Sizing the effects of temperature on fish

A general size- and trait-based model to predict temperature impact on ectotherms

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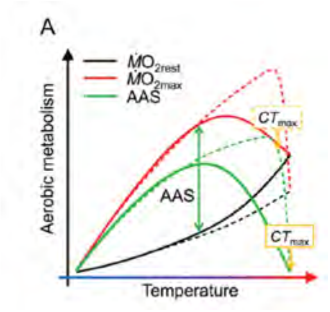
Physiology of temperature impacts

A range of eco - physiological models have been formulated, yet the general physiological principles of temperature impacts on ectotherms themselves are still vigorously debated * .

Prominent view is that the available oxygen beyond routine activity (metabolic scope) determines thermal performance and niches.

Oxygen supply may not be limiting in many species – scopes increases with temperature.



from Lefevre 2016 Cons. Phys.

* Brander et al 2013 ICES JMS

Lefevre 2016 Cons. Phys.

Pörtner et al. 2017 J. Exp. Biol.

Jutfelt et al. 2018 J. Exp. Biol.

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Oxygen supply may not be limiting in many species – scopes increases with temperature.

Despite a large body of experiments, no general mechanistic model exists to understand temperature driven physiological changes and resulting ecological outcomes.

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Towards a general model

Traits of a general model:

1. Should be parsimonious: reflect both ecology and physiology in as much detail as necessary, and as little detail as possible.

2. Should not be based on a single species but on life-history traits.

3. Should produce predictions that can be confronted with data.

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Towards a general model

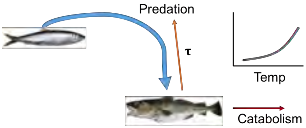
Building blocks

Bio - energetic balance:

$$P = S - D$$

$$P = (1 - \beta - \phi) f T_h h w^q - k T_k w^n$$

$$f = \frac{\tau \gamma w^p \Theta}{\tau \gamma w^p \Theta + T_h h w^q}$$



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Towards a general model

Building blocks

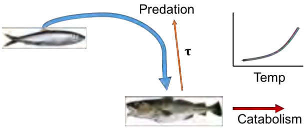
Increasing activity comes at a cost.

$$P = S - D$$

$$P = (1 - \beta - \phi) f T_h h w^q - k T_k w^n - \tau \delta k T_k w$$

$$f = \frac{\tau \gamma w^p \Theta}{\tau \gamma w^p \Theta + T_h h w^q}$$

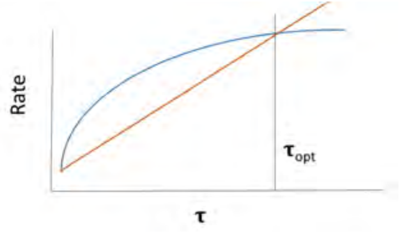
$$M = (m_0 + \tau m_\tau) w^{1-p}$$



Towards a general model

To each temperature corresponds an optimal activity level τ_{opt} – no gain with more activity beyond τ_{opt}: f saturates, but metabolic costs and mortality increase

Optimum found by maximizing $P(\tau)/M(\tau)$



Towards a general model

Building blocks

O_2 demand of feeding and energy metabolism represents a hard limit for activity.

$$
\begin{aligned}
P_{0_2} &= S_{O_2} - D_{O_2} \\
&= f_{O_2} w^n - \omega(\beta f T_h h w^q + k T_k w^n - \tau \delta k T_k w)
\end{aligned}
$$

S_{O2} is the maximum oxygen supply, P_{O2} is the metabolic scope.

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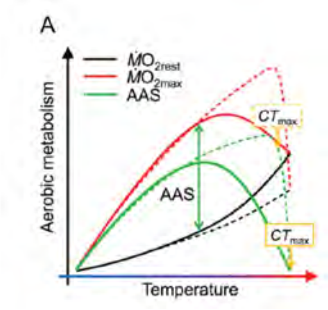
Trait based scenarios

Slow vs fast life history:

- lower resting metabolism,
- lower maximum consumption,
- higher mortality risk from foraging relative to non - active state.

Presenting results for species with dome - shaped oxygen supply ($MO2_{max}$) only.



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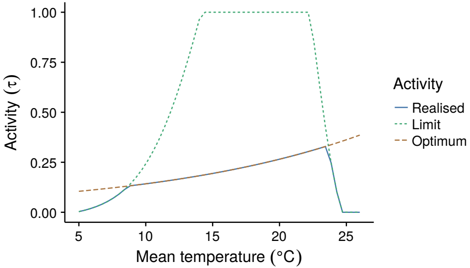
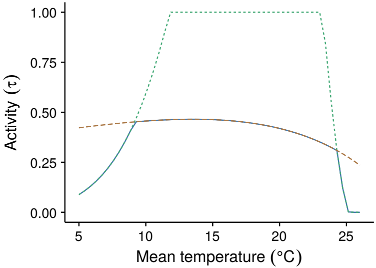
Activity and oxygen limitation

Increasing temperature leads to **increased activity** in most cases along the slow - vs. fast trait axis.





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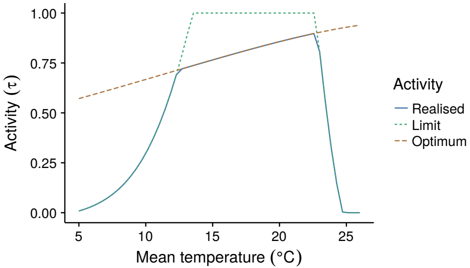
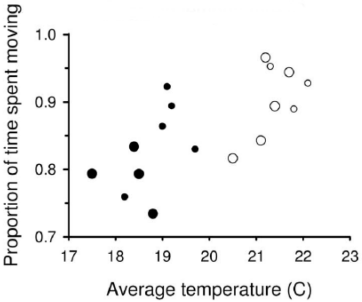
Activity and oxygen limitation

Increasing temperature leads to **increased activity** in most cases: age 0 lake trout





Biro et al. 2007, PNAS

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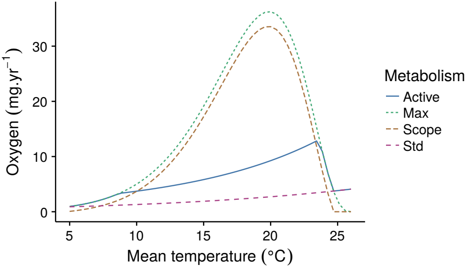
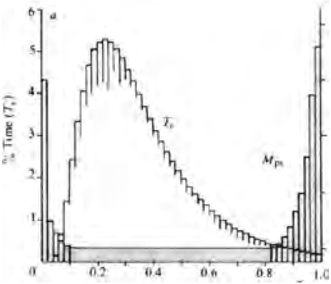
Activity and oxygen limitation

Oxygen is limiting at extreme temperatures – at intermediate temperatures it is not optimal to utilize the full scope, even for highly active species.





Priede 1977, Nature

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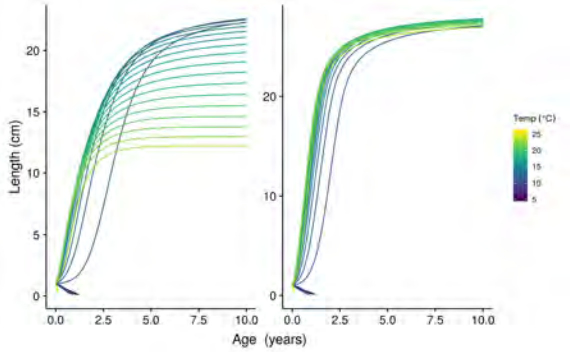
Growth, fitness and organism size

Growth peaks at higher temperature, yet leads to smaller individuals…especially in environments of low food availability.



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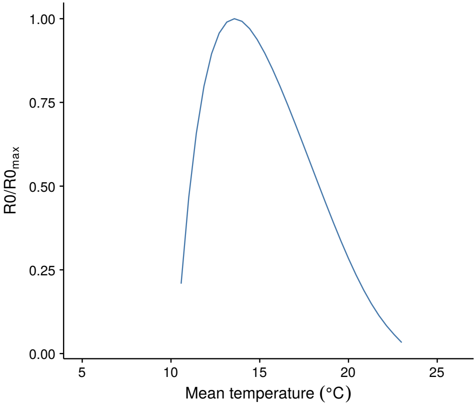
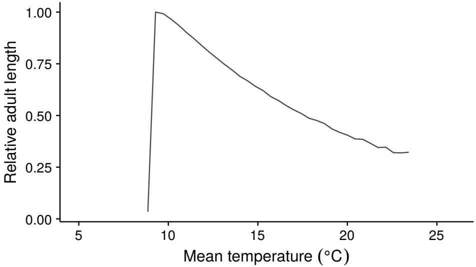
Growth, fitness and organism size

… but fitness trend usually opposes growth response – **fitness highest at low or intermediate temperatures.**



Growth, fitness and organism size

Fitness trend can be used to estimate fitness gradients and selection response to temperature - e.g., change in size-at-maturation



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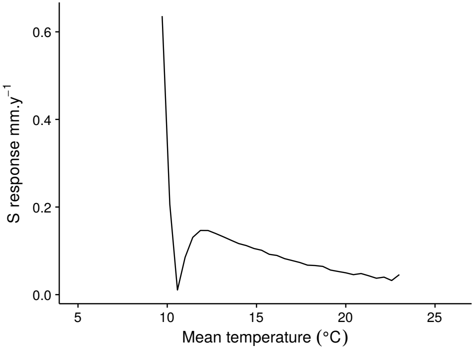

What does this buy us?

1. Our general model ***explains*** general observations of temperature response:

- Species being found at lower temperatures than “optimal” growth and metabolic scope,
- Smaller individuals at high temperature: the temperature-size-rule,
- Increased activity with temperature.

2. We can use this framework to derive general ***predictions***:

- Organism size responds to temperature, both via phenotypic plasticity (immediate) and selection (slow!).

3. Size- and trait-based formulation means the framework can be ***applied*** in size-based ecosystem models.

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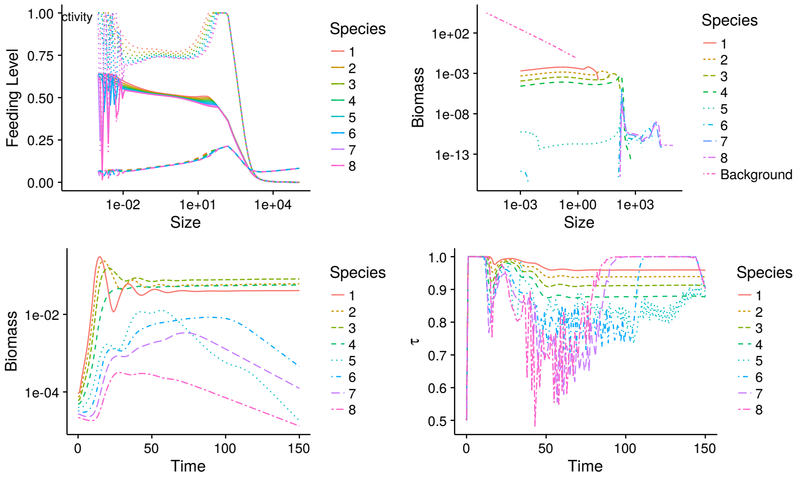
Post-script

With temperature and adaptive foraging, dynamics are unstable…



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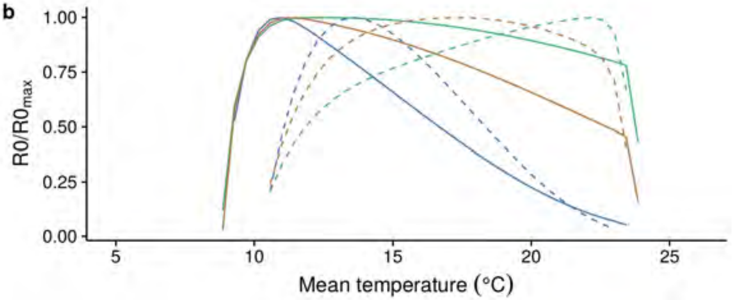
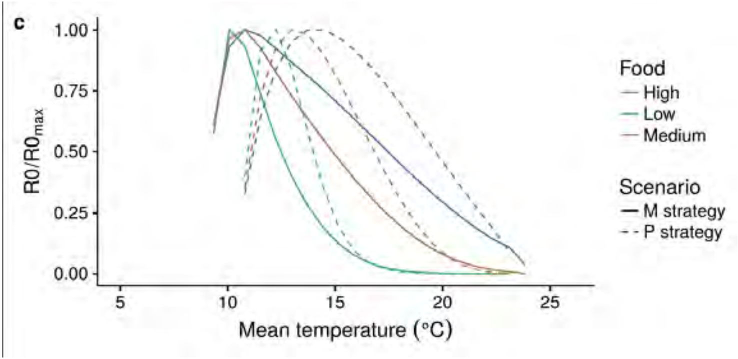
Post-script

Fitness trends depend on activity cost - more efficient foraging leads to shift in temperature optimum to higher temperatures.



Post-script

Fitness trends depend on food - more available food leads to a slower decline of fitness with higher temperatures.



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