Density-dependence versus density independence mechanisms driving resident Coastal Cutthroat Trout populations under climate change

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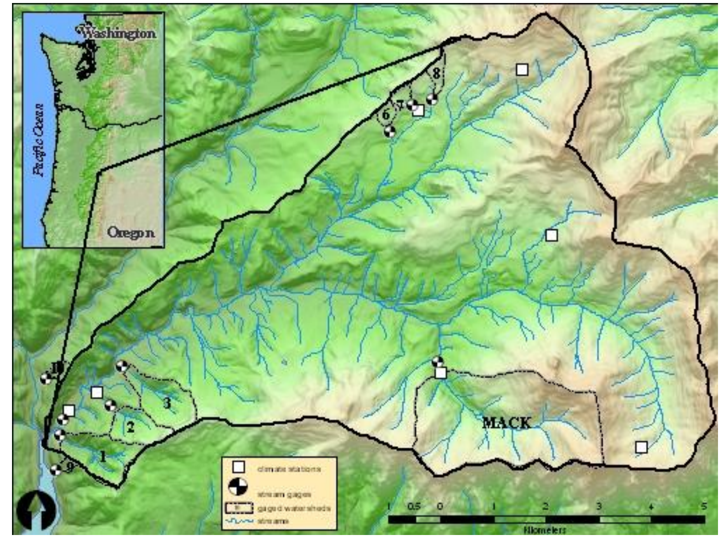
Artwork by Azita Roshani

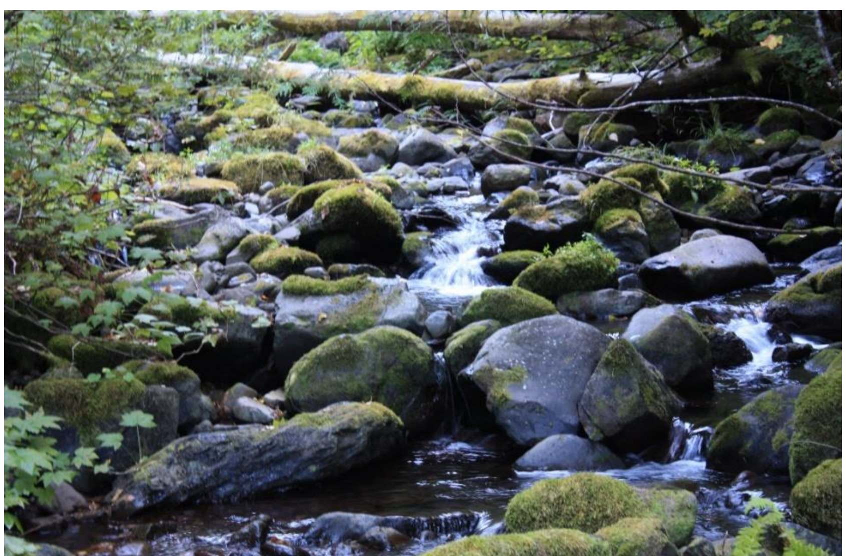

SIMMS

Study sites located at Mack Creek, HJA Experimental Forest

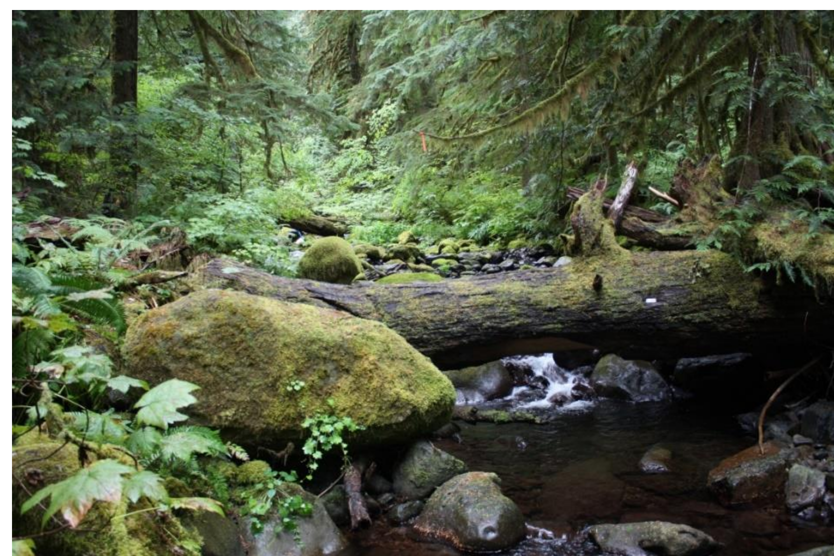
Artwork by Azita Roshani



Second Growth (SG; harvested in 1964)



Old Growth (OG)



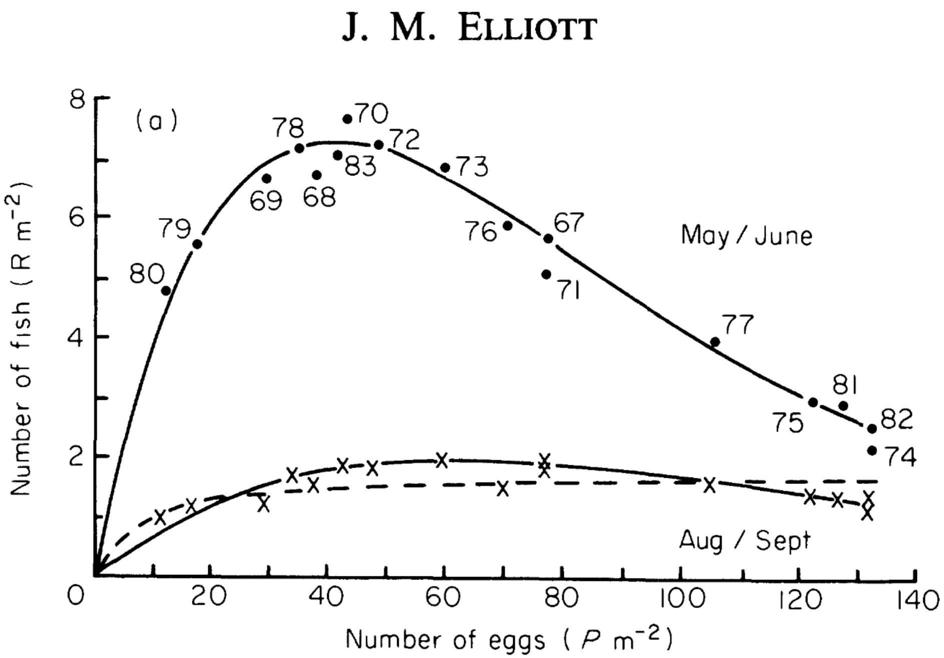
Ecological value of the Mack Creek long-term data

- Quantifying the dynamics of natural populations is a central question in ecology
- Few studies document the drivers of fluctuations in population abundance
    - logistical issues
    - statistical uncertainties
    - difficulty of experiments at population-level
- Effects of climate change at the population-level are difficult to quantify due to confounding factors

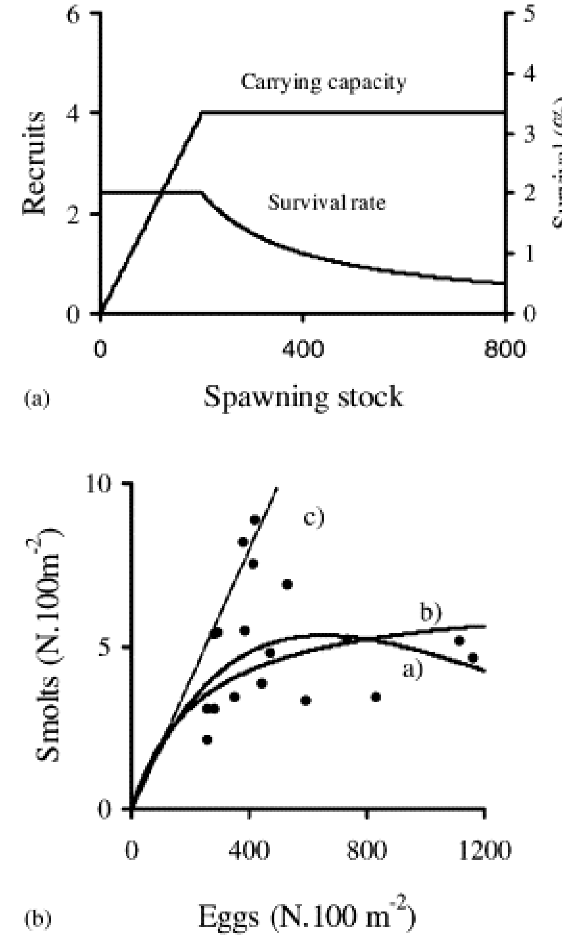
Part 1: Population regulation and stream-dwelling trout

- Drivers of abundance
  - density dependent (competition or predation)
  - density-independent (environmental variability)
- Stream-dwelling organisms
  - environmental variation
  - patchiness and small-scale population differentiation

Regulation in natural populations
Density dependence

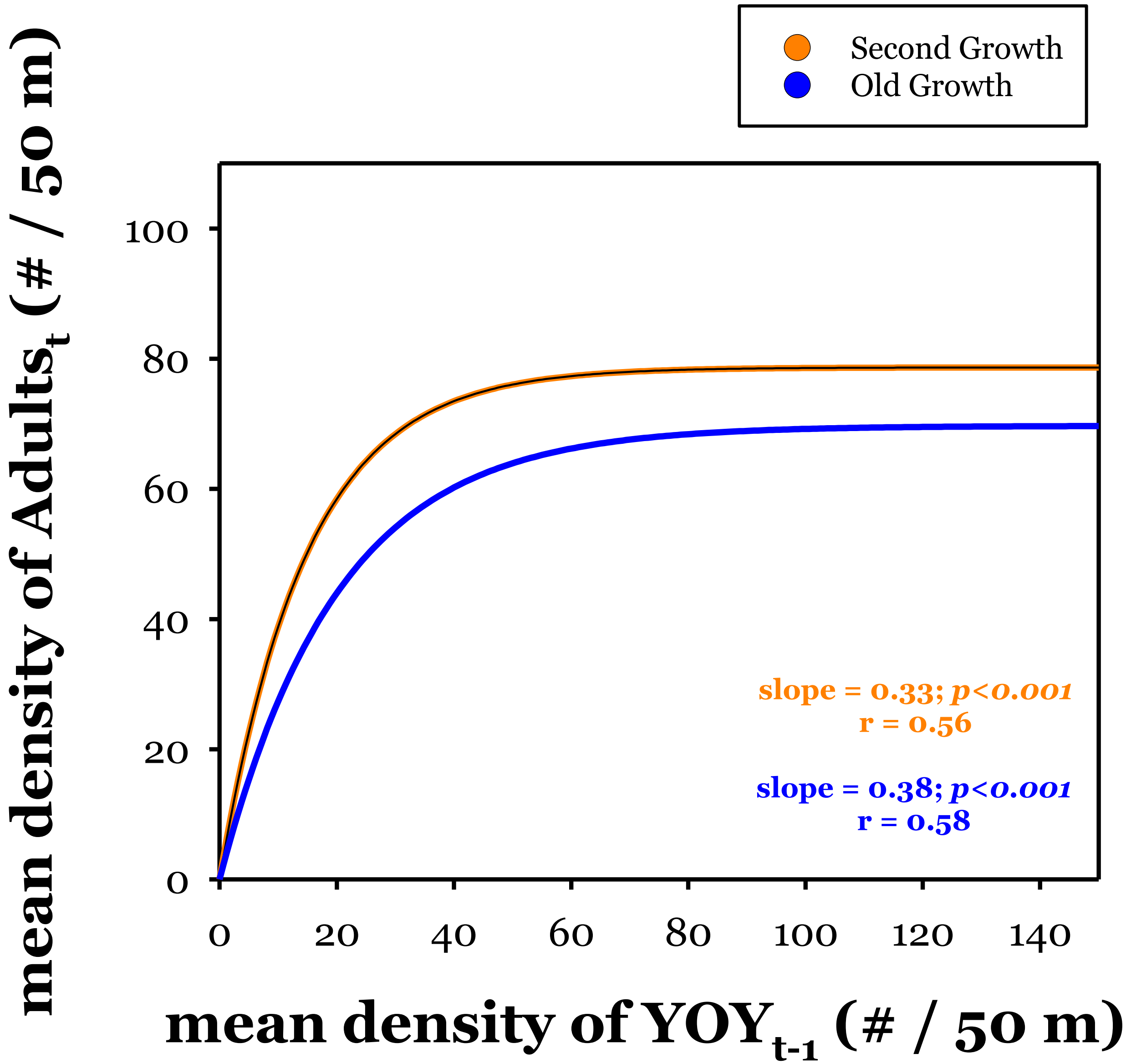


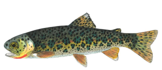
Elliot (1984)



Milner et al. (2003)

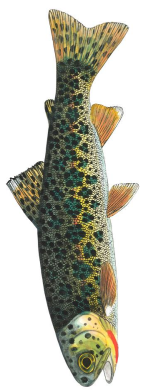
Density dependence

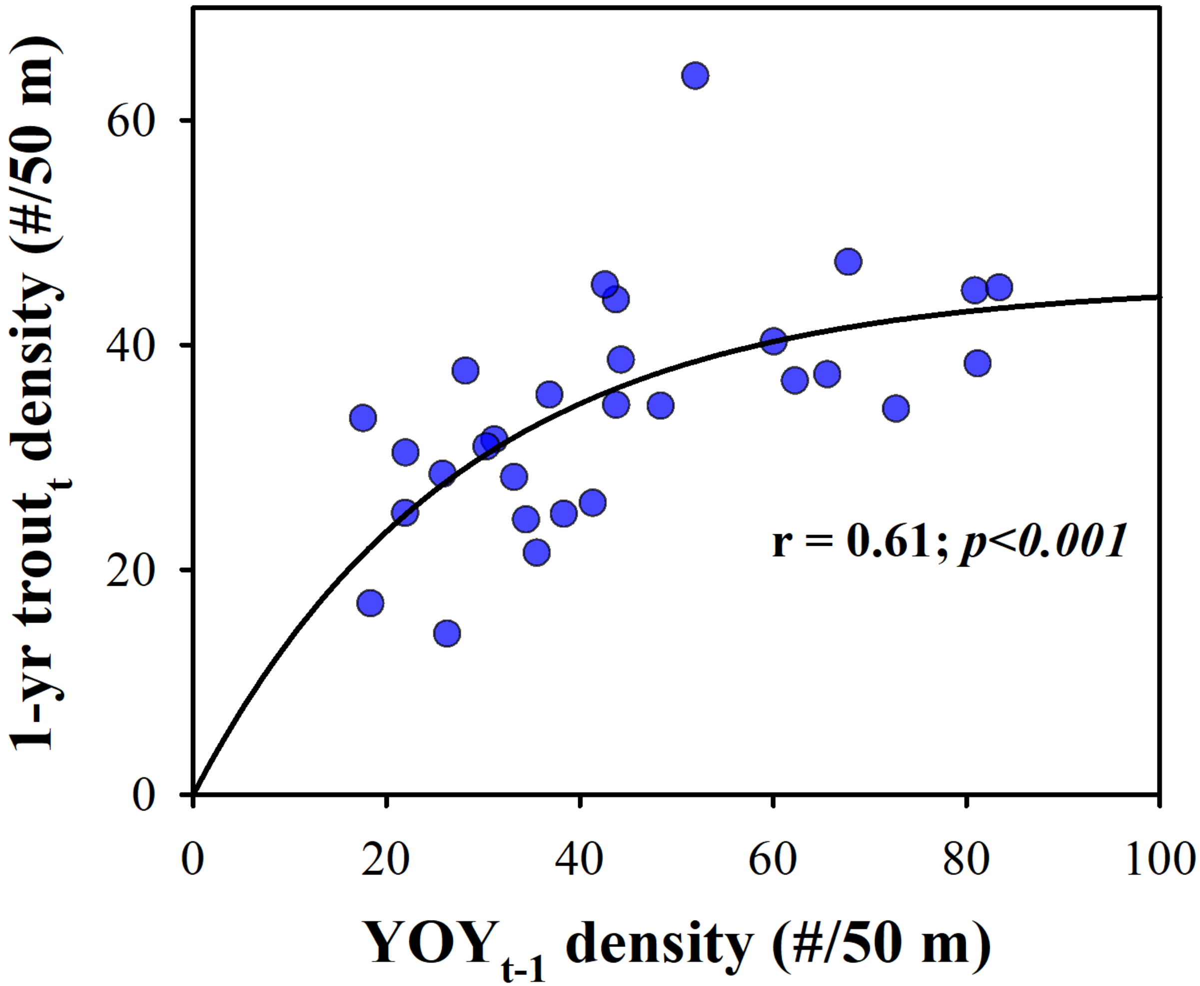




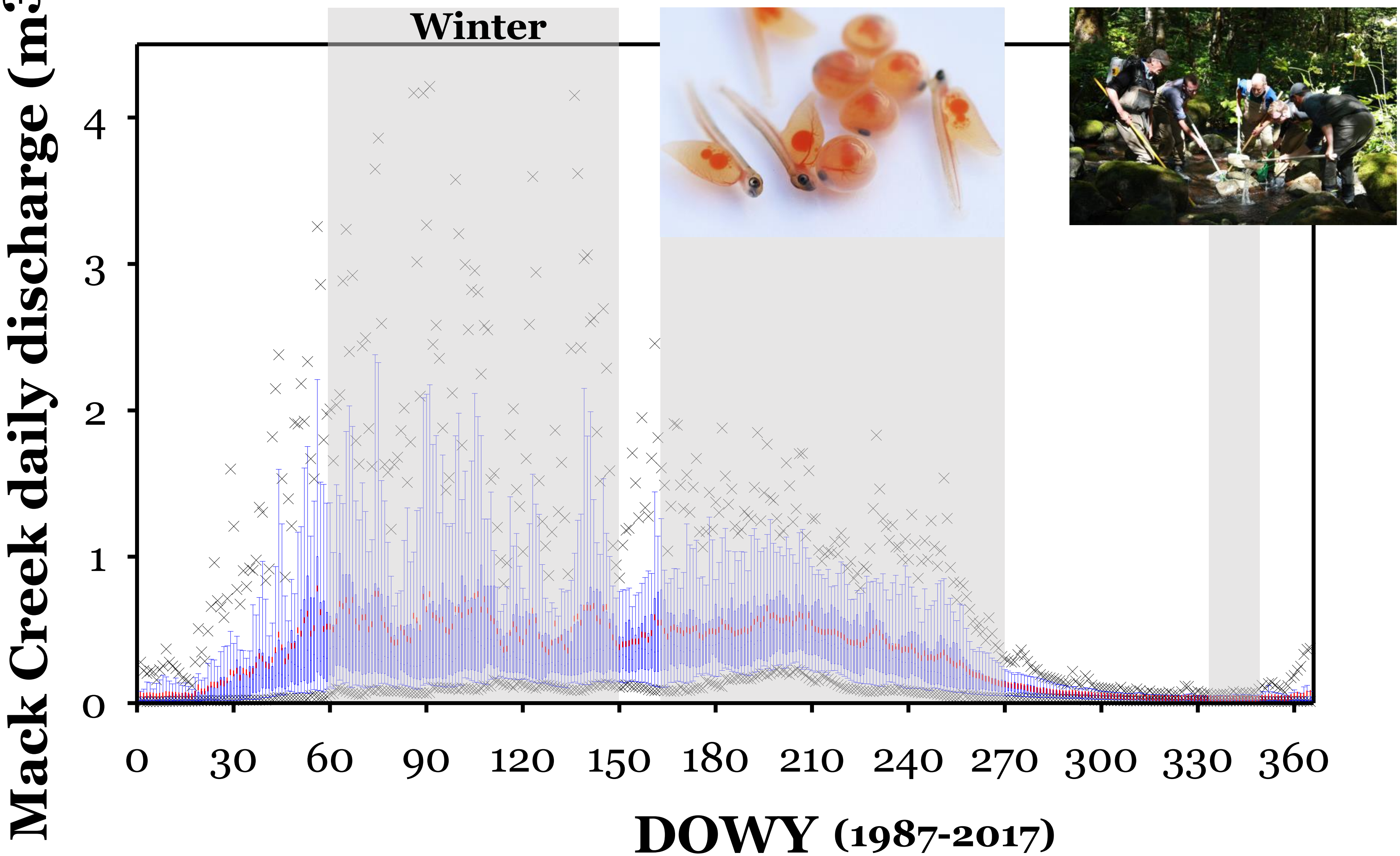
Density dependence

Summer adult trout abundances are positively associated to the YOY abundance from the previous year





Regulation in natural populations
Density-independence



Metrics of flow (density-independence)

Table III. Hydrologic indices with the largest absolute loading for each of the two to four statistical significant principal components for each stream type in each of the nine components of the flow regime

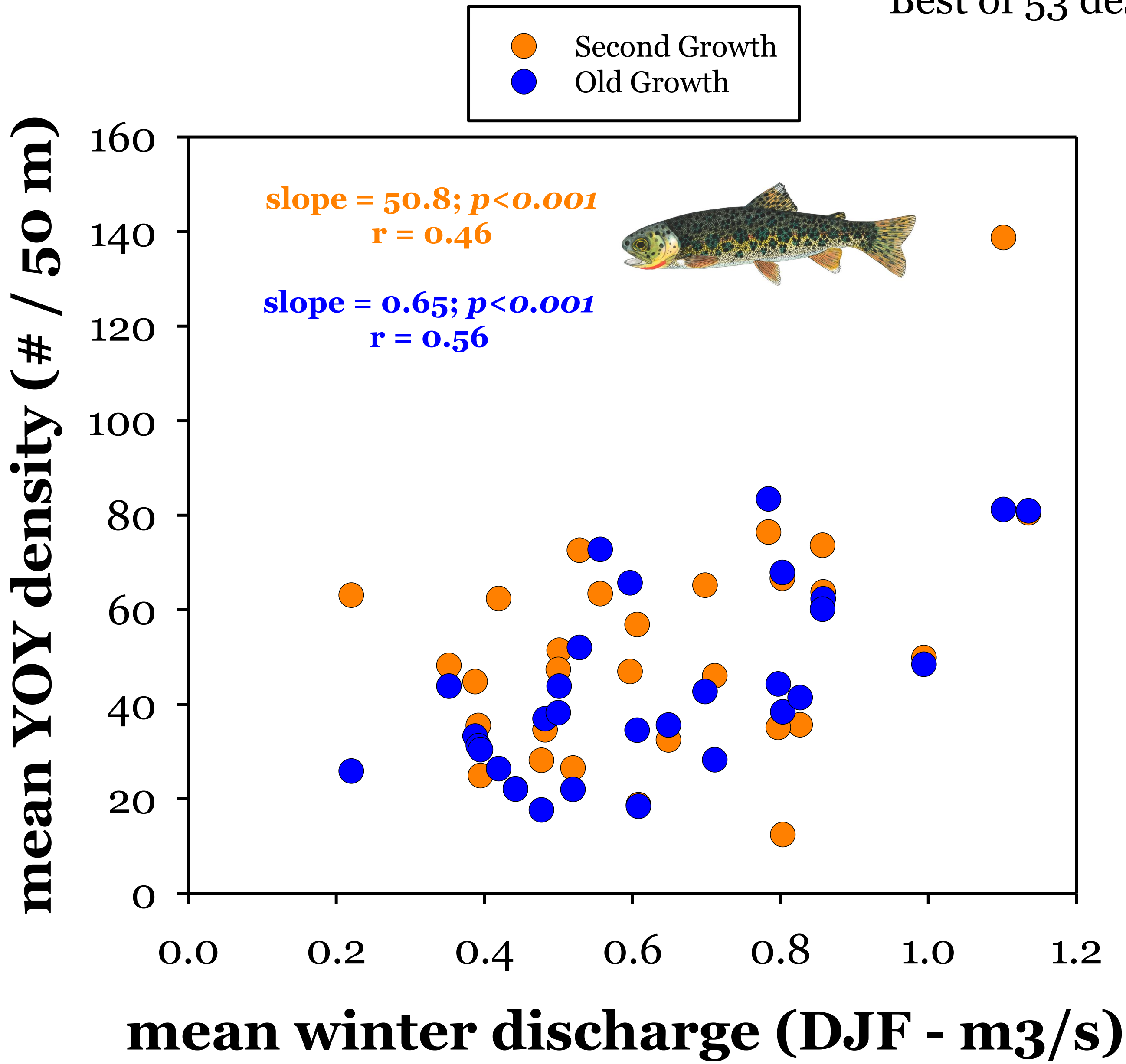
Flow component	Stream classification: Intermittent		Stream classification: Perennial				All streams
	Harsh intermittent	Intermittent flashy or runoff	Snowmelt	Snow and rain	Superstable or stable groundwater	Perennial flashy or runoff	
Magnitude of flow events							
Average flow conditions	**M_A34**, **M_A22**, **M_A16**	M_A37, **M_A18**, **M_A21**, M_A9	**M_A29**, M_A40	M_A3, M_A44	M_A3, M_A41, M_A8	**M_A26**, M_A41, M_A10	M_A5, M_A41, M_A3, M_A11
Low flow conditions	M_L13, M_L15, M_L1	M_L16, M_L6, M_L22, M_L15	M_L13, M_L22	M_L13, M_L14	**M_L18**, M_L14, M_L16	**M_L17**, M_L14, M_L16	**M_L17**, M_L4, M_L21, M_L18
High flow conditions	M_H23, M_H14, M_H9	M_H23, M_H4, M_H14, M_H7	M_H1, M_H20	M_H17, M_H20	M_H17, M_H19, M_H10	M_H23, M_H8, M_H14	M_H16, M_H8, M_H10, M_H14
Frequency of flow events							
Low flow conditions	**F_L2**, F_L3, **F_L1**	F_L3, **F_L2**, **F_L1**	F_L3, **F_L2**	F_L3, **F_L2**	F_L3, **F_L1**, **F_L2**	F_L3, **F_L2**, F_L3	F_L3, **F_L2**, F_L3, **F_L1**
High flow conditions	**F_H2**, F_H5, F_H7	F_H3, F_H7, **F_H2**, F_H10	F_H8, F_H11	F_H3, F_H5	F_H3, F_H6, F_H11	F_H4, F_H6, F_H7	F_H3, F_H6, F_H7, **F_H2**
Duration of flow events							
Low flow conditions	D_L13, **D_L1**, **D_L2**	**D_L18**, **D_L16**, D_L13, **D_L1**	**D_L5**, **D_L16**	**D_L6**, D_L13	**D_L9**, D_L11, **D_L16**	**D_L10**, **D_L17**, **D_L6**	**D_L18**, **D_L17**, **D_L16**, D_L13
High flow conditions	**D_H10**, **D_H5**, D_H22	D_H13, **D_H15**, D_H12, D_H23	D_H19, **D_H16**	D_H12, D_H24	D_H11, D_H20, **D_H15**	D_H13, **D_H16**, D_H24	D_H13, **D_H16**, D_H20, **D_H15**
Timing of flow events	**T_H1**, **T_L2**, **T_H2**	T_A1, T_A2, **T_L1**, T_H3	T_A1, T_A3	T_A1, **T_L1**	T_A1, **T_H1**, **T_L2**	T_A1, T_A3, T_H3	T_A1, T_H3, T_A1, **T_L2**
Rate of change in flow events	**R_A4**, **R_A1**, R_A5	**R_A9**, R_A6, R_A5, R_A7	**R_A1**, **R_A8**	**R_A9**, **R_A8**	**R_A9**, **R_A8**, R_A5	**R_A9**, R_A7, R_A6	**R_A9**, **R_A8**, R_A6, R_A5

For example, based on all 420 streams the hydrologic indices M_A5, M_A41, M_A3, M_A11 exhibit the largest absolute loadings on first, second, third and fourth principal components, respectively, for the magnitude of average flow conditions. Bold indices represent Indicators of Hydrologic Alteration.

Olden and Poff (2003)

Density-independence

Best of 53 descriptors of flow



Density dependent versus density independent processes (multi-model selection & information-theoretic approach) – *a priori hypotheses*

Variable to include in models	#YOY	#Trout Adults
Qmean_winter	+	+/-
Qmean/Qmedian	+	+/-
#adults (t)	-	na
#adults (t-1)	+	+
#salamanders (t)	-	-
min size YOY (t)	-	na
max size adults (t)	-	-
max size adults (t-1)	+	+
#YOY (t-1)	na	+
min size YOY (t-1)	na	+

Part 1: Summary of findings

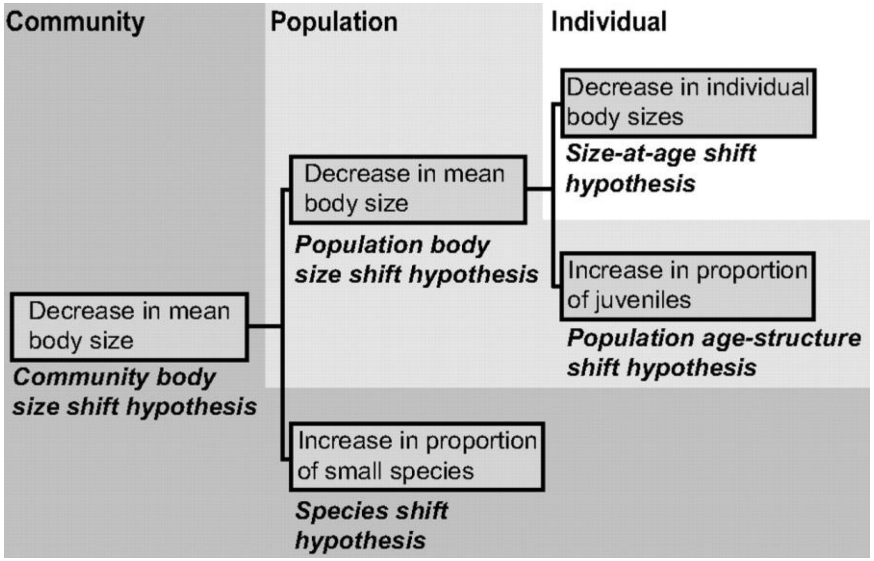
Variable	Old growth #YOY AICC = 201.1 avg. AICC = 209.7	Old growth #Adults AICC= 180.8 avg. AICC = 208.2	Second growth #YOY AICC = 218 avg. AICC = 230	Second growth #Adults AICC= 185.4 avg. AICC = 216.3
DI - Qmean_winter	+ (***)			
DI - Qmean/Qmedian	+	-	+ (***)	-
DD - #salamanders (t)	-	+	-	+
DD - min size YOY (t)			- (***)	
DD - #YOY (t-1)		+ (***)		+ (***)

1. Trout populations are affected by both density independent and density dependence processes

2. Timber harvest appears to facilitate density dependence processes for younger trout

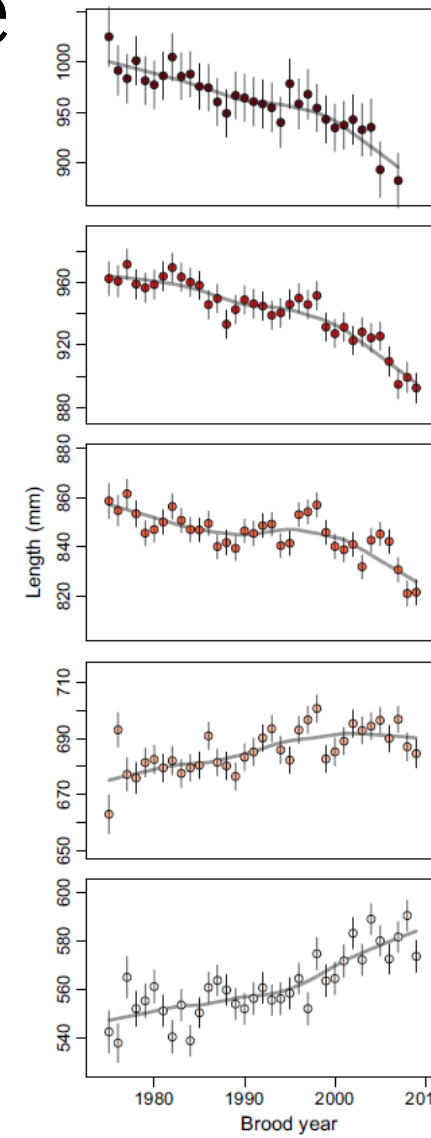
Part 2: Hypotheses related to climate change impacts on species

- Range shifts towards the poles (Parmesan and Yohe 2003)
- Changes in phenology (Walther et al. 2002)
- Shrinking body sizes (Daufresne et al. 2009)



Daufresne et al. (2009)

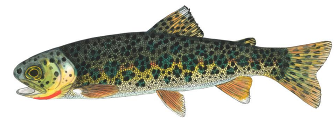
Potential causes of change in salmon age-size structure

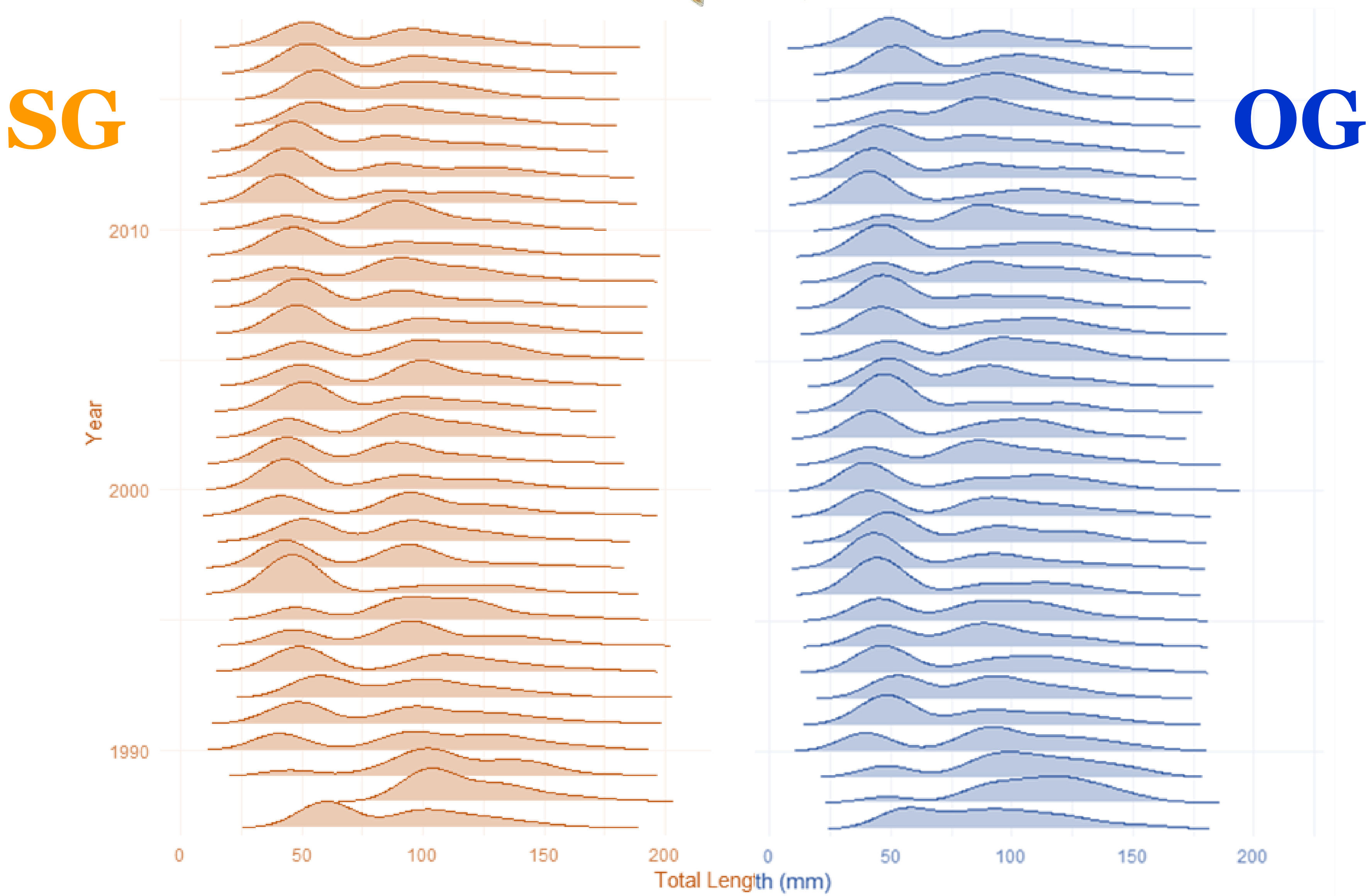


- Size-selective harvest
- Fishes from hatcheries increase competition for food
- Environmental change (e.g., temperature, ocean productivity)

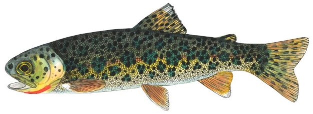
Ohlberger et al. (2017)

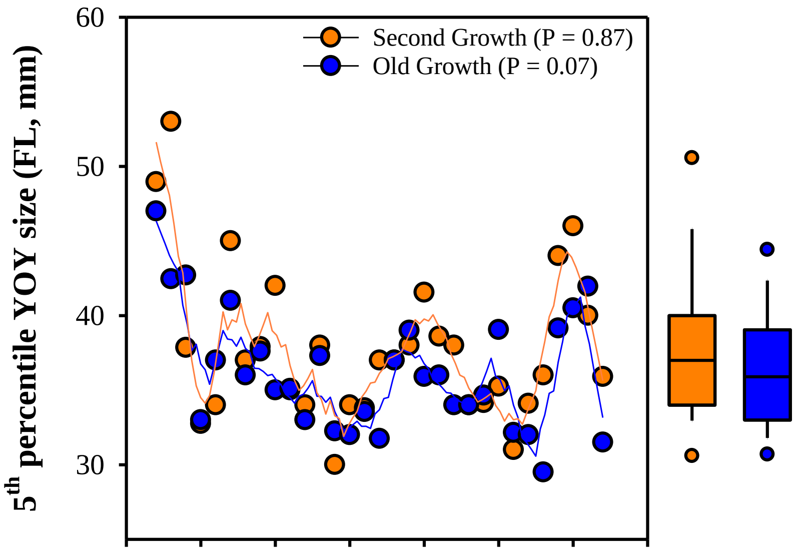
Size distributions at Mack Creek over time

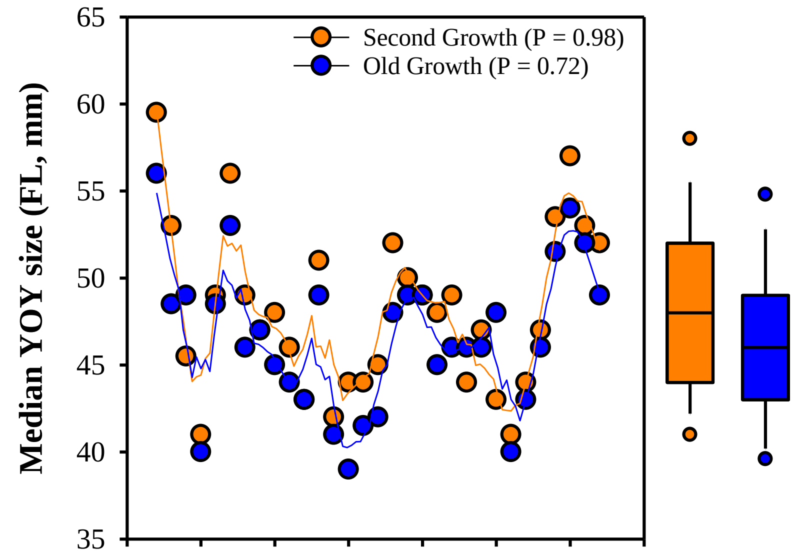




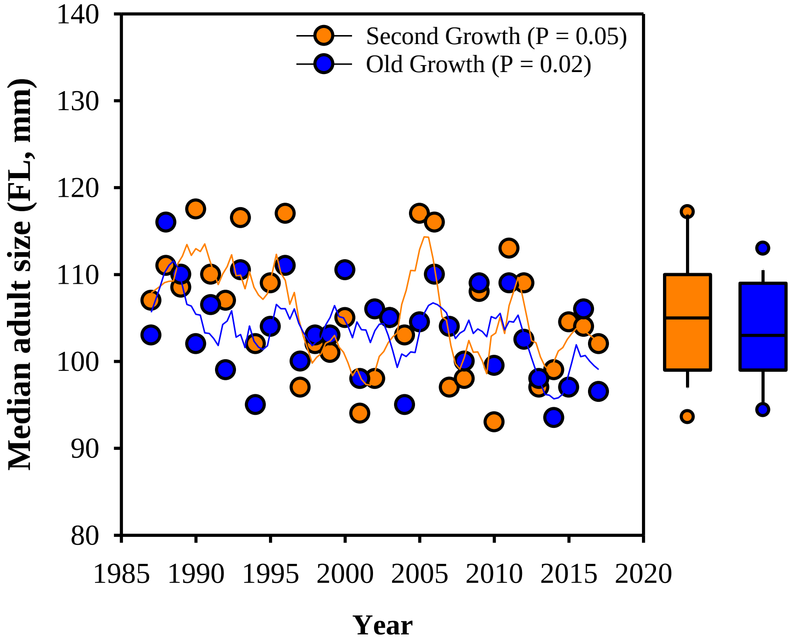
No trends in YOY size

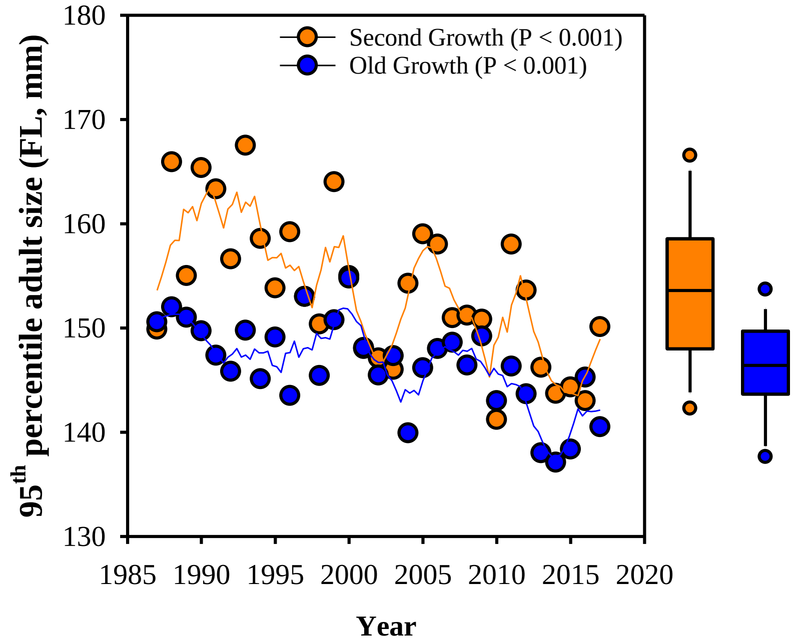




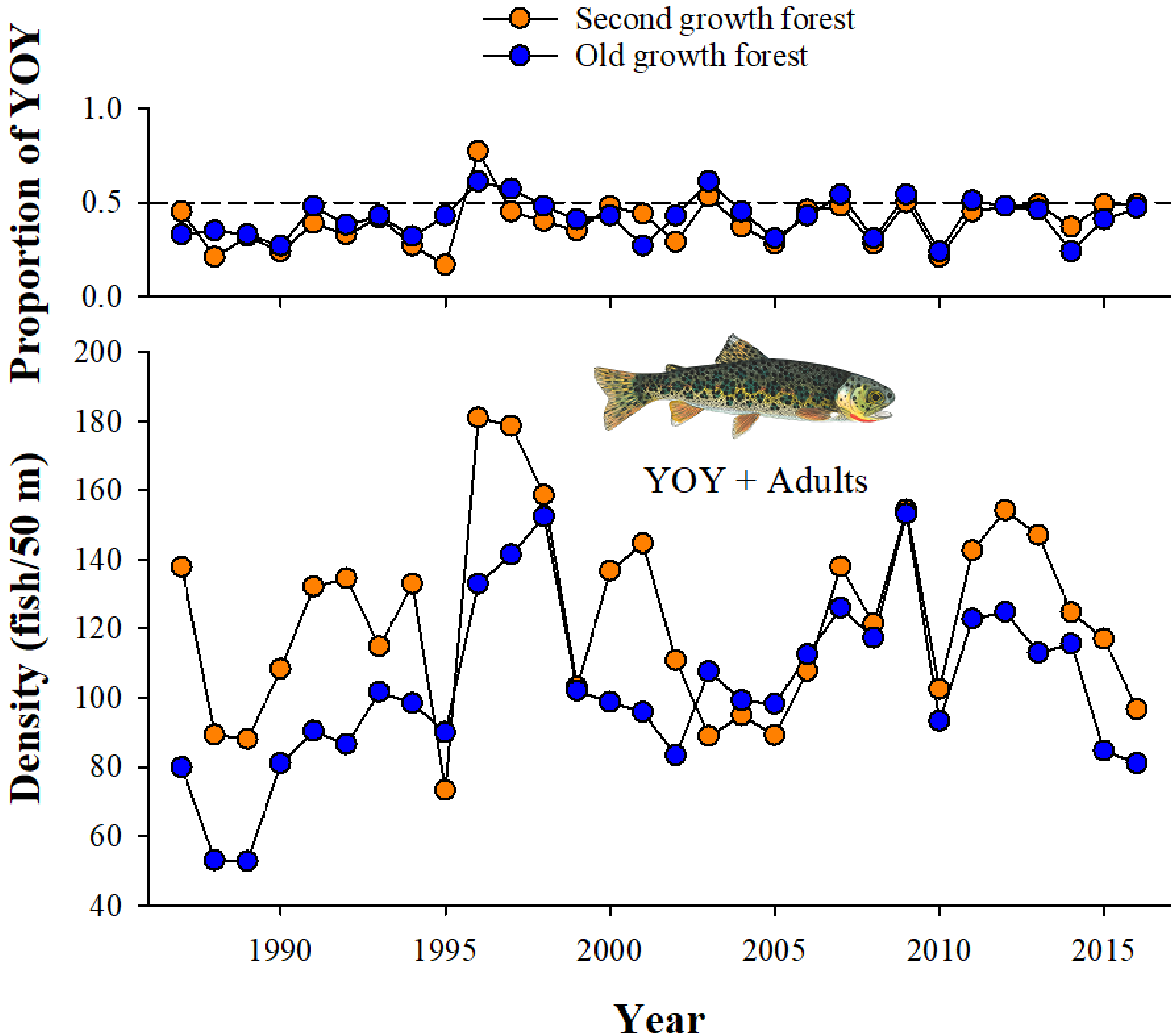


Adult size has decreased

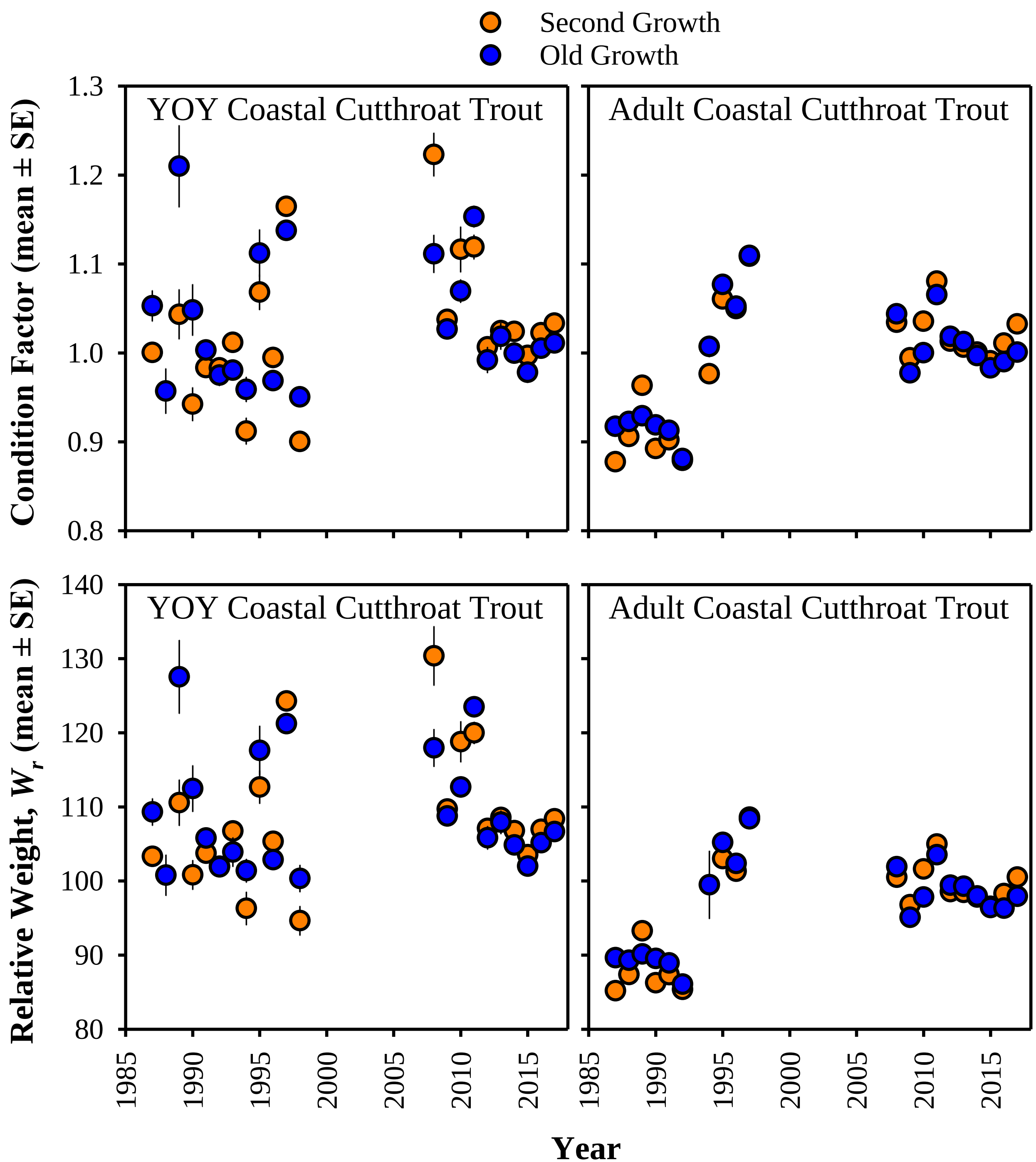




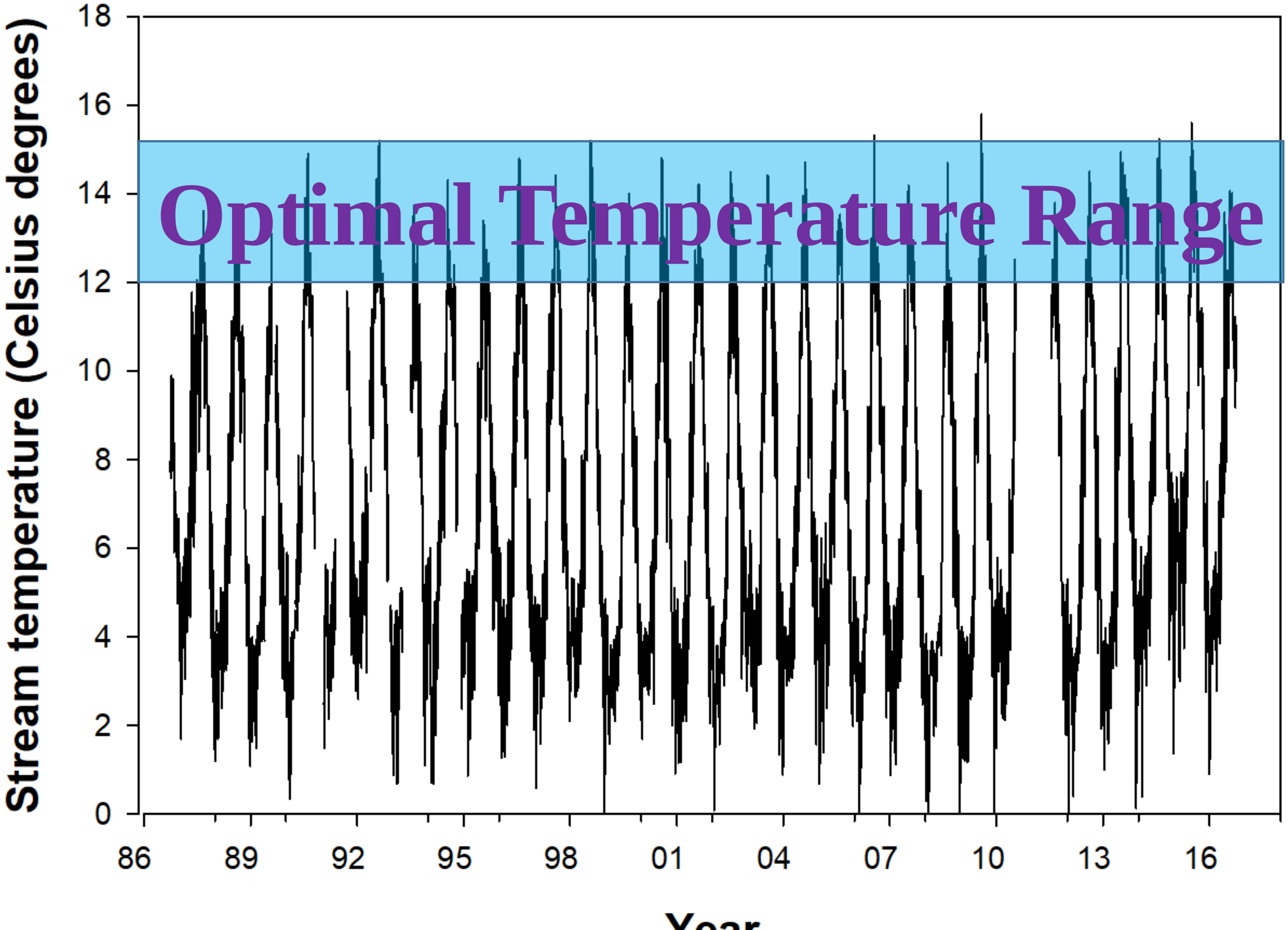
Density dependence?



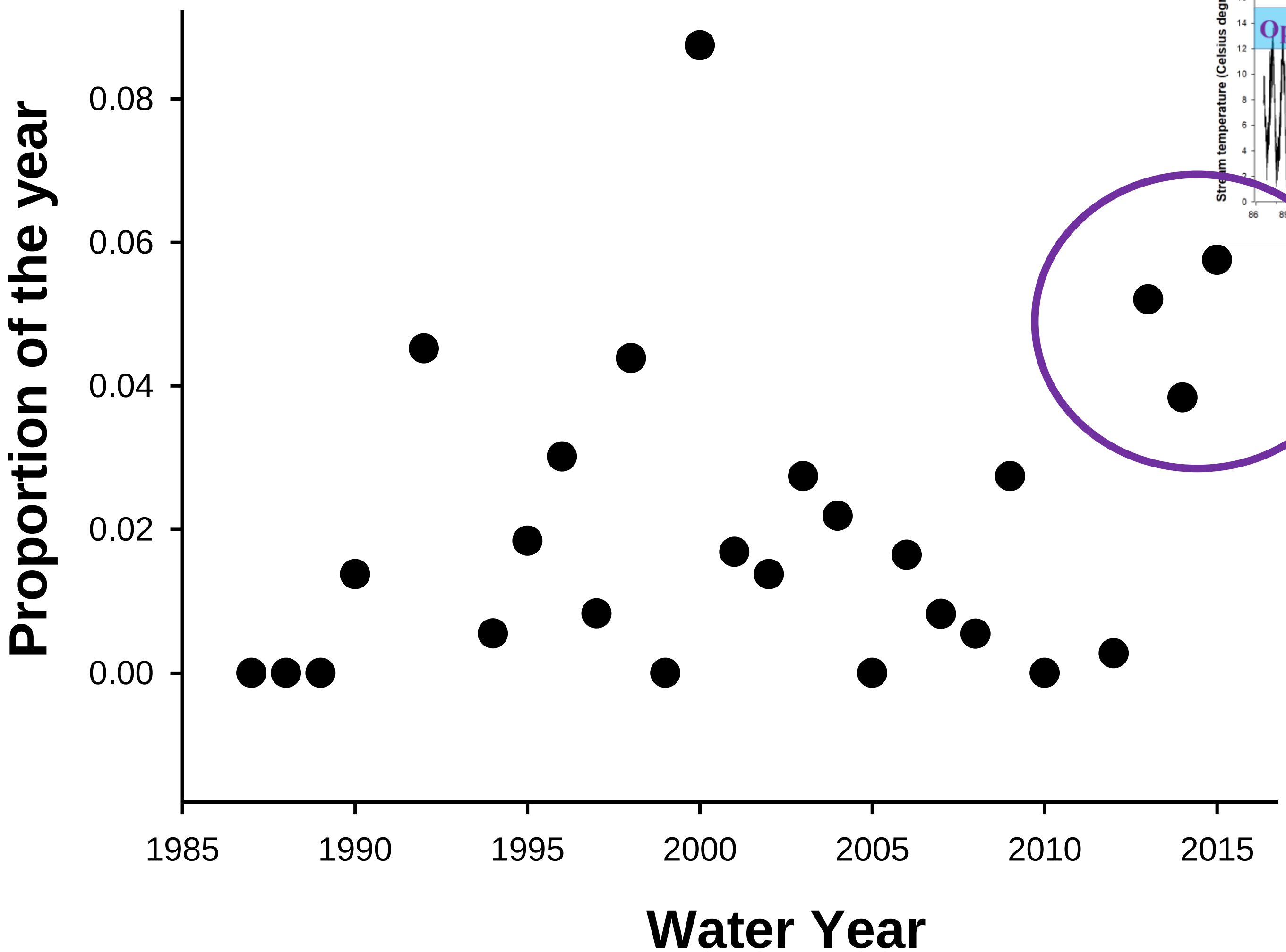
Food availability?

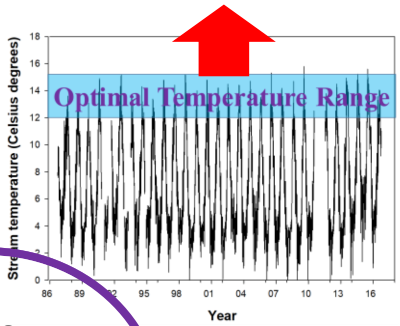


Stream temperature, Mack Creek

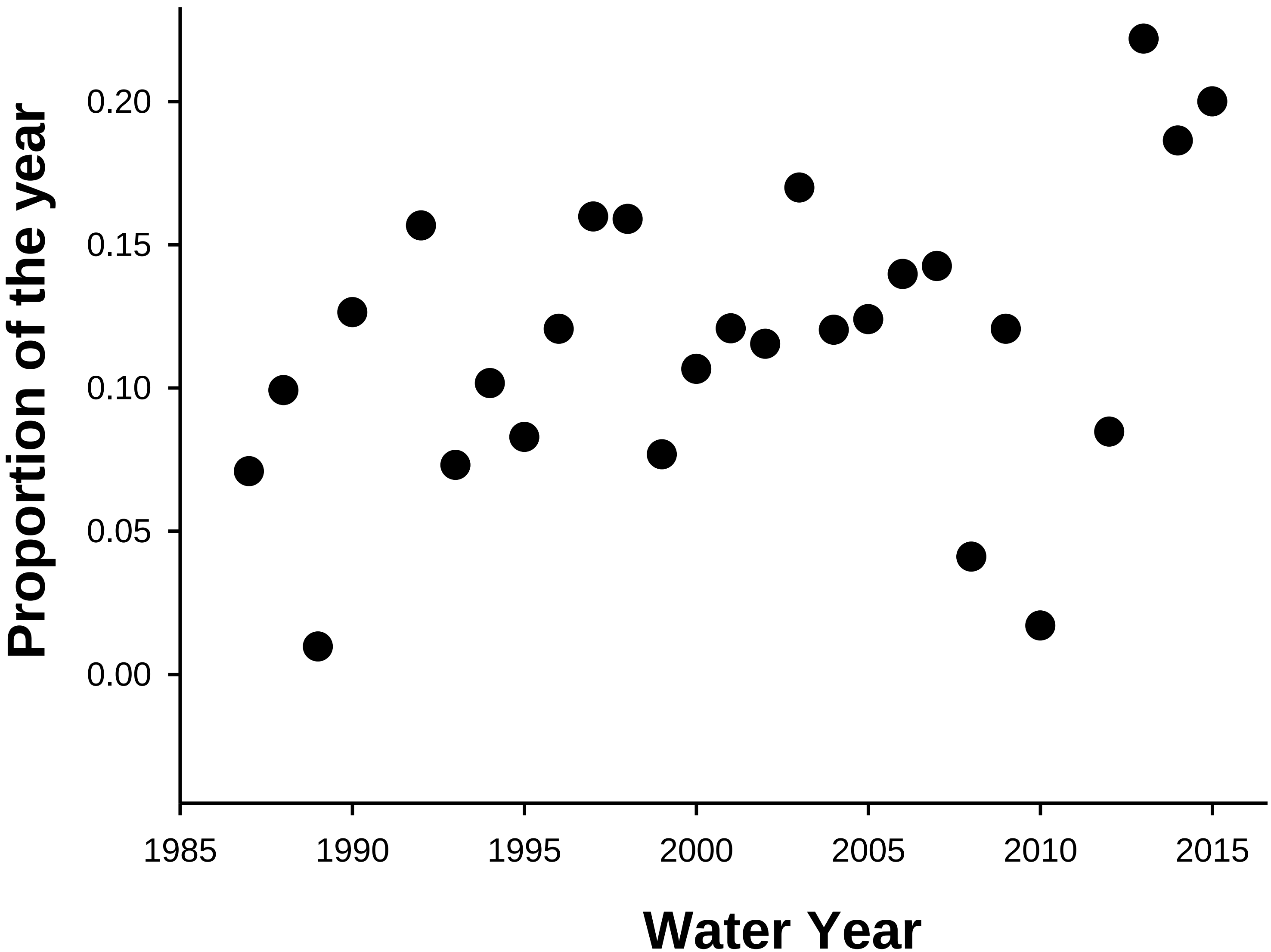


No trend in the # of days warmer than thermal optima (daily max)

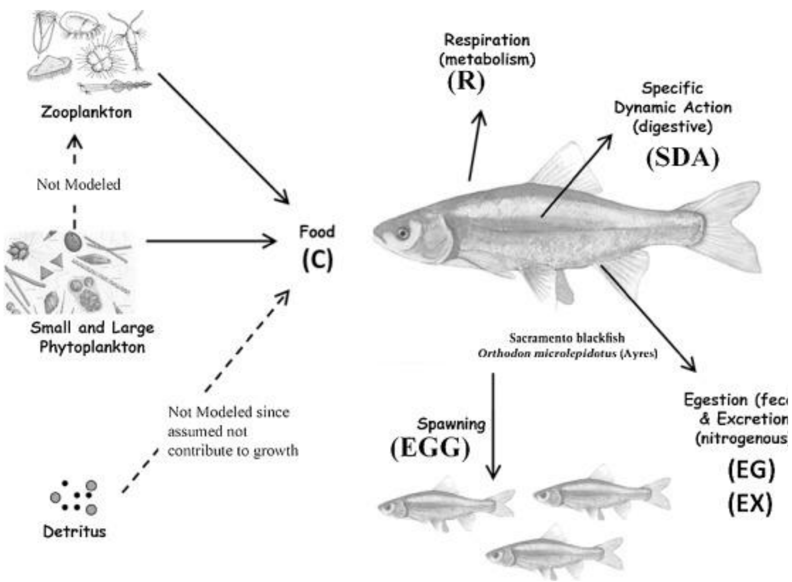




More days within the thermal optima over time (daily mean)



Bioenergetics



https://www.sciencedirect.com/science/article/pii/S03
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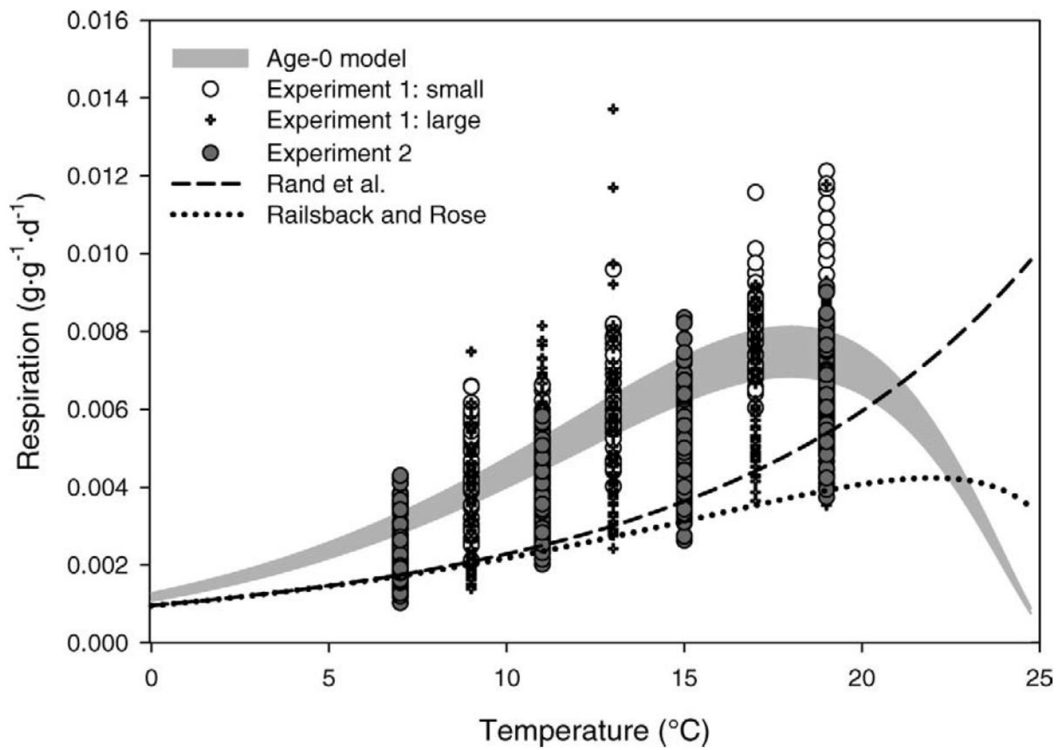
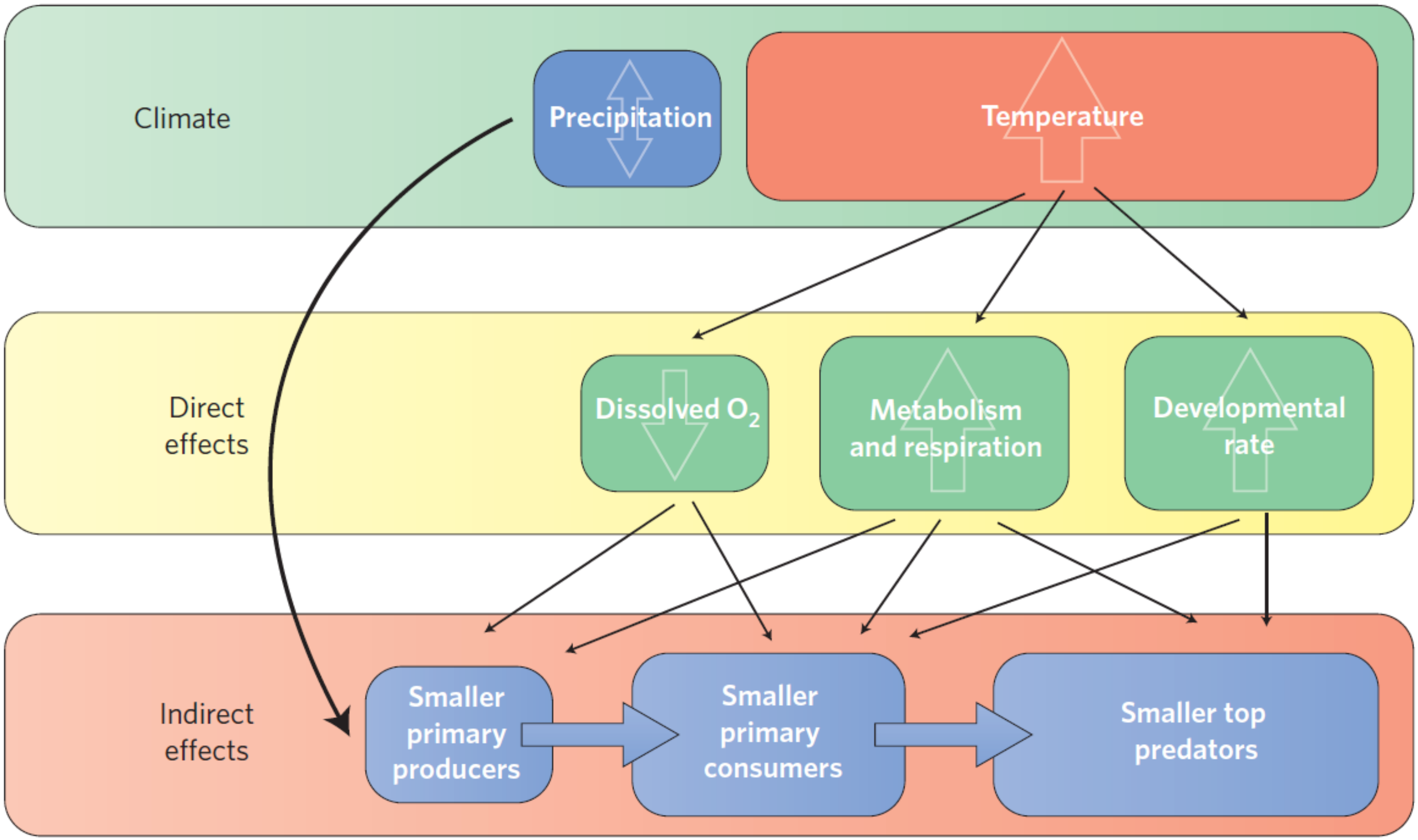


Tyler and Bolduc (2008)

Potential processes affecting size under climate change



Sheridan and Bickford (2011)

Part 2: Summary of findings

- Our results support the hypothesis of shrinking body size due to climate change even in locations with historical land-use modifications
- The effects are more pronounced in larger individuals suggesting cumulative effect may be occurring along lifespan

Bergmann's rule

- Individuals in colder environments grow more slowly, but are larger as adults
- Body mass increases, body surface area gets proportionally smaller, which contributes to reduced rates of heat-loss

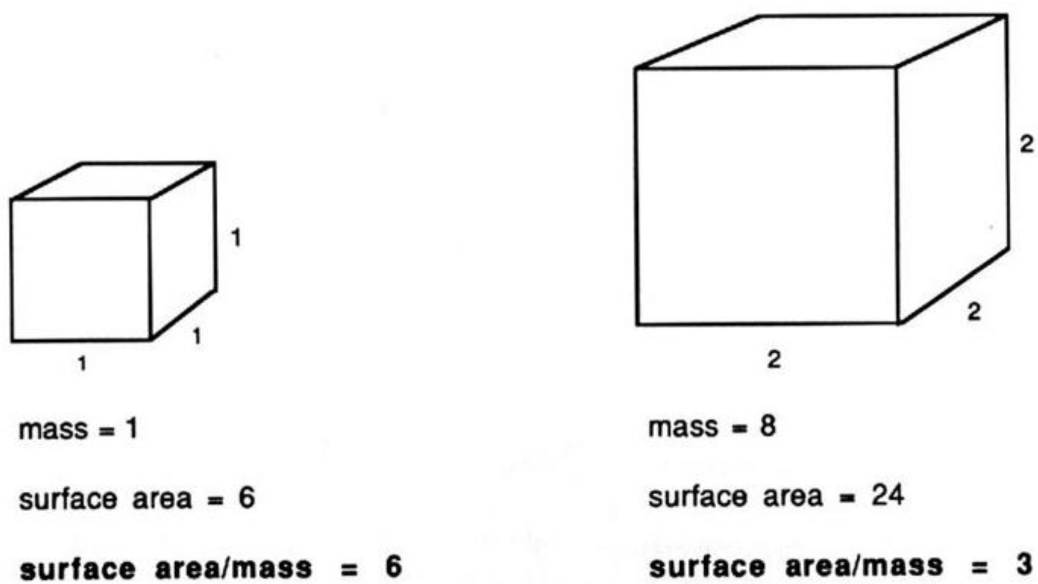
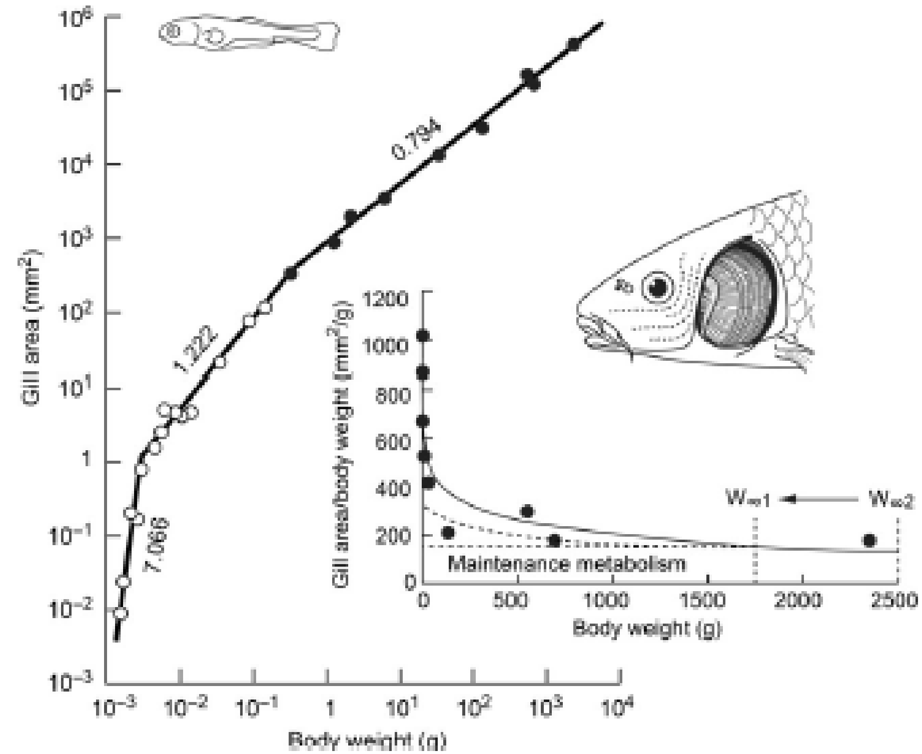


Illustration of Bergmann's Rule from Ruff (1994:71)

Gill-Oxygen Limitation Theory (GOLT)

- Geometric limitation of the growth of gills lead to a decrease in maximum body size under warming
- Gills cannot keep up with the demand of growing three-dimensional bodies



Pauly and Cheung (2017)