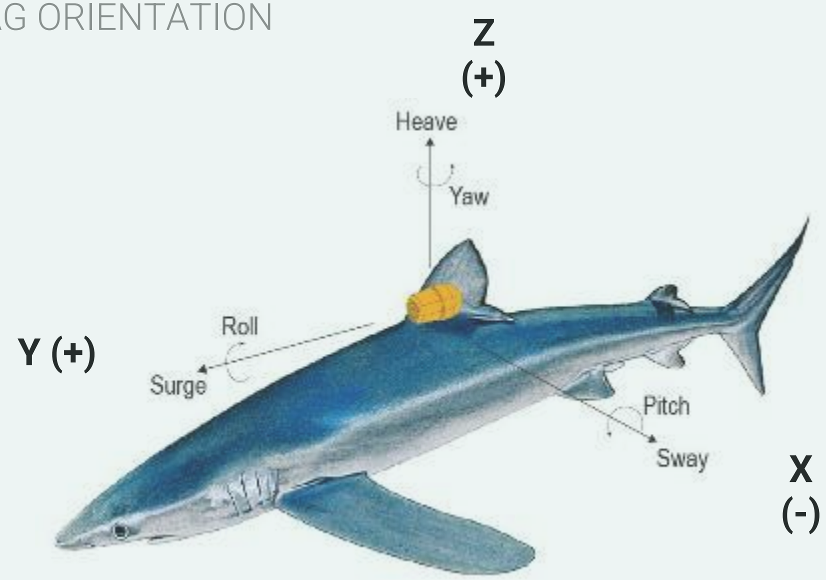
Static component – constant force of gravity.

Dynamic component –High frequency waves caused by dynamic movements such as caudal fin stroking and rapid turning.

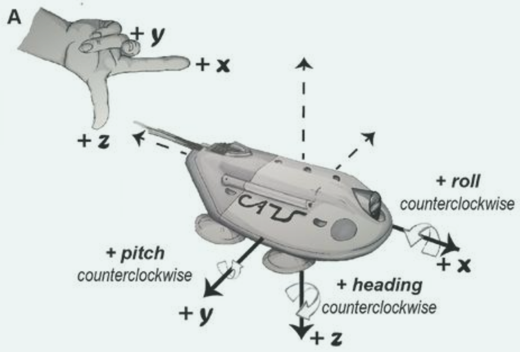




TAG ORIENTATION



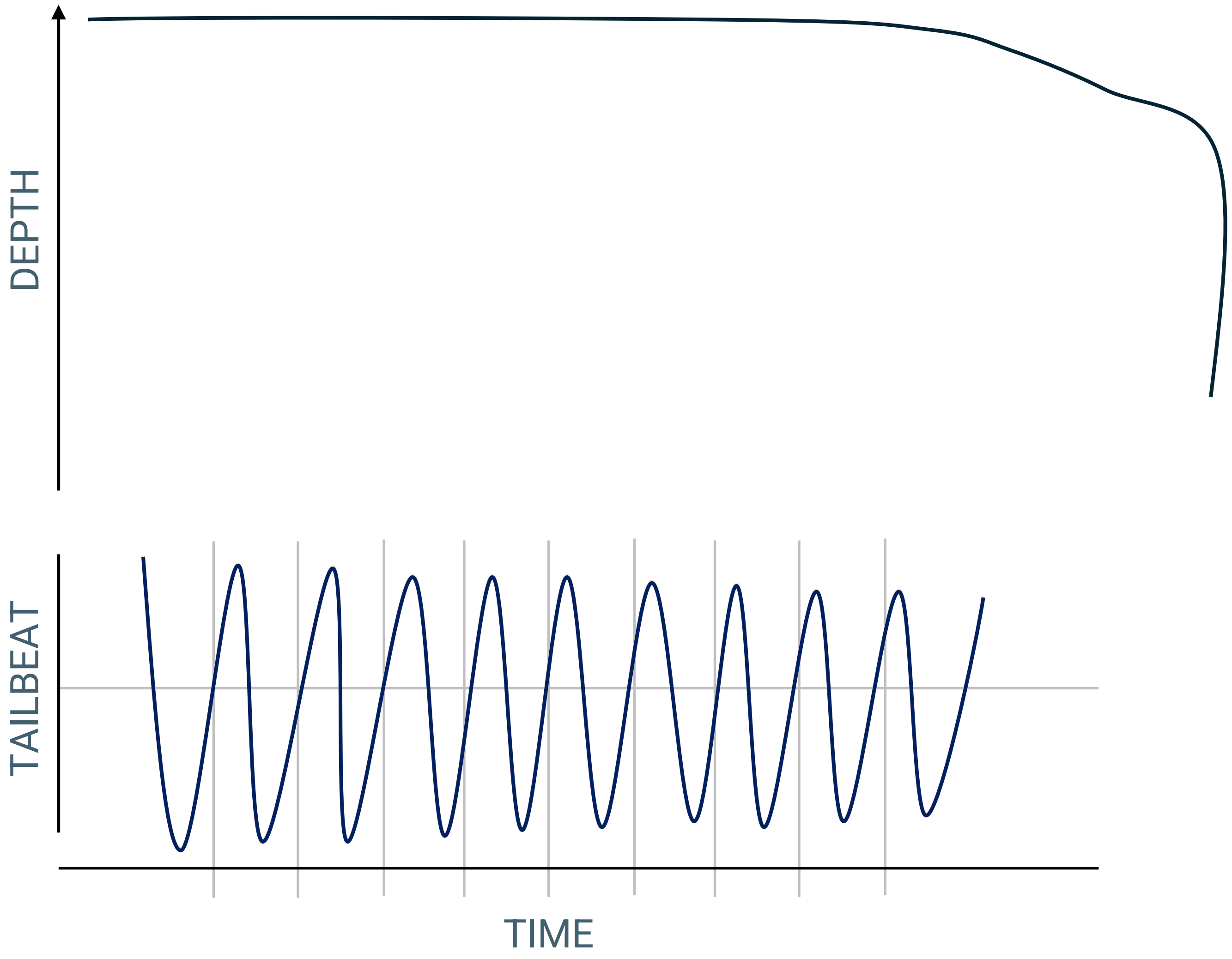
Other tags can have a different axis convention

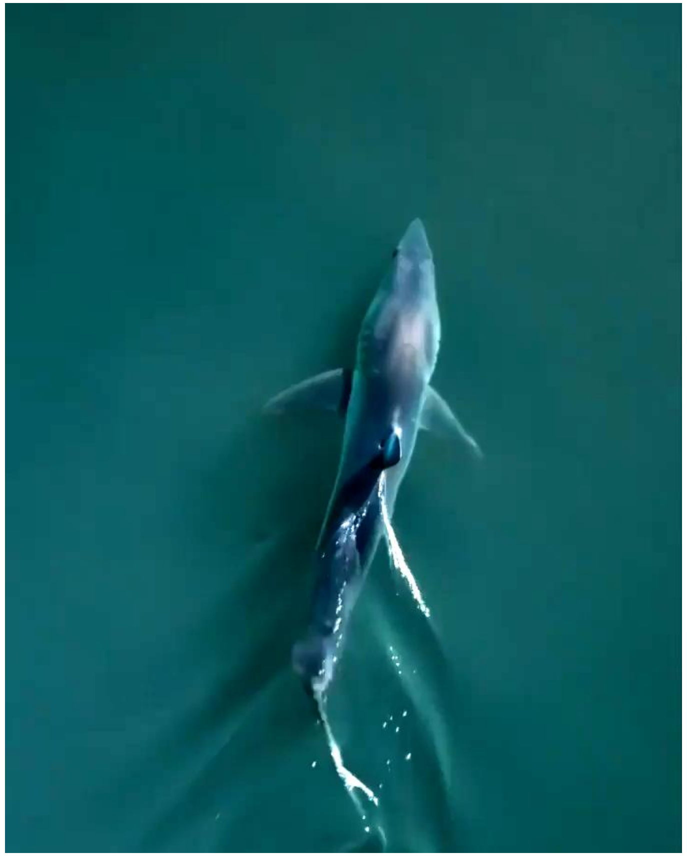


EXTRACTING SWIMMING KINEMATICS FROM HIGH-RESOLUTION DATA

TAILBEAT SIGNAL

Tailbeat frequency – calculated from dynamic component of sway



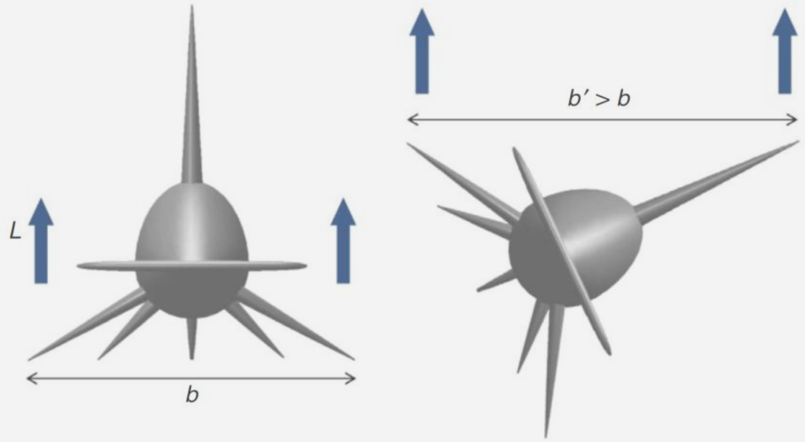


EXTRACTING SWIMMING KINEMATICS FROM HIGH-RESOLUTION DATA

SWIMMING ANGLES

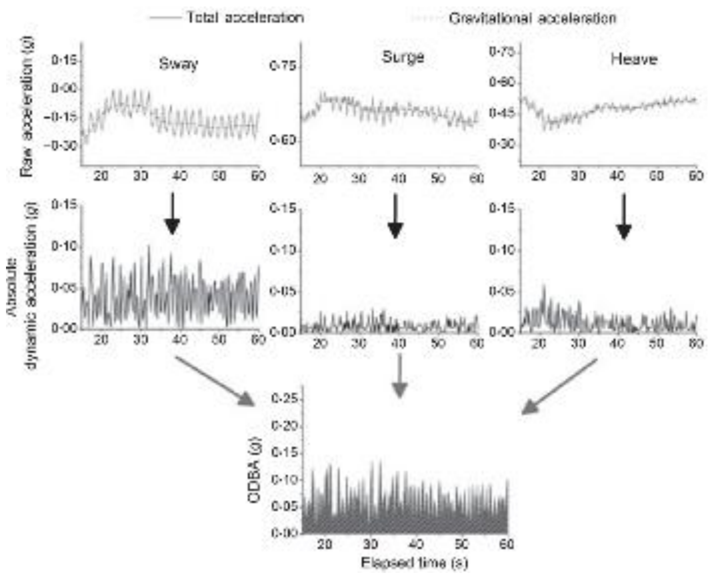
Pitch angles– calculated from static component of surge

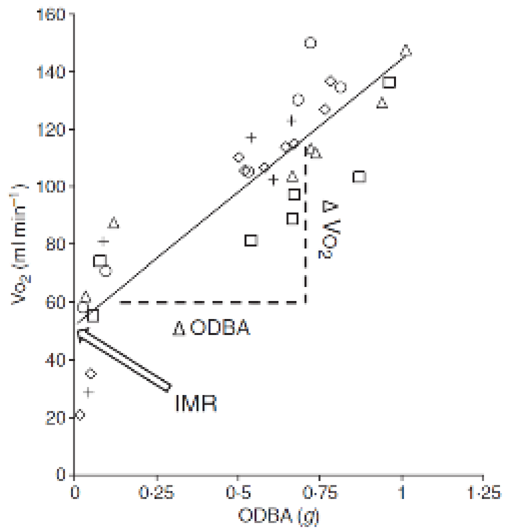
Roll angles – calculated from static component of sway and heave

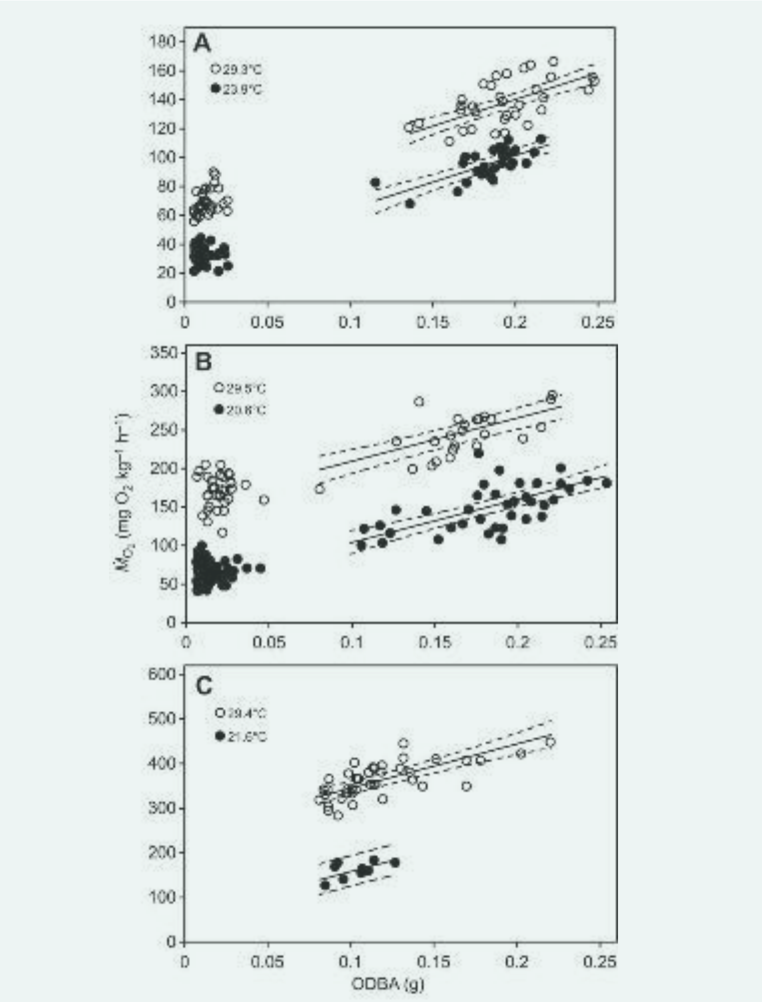


EXTRACTING SWIMMING KINEMATICS FROM HIGH-RESOLUTION DATA

OVERALL DYNAMIC BODY ACCELERATION - ENERGY EXPENDITURE



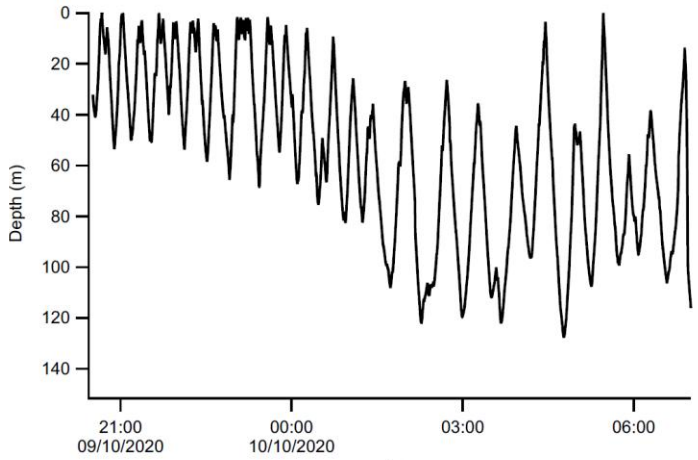




Data Analysis using IGOR

1. INSTALL IGOR AND ETHOGRAPHER EXTENTION
2. IMPORT HIGH-RESOLUTION DATA
3. FILTER ACC WAVES
4. OVERALL DYNAMIC BODY ACCELERATION - ODBA
5. CALCULATE PITCH AND ROLL ANGLES
6. EXTRACT TAILBEAT SIGNAL
7. FILTER AND SAVE

FILES: bs_depth_data
bs_acc_data



Data Analysis using IGOR

1. INSTALL IGOR AND ETHOGRAPHER EXTENTION

1. Software Installation:
1.1. **Igor Pro:** Install Igor Pro from Wavemetrics:
License Activation: Follow the instructions provided by Wavemetrics to activate your Igor Pro license (for the class, use the free trial of 30 days)

2. Extension Installation:
2.1. **Ethographer*:** extension on IGOR that enables bio-logging data to be viewed and analyzed
https://sites.google.com/site/ethographer/download

PLOS ONE

OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

Can Ethograms Be Automatically Generated Using Body Acceleration Data from Free-Ranging Birds?

Kentaro Q. Sakamoto, Katsufumi Sato, Mayumi Ishizuka, Yutaka Watanuki, Akinori Takahashi, Francis Daunt, Sarah Wanless

Published: April 30, 2009 • https://doi.org/10.1371/journal.pone.0005379

Sakamoto et al., 2009

Data Analysis using IGOR

2. IMPORT HIGH RESOLUTION DATA

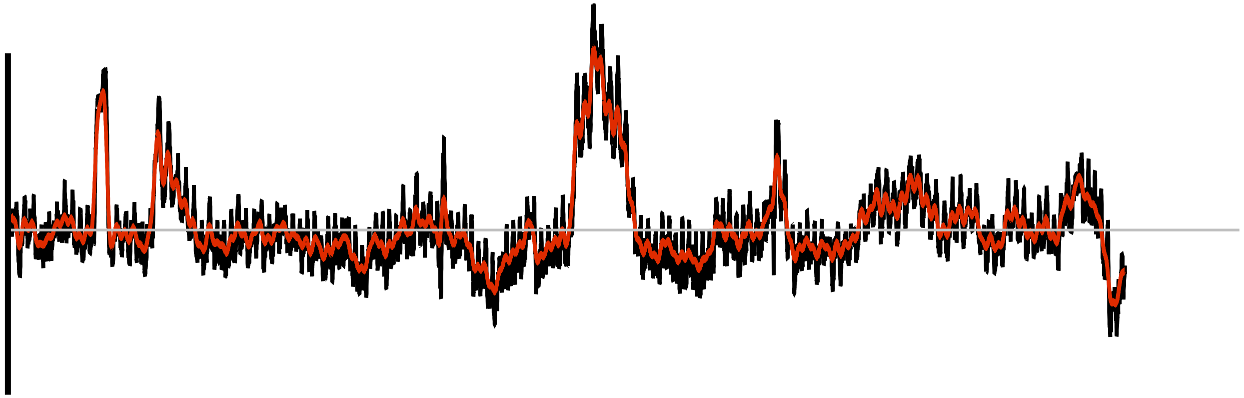
1. Load Data:
• In IGOR, navigate to **Data > Load waves > Load delimited text**.
• Select both “bs_depth_data.csv" and “bs_acc_data.csv" files.
• **Check** sampling frequency
• Confirm the values: 1 Hz (1 sec) for environmental data and 20 Hz (0.05 sec) for acceleration data.

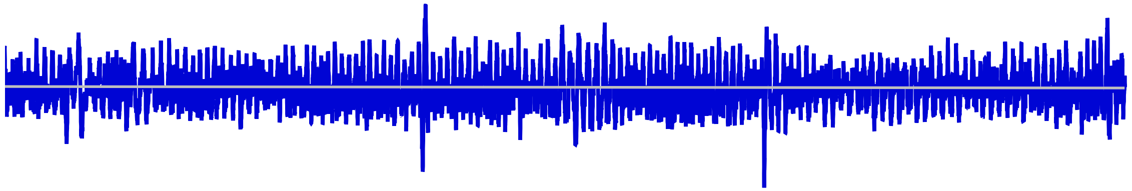
2. Set Wave Scaling:
• To scale data, you need both starting datetime and sampling frequency
• Go to **Data > Change wave scaling**.
• Select **Date & Time** type, specify the start datetime, set the **Delta** which corresponds to the sampling frequency, and choose the variables to be scaled
• Separately for depth and acceleration (x,y,z) data

3. Plot timeseries (using Ethographer) to check if the end and start date of both files are correct:
• Go to **Misc > Run Ethographer** and then **Ethographer > Time series analysis**.

Data Analysis using IGOR

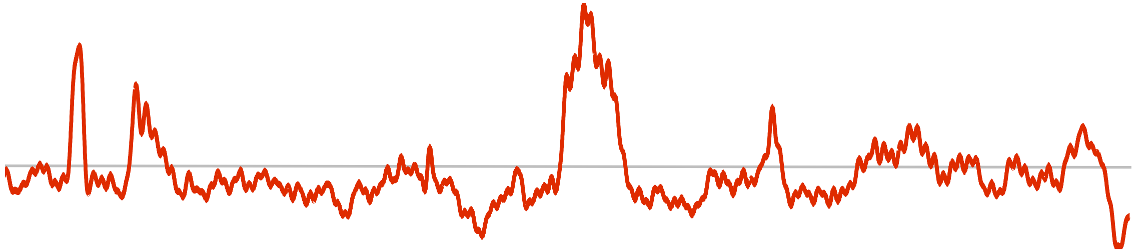
3. FILTER ACCELERATION WAVES





DYNAMIC ACCELERATION

Tailbeats, ODBA



STATIC ACCELERATION

Pitch, Roll

Data Analysis using IGOR

3. FILTER ACCELERATION WAVES

1. PSD Analysis:

- Go to **Windows > Procedure Windows > Procedure Windows**.
- Paste the following code**: #include <power spectral density>**
- Go to **Macros > psd >** select sway axis (accX) and segment alignment as 512 (or <).
- PSD plot will show up.
- **Peak** on frequency represent the average tail beat frequency
- You can also confirm by looking to the sway wave (lat.acceleration)
- **Lower peak** will be used to **remove static** part from the acceleration.

2. Static Acceleration Filter:

- Apply low-pass filter: Go to **Analysis > Filter > Apply low pass filter**.
- Select accX as the input data.
- Name the output wave "staticX".
- Set the "start of reject band" to the lower peak frequency identified in step 3c (e.g., 0.18).
- Set the "end pass band" to the lower peak frequency divided by 10 (e.g., 0.018).

2. Dynamic Acceleration:

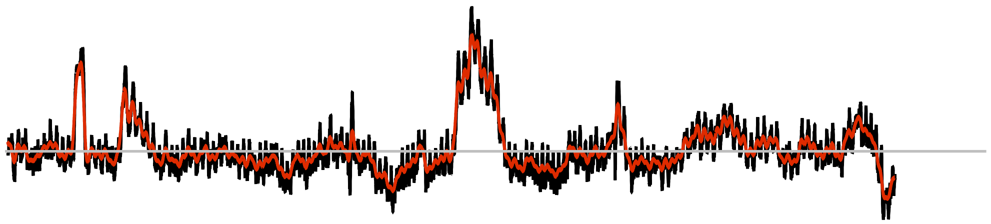
- Go to Data > Duplicate wave; Names - dynamic; template wave - staticX
- Apply the formula on ‘code’ window´: **dynamicX=accX-staticX**

Data Analysis using IGOR

4. ODBA

1. Calculate dynamic for the other axis (Y, Z)

- Follow the same steps as before
- Create a plot to check differences between raw acceleration vs static of each X,Y,Z
- Go **to Graph > Append traces to graph**.
- On the right side, select the "staticX" wave.
- In the lower "axis" tab, select the location of accX.
- In the left menu, select "calculated".



2. ODBA:

- Calculate Overall Dynamic Body Acceleration (ODBA):
- Create wave called ‘odba’ by duplicating ‘staticX’
- Go to **Data > Duplicate wave**.
- Apply **ODBA** formula on ‘code’ window: **odba = abs(dynamicX)+abs(dynamicY)+abs(dynamicZ)**

Data Analysis using IGOR

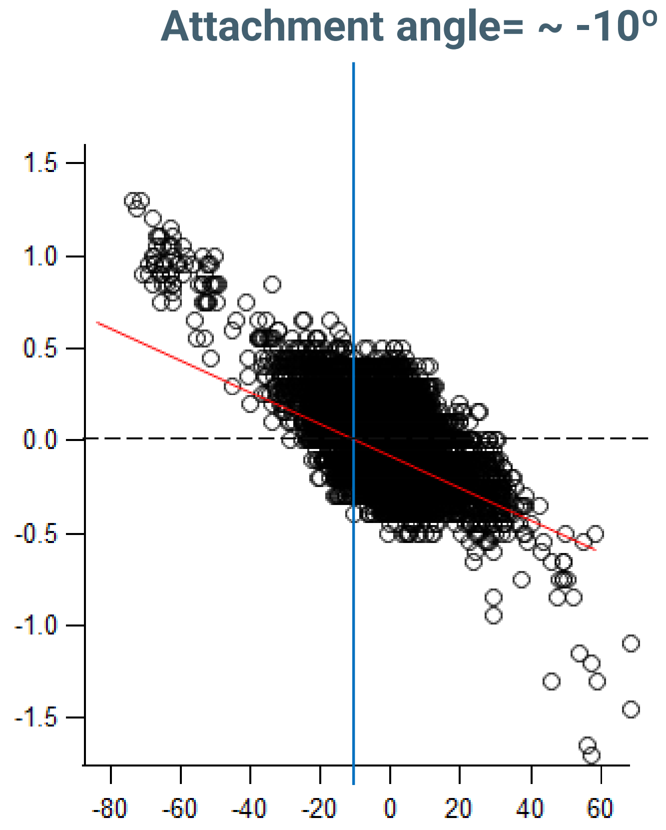
5. PITCH AND ROLL ANGLES

1. Calculate Pitch from Static Acceleration:

- Go to **Data > Duplicate wave**.
- Create a new wave named pitch by duplicating "staticY.
- Apply pitch formula**: pitch = asin(staticY) * 180 / Pi**

2. Correct Pitch Angles (Kawatsu 2009 method):

- Calculate depth difference with the function: **CalcDif(depth,1)**
- Subsample pitch to 1Hz. Duplicate ‘depth’ (1Hz wave) with the name pitch1H
- Apply the function: **pitch1Hz = pitch(x)**
- Plot depth difference vs. pitch: **Window > New graph**
- Set ywave to "depth_Dif" and xwave to "pitch1Hz".
- Add linear regression: **Analysis > Quick fit > Line**.
- Find pitch at depth difference zero (attachment angle)
- Apply the formula: **pitch = pitch – attachment angle**



3. Calculate Roll from Static Acceleration:

- Go to Data > Duplicate wave static into ‘roll’ wave.
- Apply the roll formula**: **roll=atan(staticX/staticZ) * (180/Pi)**
- Correct Roll angles same way you did for pitch

Data Analysis using IGOR

6. TAILBEAT FREQUENCY

1. Perform Spectrum Analysis (others like CWT filter)
• Go to **Graph Toolbox > Spectrum Analysis**.
• Choose the desired acceleration wave (i.e., "dynamicX“)
• To select the wave in SA, you need to have the wave selected on the plot window
• Set **minCycle** and **maxCycle** ranges based on your species and expected tailbeat frequency. Start with broad values (e.g., 0-12) for initial exploration, then refine based on observations.
• **Set time** range (all track or sections)
• Calculate spectrum: **Click Calc**.
• Visualize and customize: Adjust the plot color.

Data Analysis using IGOR

6. TAILBEAT FREQUENCY

2. Extract Tailbeat Signals using the Peak Tracer

• After running SA, select **Peak Tracer** option
• Adjust **threshold** and **entropy** (go for 50% and 90%, respectively)
• Experiment with different values to achieve a clean ‘line’ without excessive noise (peaks).
• Click **Save** to create DominantCycle (TB frequency) and DominantAmplitude (TB amplitude) waves with 1-second time intervals.
• Ensure the saved waves exhibit expected patterns and trends.

3. Noise Reduction on TBF (optional)

• Calculate TBF difference by applying a **mask: Mask analysis > Calc > Wave > Diff** (**central difference method)** to calculate the difference between consecutive values in the "DominantCycle" wave.
• **Make Analysis > Stats > Make Mask** and remove values from "DominantCycleDiff" that higher/lower than "-0.3 to 0.3" (as starting points, but adapt based on data distribution) – DifMask
• Select wave: DominantCycle_Dif, method: value; range: -0.3 – 0.3; output: DifMask
• **Mask Analysis > Misc > Convert Wave into XY**: wave – DominantCycle; mask – Dif Mask; select Timeseries; click on **Convert**
• It will create a filtered ‘DominantCycle_select’ wave

Data Analysis using IGOR

6. TAILBEAT FREQUENCY

4. Clustering Analysis: (split into different behaviours)
• Go to **Analysis > Clustering > K-Means clustering**.
• Set the number of clusters to **4** and click **Start**.

5. Identify periods of gliding (likely)
• Set the number of clusters to **20** and click **Start**.
• Identify curve with **lower signal (likely gliding)** – cluster number?
• Click **Save** to create a new wave named "Etho_Category".
• Go to **Make Analysis > Stats > Make Mask,** select Etho_Category and cluster number
• Choose the cluster corresponding to gliding.
• Refine gliding by selecting only periods **lasting more than 3 seconds**
• Use **Make Analysis > Calc > Event duration** with a minimum duration of 3 seconds and infinite maximum.

Data Analysis using IGOR

7. FILTER DATA AND SAVE

1. Create a mask for periods above 1 meter depth

• Go to **Make Analysis > Stats > Make Mask**, select **depth** and >2 to Inf.
• Name this mask as Surface
• **Mask Analysis > Misc > Convert Wave into XY**: wave – depth; mask – Dif Mask; select Timeseries
• It will create a filtered ‘depth_select’ wave (run for all the variables to clean surface noise -tag wobbling)

2. Build dataframe

• Go to **Window > New Table >** Select the variables that you want.
• **Save > Table Copy** (table window must be selected)