Enzymatic Regulation of Zooplankton Respiration

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Based on metabolism (Klieber’s Law), but applied to growth, to development time, to the ocean, & to many other biological phenomenon.

- Philosophy: Supply-side Economics*

- $R = F(\text{Metabolic Distribution Networks})$

- $R = \text{Delivery rate of these fractal networks}$
Metabolic Theory of Ecology

\[ R = K_0 M^{3/4} e^{-E_a/kT} \]

- **Part A:** *Nutrient* dependency [reactants]
- **Part B:** *Biomass* dependency (Kleiber’s Law) [reactant fluxes, reaction rates]
- **Part C:** *Temperature* dependency (Boltzmann Factor) [system kinetic energy]
Why Kleiber’s Law is correct.

**Zooplankton R & Φ obey Kleiber’s Law**

**Kleiber's Law (Zooplankton, 5 phyla)**

- **R** = 1.5W^{0.76}
- **Φ** = 3.3W^{0.79}
- \[ y = 0.7913x + 0.5155 \]
  \[ R^2 = 0.9458 \]

- \[ y = 0.7565x + 0.1757 \]
  \[ R^2 = 0.9363 \]
Why the MTE is right.

\[ R = f(M + T) \]
Why Kleiber’s Law and the MTE are wrong.

The MTE & Kleiber’s Law can’t predict respiration under nutrient limiting Conditions.
Our alternative is based on the recognition:

1. That the electron transport system (ETS) controls respiration and is a measure of potential respiration ($\Phi$).

2. That mitochondrial NADH (and NADPH) control the activity of the ETS.

3. And that Michaelis-Menten kinetics describes the impact of substrate (reactant) limitation on reaction rates.
Ae^{-Ea/RT}

\[ R = S\Phi A \left( e^{-Ea/RT} \right) / (K_\beta + S) \]

In addition, we can build on 100 years of research by recognizing the Arrhenius equation’s efficiency in describing the temperature dependence of biological as well as chemical rate processes. Note! \( A \) is necessary!
A counter proposal: A First Principle Respiration Model*

\[ R = S\Phi_A \left( e^{-\frac{E_a}{RT}} \right) / (K_\beta + S) \]

- Based on: respiratory potential (\( \Phi \)) as set by the respiratory electron transport system.

- Philosophy: Demand-side *Economics*

- \( R = f(\text{Cellular Demand for ATP}) \)

- \( R = \text{Delivery rate of } e^- \text{ to Cyt a-a}_3 \)
A counter proposal: A First Principle Respiration Model*

\[ R = S \Phi A \left( e^{-\frac{E_a}{RT}} \right) / (K_\beta + S) \]

- **Part A:** Michaelis-Menten *Nutrient* dependency \((\text{NADH} + \text{NADPH})°\)

- **Part B:** *Respiratory potential* dependency \((\Phi\text{ from ETS activity})\).

- **Part C:** *Temperature* dependency \((\text{Arrhenius Reaction Rate Theory})\).
Biomass replaceable by Potential Respiration (Φ)!

\[ R = SΦA \left( e^{-\frac{E_a}{RT}} \right) \left/ \left( K_β + S \right) \right. \]

Log(Respiration vs Log (Φ))

Respiration vs Φ

\[ y = 0,9414x - 0,3444 \]

\[ R^2 = 0,9811 \]

\[ y = 0,4656x - 1,5603 \]

\[ R^2 = 0,9846 \]
A First Principle Model for Respiration

\[ R = S \Phi A \left( e^{-E_a/RT} \right) / (K_\beta + S) \]

Food Source, biomass, ETS, & R as f (time)
**A First Principle Model for Respiration**

$$R = S \Phi A \left( e^{-\frac{E_a}{RT}} \right) / (K_\beta + S)$$

Pyruvate & R as f(tin)

As falls the pyruvate in the culture medium, so falls the ETS reactants. And thus falls the respiration rate!

As falls the substrate in an enzyme reaction, so falls the activity of the enzyme!

[v = \frac{V_{max}}{2}

\begin{align*}
V_{max} & = \frac{V_{max} [S]}{K_m + [S]} \\
K_m & \text{ Substrate}
\end{align*}
A First Principle Model for Respiration

\[ S(t) = f([DOC] + [Cell Protein]) \]
A First Principle Model for Respiration

\[ R = S \Phi A \left( e^{-\frac{E_a}{RT}} \right) / (K_\beta + S) \]

**Diagram:**
- **Y-axis:** Respiration (Predicted & Measured)
- **X-axis:** Time (hours)
- **Graph:** Measured and Modeled respiration over time.
A First Principle Model for Respiration

\[ R = S \Phi A \left( e^{-E_a/RT} \right) / (K_\beta + S) \]
\[ R = f(T). \] Use the Arrhenius Equation, it incorporates the Boltzmann Factor!

\[ R = S\Phi A \left( e^{-\frac{E_a}{RT}} \right) / (K_\beta + S) \]

**Zooplankton bathipelagic**

- **Potential Respiration (nL O$_2$ h$^{-1}$ l$^{-1}$)**
  - Graph showing potential respiration against temperature (°C)
  - Maximum at around 16°C

- **Log (Potential Respiration)**
  - Graph showing log potential respiration against $1/\text{Temp} \times 10^3$ (°K)
  - Slope = $-E_a/R$
  - $E_a = 13.2$ kcal/mol
CONCLUSION

- The MTE and Kleiber’s Law alone can not predict or explain respiration on the small scale.

- Potential respiration, substrate depletion, and Michaelis-Menten kinetics can explain and predict respiration on the small scale.
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