Tennessee TECH

Gill length correlates with gill surface area in the Streamside Salamander (*Ambystoma barbouri*)

Logan Gaither, Julia M. Thulander, Joshua M. Hall

Introduction

- Gill branch length is a common and accessible measurement for respiratory potential. However, gill surface area is thought to be a more reliable measurement but is harder to obtain (Klahs, 2025).
- Little studied is how the length of one gill branch (e.g. anterior gill) relates to other gill features, such as the length of other gill branches or gill surface area. Correlations would indicate that simple measures of branch length are useful to understand physiology.

Methods

- We randomly selected n=35 larvae from a previously conducted egg incubation study across 4 temperature treatments: 5, 10, 20, 22ºC (Thulander & Hall, 2025).
- Photos of each larvae were taken at different ages: hatching, 30, and 60 days post hatching.
- We used ImageJ to digitally measure all 3 gill branch lengths for one side, and gill area (branch and fimbriae) of one highly visible gill (Fig. 1).
- We used linear mixed effects models in R (package lme4) to evaluate correlations among gill measures while using individual ID as a random effect to account for repeated measures.
- Example model:

Gill trait1 ~ gill trait2 + age + gill trait2:age + (1|ID) (see Tables 1-3 for example results)

Results

- The anterior gill ("Gill 1") length correlated with the other 2 gill lengths (Fig. 2) as well as the sum of all 3 gill lengths. Gills 2 & 3 correlated with each other, and gill area correlated with gill length (Fig. 3).
- In general, the strength of the correlations increased over time because slopes increased over time (i.e. interaction between age and gill length): the correlations were weaker at hatching and stronger at 60 days (Fig. 2-3)

Figure 1. ImageJ software examples of length and area measurements for a 30-day medial gill salamander photo.

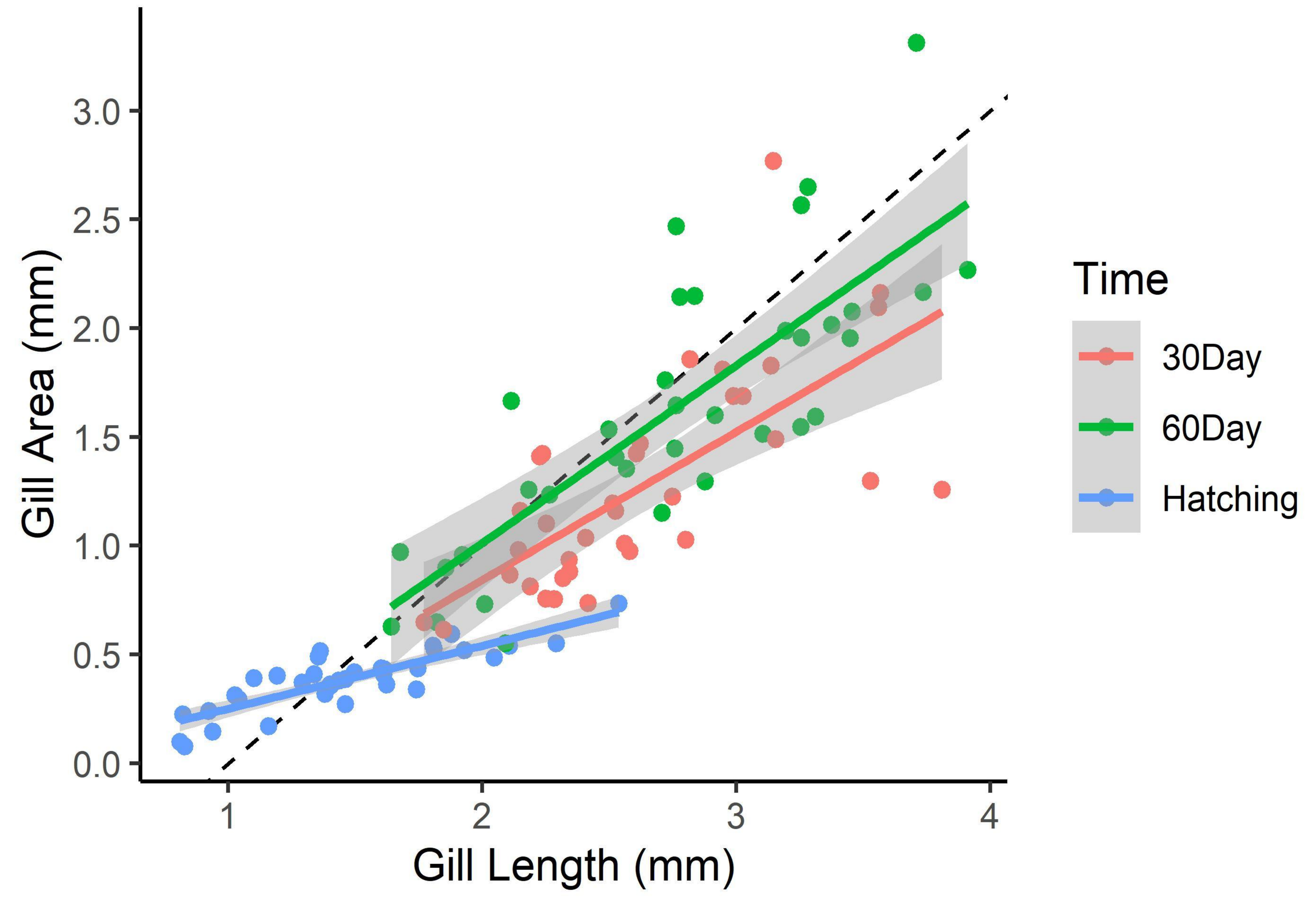

Figure 3. Relation of gill area and gill length. The dashed line is the line of isometry (slope = 1)

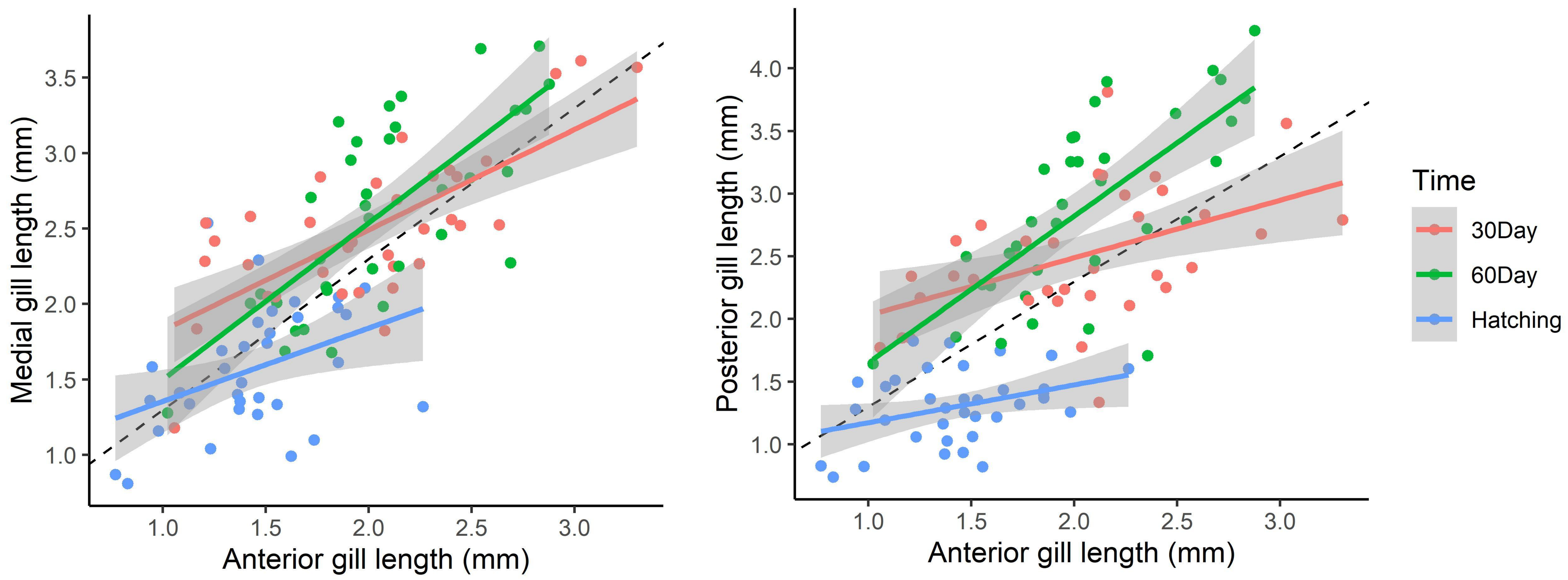

Figure 2. Relation of gill 2 (A) and gill 3 (B) length with gill 1 across ages. The dashed line is the line of isometry (slope=1).

	log(GillArea)		
Predictors	*Estimates*	*CI*	*p*
Intercept	-1.16	-1.63 – -0.69	**<0.001**
Gill Length	0.51	0.33 – 0.68	**<0.001**
Time[60Day]	0.09	-0.50 – 0.68	0.768
Time[Hatching]	-1.22	-1.77 – -0.67	**<0.001**
GillLength × Time[60Day]	0.03	-0.19 – 0.24	0.791
GillLength × Time[Hatching]	0.40	0.14 – 0.67	**0.003**
Random Effects			
σ^2	0.06		
$\tau_{00\ EmbryoID}$	0.02		
ICC	0.24		
$N_{EmbryoID}$	35		
Observations	105		
Marginal R^2 / Conditional R^2	0.874 / 0.904		

Table 1. Results of model regressing gill area on length, log transformed.

	Gill2		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	1.33	0.83 – 1.82	**<0.001**
Gill1 Anterior	0.58	0.34 – 0.82	**<0.001**
Time [60Day]	-0.76	-1.49 – -0.02	**0.044**
Time [Hatching]	-0.37	-1.08 – 0.34	0.303
Gill1 Anterior × Time [60Day]	0.40	0.05 – 0.75	**0.025**
Gill1 Anterior × Time [Hatching]	-0.16	-0.59 – 0.27	0.463
Random Effects			
σ^2	0.12		
$\tau_{00\ EmbryoID}$	0.04		
ICC	0.23		
$N_{EmbryoID}$	35		
Observations	105		
Marginal R^2 / Conditional R^2	0.675 / 0.750		

Table 2. Results of model regressing gill 2 on gill 1.

	log(Gill3.Posterior.)		
Predictors	*Estimates*	*CI*	*p*
(Intercept)	0.54	0.27 – 0.80	**<0.001**
Gill1 Anterior	0.18	0.05 – 0.30	**0.007**
Time [60Day]	-0.35	-0.76 – 0.06	0.090
Time [Hatching]	-0.68	-1.07 – -0.29	**0.001**
Gill1 Anterior × Time [60Day]	0.23	0.04 – 0.43	**0.020**
Gill1 Anterior × Time [Hatching]	0.09	-0.14 – 0.33	0.442
Random Effects			
σ^2	0.04		
$\tau_{00\ EmbryoID}$	0.00		
ICC	0.11		
$N_{EmbryoID}$	35		
Observations	105		
Marginal R^2 / Conditional R^2	0.765 / 0.791		

Table 3. Results of model regressing gill 3 on gill 1, log transformed.

Conclusion

- Strong correlation between gill length and area indicates a strong positive correlation between the length of a gill branch and its respiratory potential.
- In many cases, simple measures of gill branch length will indicate among individual, or among-group differences in gill area and respiratory function.
- These relationships may be more pronounced later rather than early in development, so gill measures are not comparable across age structure.
- Additionally, the first gill's length variation seems to most strongly predict the other two gills' lengths in the latest growth period (60-day), implying that early gill length variation may be more dependent on other factors.

Klahs, A.G. (2025). *Measuring the gill morphology of larval salamanders (*Eurycea cirrigera and Ambystoma mexicanum) *in contrasting water flow* [Master's Thesis, Southeastern Louisiana University]. ProQuest.
Thulander, J.M. & Hall, J.M. (2025). *Embryonic temperature shapes morphology, physiology, and survival across life stages for an ectotherm threatened by global change*. [Master's Thesis, Tennessee Tech University]. Elsevier.