Sizing the effects of temperature on fish

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Introduction

Size-at-maturation and maximum size are key traits, defining ecological niches and driving ecological interactions[1]. Temperature has been identified in various contexts as a key driver of organism size (Bergman's rule, Temperature-size-rule…)[2]. Climate change may therefore have strong effects on organism size and follow on effects at population and ecosystem levels, but no clear framework to understand effects of temperature[3].

Aim: Develop a eco-physiological model[4] to predict effects of changing temperatures on organism size over ecological and evolutionary time-scales

Model

We set up a weight (w) based model consisting of mass and oxygen balance equations: Feeding - type 2 functional response with parameters for maximum consumption rate γ, modulated by feeding activity τ, and maximum intake h, which responds to temperature via T_M^c:

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

Mass balance: Intake is assimilated with loss from heat increment ϕ and absorption β. Metabolic loss due to standard and feeding activity (τ) metabolic costs, modulated by temperature via T_M^c

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

Oxygen balance: Oxygen sets the limit for metabolism via the cost of metabolising one gram of feed ω relative to the potential oxygen supply $f_{O_2} w^n$:

$$P_{0_2} = f_{O_2} w^n - \omega(\beta f_C T_h^c h w^q + k(1+\tau\delta) T_M^c w^n)$$

Mortality: Weight based with base mortality m_0 and activity related mortality m_τ.

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

τ is optimised at any temperature via Gilliam's rule (argmax$_\tau\{\mathbf{P}/\mathbf{M}\}$)

Strategy trade-off: minimising mortality M or maximising energy gain P

P strategy: Maximise intake at the cost of higher standard metabolism to maintain feeding activity and larger gut. Live with higher M.

M strategy: Minimise M by minimising dangerous feeding activity, minimise resting metabolism.

Ecological dynamics

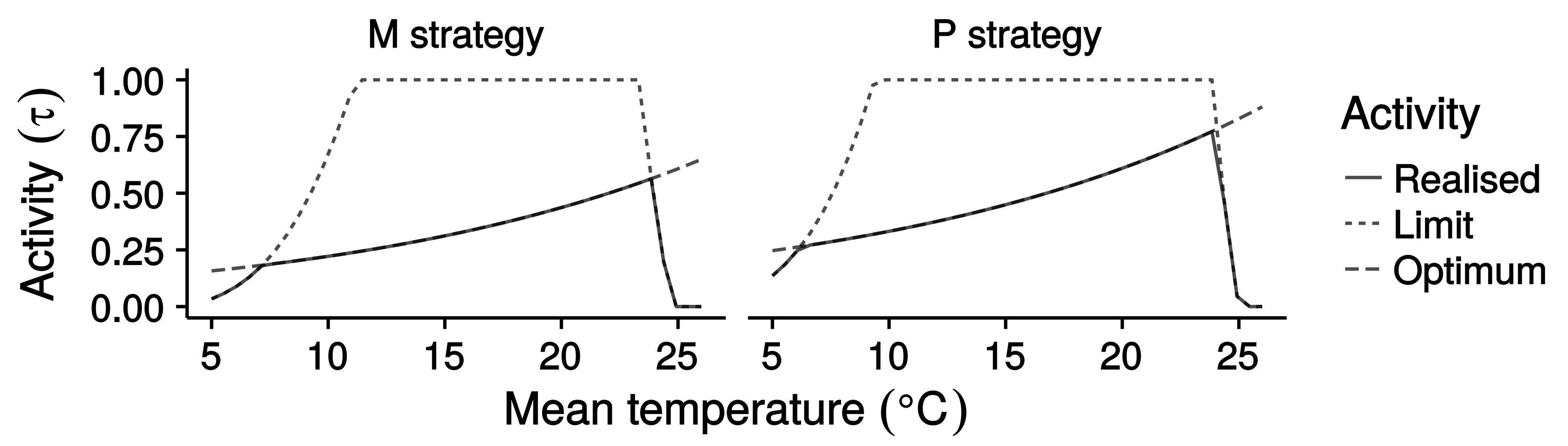

Figure 1: With increasing temperature, most organisms will increase activity τ to offset increased metabolic costs. Oxygen sets metabolic limits at extreme temperatures.

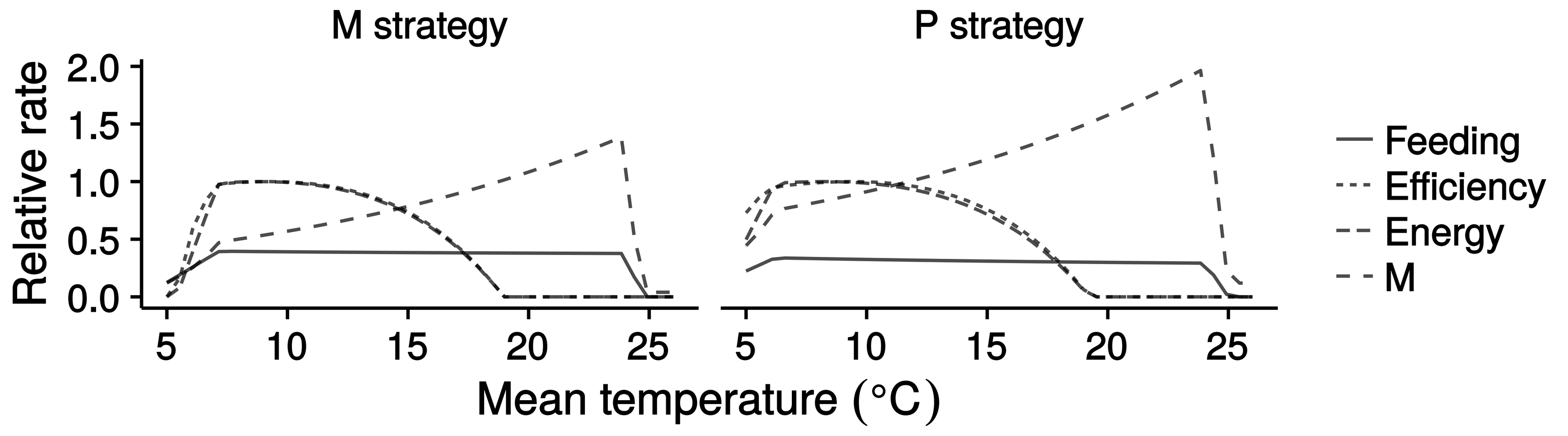

Figure 2: Feeding level, available energy and mortality are impacted by increased activity and the metabolic response to temperature.

Temperature impact on size

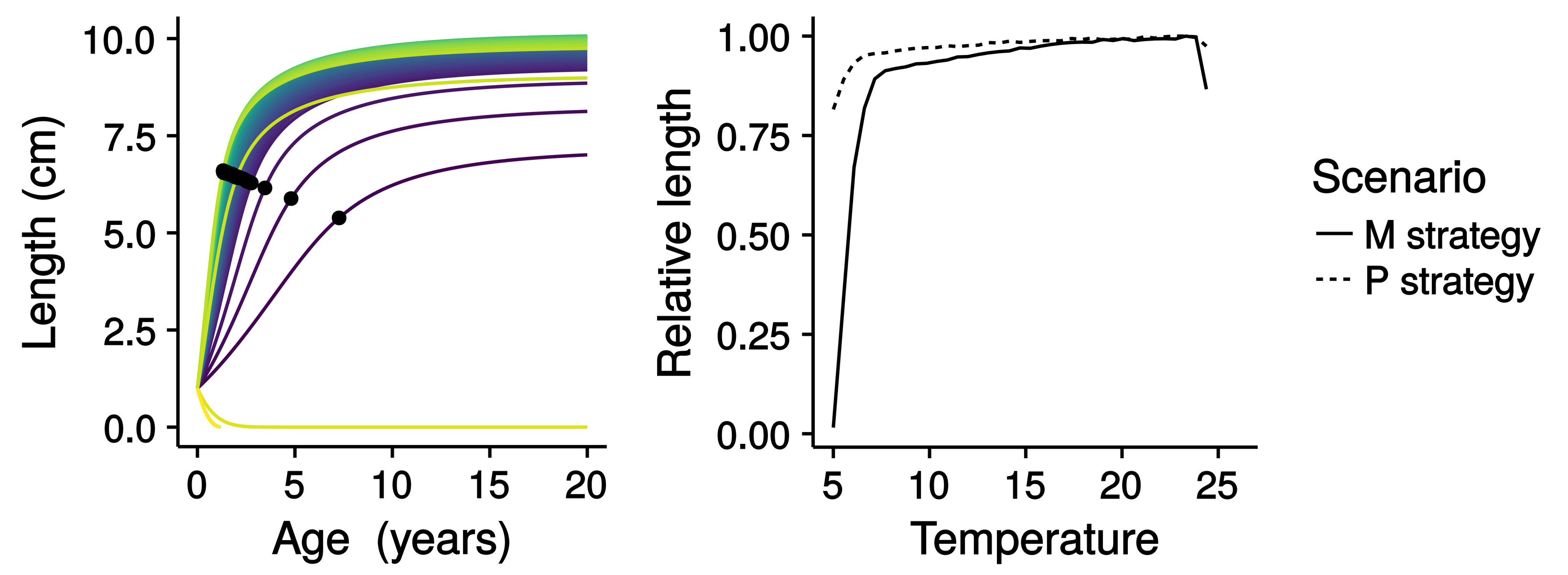

Figure 3: **On ecological time-scales**, temperature affects size via evolved maturation-reaction norms[5]. Most reaction norms found in nature have a negative slope, meaning for faster growth, maturation occurs at a larger size. Increasing temparture (left panel, purple to yellow growth curves) modifies growth, and maturation age changes according to the reaction norm (right panel).

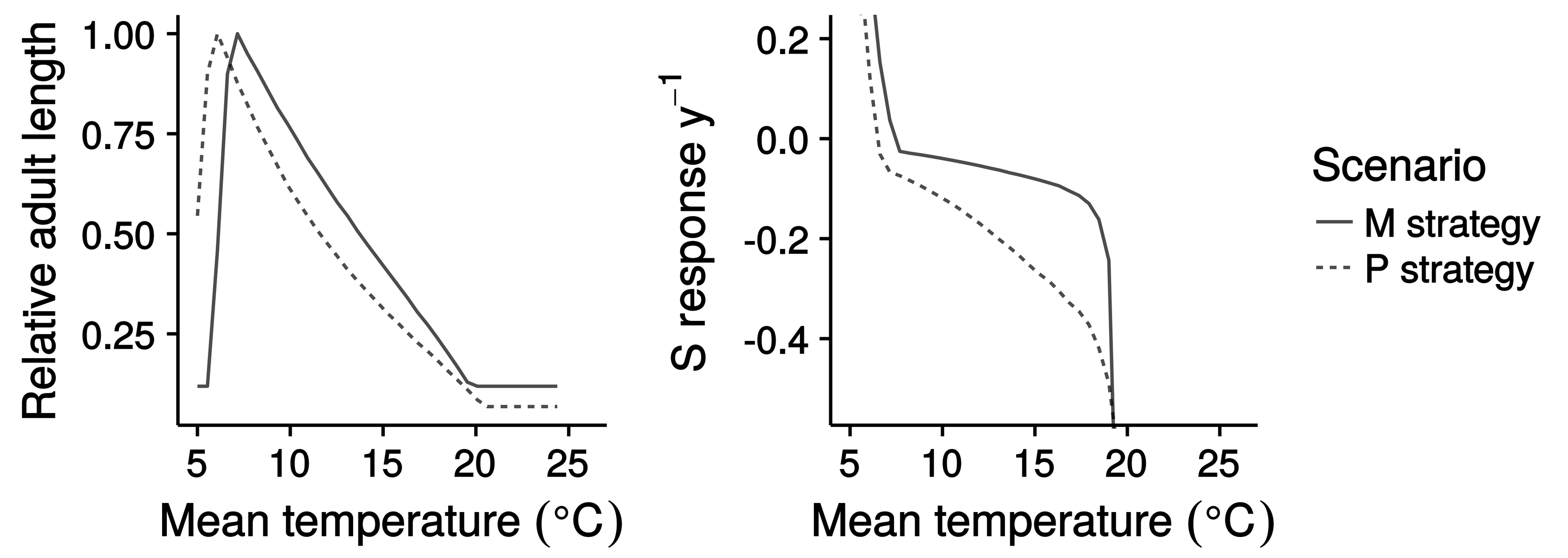

Figure 4: **On evolutionary time-scales**, selection moves the reaction norm. Size-at-maturation reacts strongly to temperature changes in the model (left panel). Selection (S) induced changes in size are slow for M strategists, fast for P strategists.

Take home messages

- **On ecological time-scales changes in adult size due to temperature alone will likely be small, and masked by changes in the environment.**
- **On evolutionary time-scales, size responds strongly. The relative selection response is strongest at temperature extremes.**
- **Size of P strategy species with high activity reacts more strongly compared to sluggish M strategy species.**

Acknowledgements & References

P. Neubauer acknowledges funding from the Royal Society of New Zealand Marsden Fast Start grant 14-DFG-001. All code for the model and this poster is accessible from github at repository Adaptive-dynamics/Sizing-fx-of-temperature.

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