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## Study Premise

Myctophids (family Myctophidae) are an important part of the ocean biological carbon pump. Accurately estimating the magnitude of their contribution to the biological carbon pump requires knowledge of the species’ field metabolic rates; the time-averaged energy expenditure of a free-living organism in its natural habitat. In this study, we calculate Moto, a mass-specific proxy of metabolic rate derived from otolith d13C, for six species of myctophids from the Scotia Sea (*Electrona antarctica, E. carlsbergi, Gymnoscopelus braueri, G. nicholsi, Krefftichthys anderssoni* and *Protomyctophum bolini*).

### Research Questions

* Do Moto values scale with body mass and temperature, according to metabolic theory?
  + Among and within species.
* Do Moto values vary among species, after body mass and temperature are accounted for?
* Among species:
  + Moto = a + bW \* W + bT \* T + a\_VarSpecies (model 1).
    - W = body mass
    - T = temperature (Celcius)
    - a\_VarSpecies = variable intercept of species
* Within species:
  + Moto = a + bW \* W + bT \* T (model 2).
    - W = body mass
    - T = temperature (Celcius)

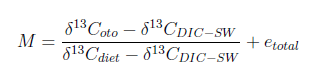
## Methods

For most otoliths, only the outer portion was sampled (100-200um depth), corresponding to the most recent part of the fish’s life. Where otoliths were too small to be milled (all *K. anderssoni* and some *P. bolini*), whole otoliths were crushed to obtain the sample.

### Moto

A mixing model was used to estimate the proportion of metabolic carbon in the blood,

M:

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Where d13Coto is the d13C value of the fish's otolith, d13CDIC-SW is the value for d13C

of dissolved inorganic carbon (DIC) ingested by the fish through seawater, d13Cdiet

is the d13C of the diet, and etotal is the isotopic fractionation from DIC to blood,

blood to endolymph, and endolymph to otolith. For this study we assumed that etotal

was invariant across species, and that Moto values were directly proportional to the

percentage of metabolic carbon in the fish's blood (Chung et al., 2019a).

### Temperature

d18O of otolith aragonite can be used to estimate the ambient temperature experienced

by a fish (Hoie et al., 2004; Thorrold et al., 1997). Experienced temperature (T) was

reconstructed using the following equation:



Where d18Ooto is the d18O of the otolith, d18OSW is the d18O of the ambient seawater,

and a and b are parameters, set according to Hoie et al. (2004).

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## Results

### Moto Among Species

* Species mean and standard deviations of Moto predictions, accounting for body mass and temperature (figure 1), from highest to lowest.
  + *E. antarctica* = 0.2115 ± 0.0177
  + *G. braueri* = 0.1999 ± 0.0181
  + *K. anderssoni* = 0.1938 ± 0.0183
  + *E. carlsbergi* = 0.1725 ± 0.0182
  + *P. bolini* = 0.1705 ± 0.183
  + *G. nichosli* =0.1444 ± 0.0201
* *G. nichosli* also had a variable intercept significantly less than zero (figure 4).
  + Suggests *G. nicholsi* has significantly lower Moto values than the other species.

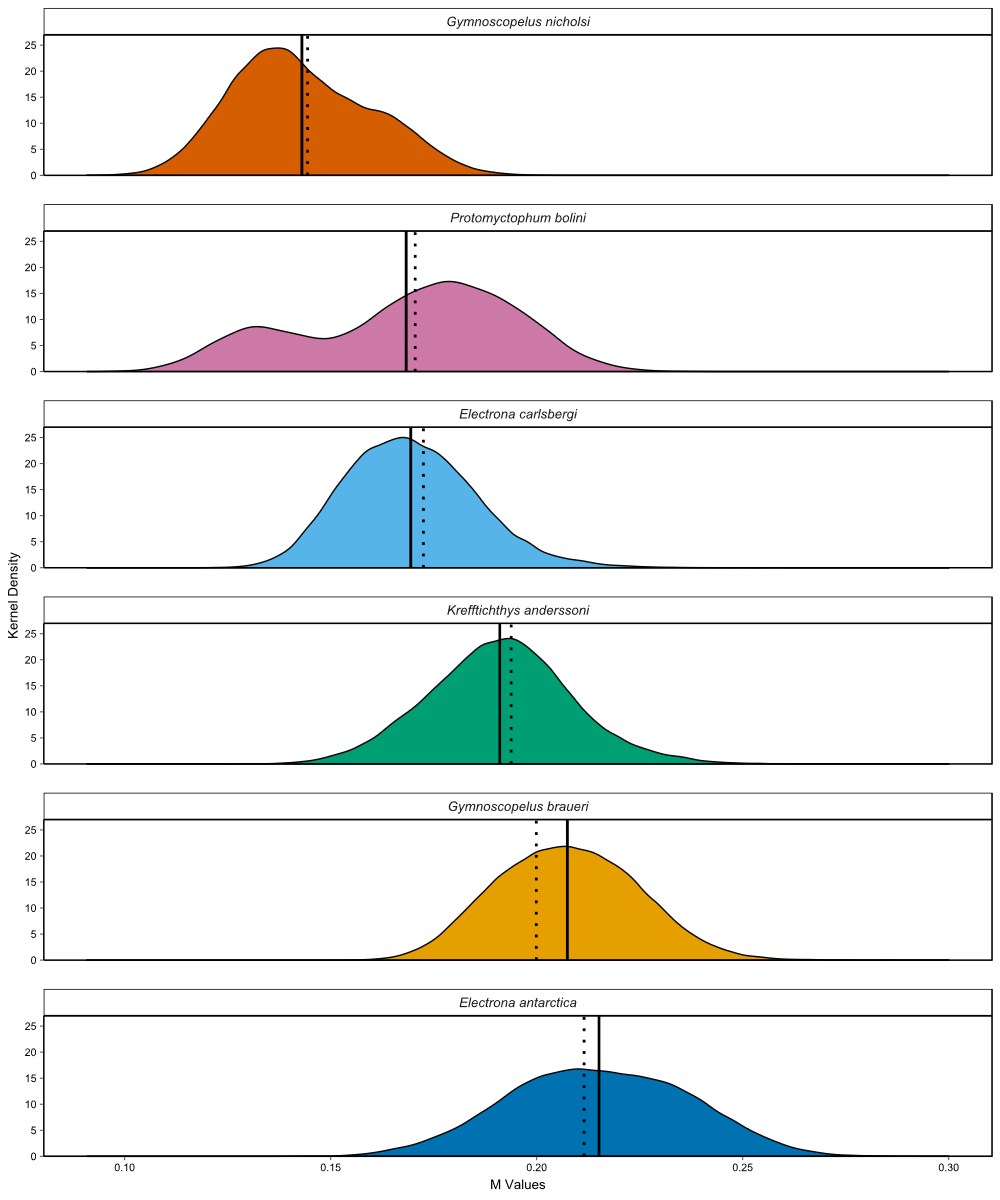


Figure 1 - Kernel density of posterior predictions of Moto, grouped by species (orange = *Gymnoscopelus nicholsi*, pink = *Protomyctophum bolini,* light blue = *Electrona carlsbergi*, green = *Krefftichthys anderssoni*, yellow = *Gymnoscopelus braueri*, dark blue = *Electrona antarctica*). Solid lines indicate the mean Moto value of these posterior predictions for each species. Dotted lines indicate the species mean Moto when body mass and temperature are accounted for, according to model 1.

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### Body Mass and Temperature Among Species

* Temperature range from -1.87 to 2.99°C.
* Posterior predictions of the scaling exponent for temperature (bT) are negative (figure 4).
  + Indicates a negative effect of temperature on Moto when body mass and species are accounted for. (figure 2).

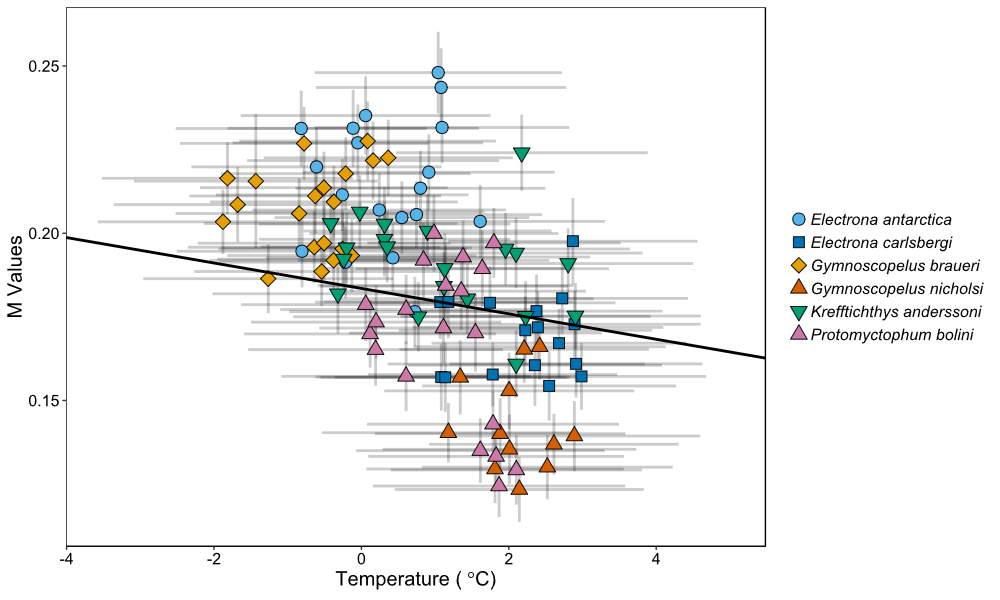


Figure 2 - Mean posterior predictions of Moto against mean reconstructed temperature (°C) for each individual. The solid line shows the mean linear model of Moto and temperature, accounting for body mass and grouped by species.

* Body mass ranged from 0.5 to 38.7g wet weight.
* Posterior predictions of scaling exponent for body mass (bW) overlapped with zero (figure 4).
  + Indicates no significant effect of body mass on Moto when temperature and species are accounted for.

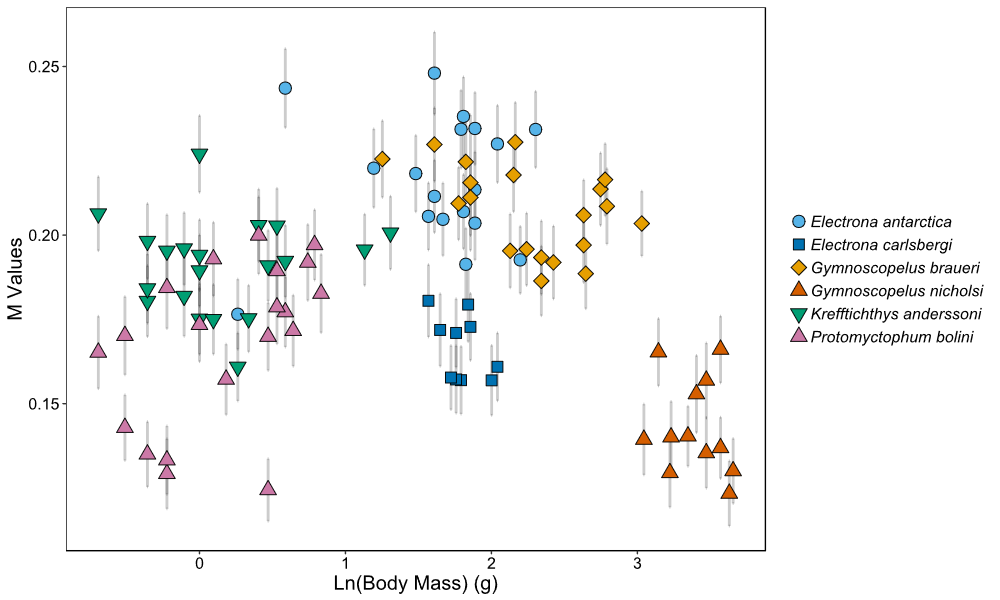


Figure 3 - Mean posterior predictions of Moto against mean log body mass (g) for each individual.

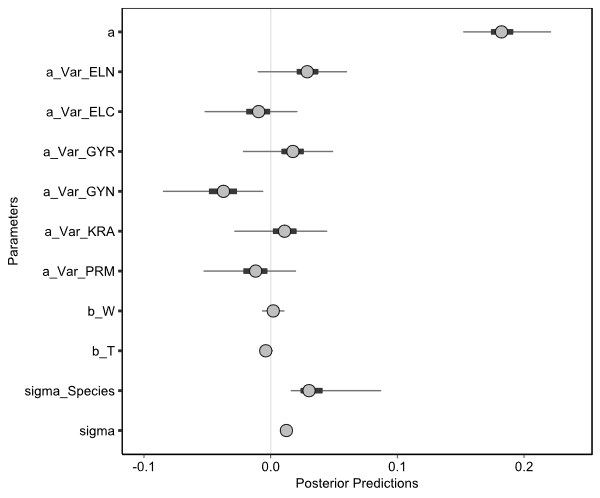


Figure 4 - Posterior predictions for model 1 (Moto = a + bW \* W + bT \* T + a\_VarSpecies). Circles indicate the mean of the posterior predictions. Thick lines show the 50% confidence intervals, while thin lines show the 95% confidence intervals. ELN = *Electrona antarctica*, ELC = *E. carlsbergi*, GYR = *Gymnoscopelus braueri*, GYN = *G. nicholsi*, KRA = *Krefftichthys anderssoni* and PRM = *Protomyctophum bolini.*

### Body Mass and Temperature Within Species

* Only posterior predictions which did not overlap zero (significant) were bW for *G. braureri* and *P. bolini.*
* Negative bW for *G. braueri* (bW = -0.0159 ± 0.0089).
  + Negative effect of body mass on Moto when temperature accounted for.
  + Consistent with metabolic theory. Mass-specific metabolic rate (Moto) decreases with increasing body size.
* Positive bW for *P. bolini* (bW = 0.0262 ± 0.0124).
  + Positive effect of body mass on Moto when temperature accounted for.
  + Opposite to metabolic theory.

## Ideas/Discussion

* Species is the most useful variable in modelling Moto values.
  + Due to ecology.

### Species Differences

* High Moto species known to perform diel vertical migration (DVM) year round, and have broad depth range (0-1000m).
  + *E. antartica, G. braueri, K. anderssoni.*
* Daily or near daily migrations by these species may increase metabolic costs.
* In contrast, sparse evidence for DVM in *G. nicholsi* and *P. bolini,* and *E. carlsbergi* only migrates in the summer.
* Question: Do these species swim to migrate vertically, or do they use swim bladders, or another method of buoyancy control?
  + *E. antartica, G. braueri* and *G. nicholsi* only have residual swim bladders, so presumably they swim.
  + *K. anderssoni, P. bolini* and *E. carlsbergi* all have well developed swim bladders.
* *G. nichosi* becomes benthopelagic in late adulthood.
  + Associated with less movement and lower metabolic rate compared to pelagic fishes.
  + May explain why their Moto values are significantly different.
* Question: Does this seem plausible? Is there anything else about *G. nicholsi* which might explain the lower Moto?

### Apparent Negative Temperature Correlation