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Allometry of freshwater crab, *Hypolobocera Aequatorialis* (Pseudothelphidae), native to Ecuador.

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RESUMEN

El cangrejo de montaña *Hypolobocera aequatorialis* es una especie nativa de Ecuador, el objetivo de este trabajo fue determinar su alometría. Las muestras fueron recolectadas entre mayo y junio de 2022 en el sitio de Pintohuayco, provincia de Chimborazo, Ecuador. Las variables morfométricas registradas fueron: ancho, largo y alto del carapacho (AnC, LC, AlC, respectivamente) y quelas (AnQ, LQ, AlQ, respectivamente), así como el peso individual. El ancho de abdomen (AW) fue registrado únicamente en hembras. Los modelos: lineal, umbrales y dos segmentos se ajustaron a datos transformados en logaritmo natural. El mejor modelo fue seleccionado utilizando los pesos del Criterio de Información de Akaike en su versión corregida (*Wi AICc*). La relación talla-peso se estimó mediante el modelo potencial. Un total de 201 individuos fueron recolectados. Las hembras presentaron las mayores tallas. Los mejores modelos fueron dos segmentos y umbrales. El nivel de alometría fue principalmente isométrico ($b = 1$) y alométrico negativo ($b < 1$) para el primer y segundo segmento, respectivamente. La relación talla-peso mostró una alometría negativa ($b < 3$). Suponemos que los puntos inflexión de los mejores modelos muestran cambios morfométricos relacionados con el uso del hábitat como alimentación, protección contra depredadores y comportamiento de apareamiento.

Palabras Clave: Akaike, isometría, punto de inflexión, quelas, relación morfométrica.

ABSTRACT

Freshwater crab *Hypolobocera aequatorialis* is native to Ecuador, the objective of this work was determining its allometry. Field samplings were done between May and June 2022, in the Pintohuayco site, Province of Chimborazo, Ecuador. The recorded morphometric variables were width, length, and height of the carapace (CW, CL, CH, respectively), and chelae (ChW, ChL, ChH, respectively), as well as the individual weight. Abdomen width (AW) was registered only in females. The models: linear, thresholds and two segments were fitted to natural logarithm-transformed data. The best model was selected using the bias corrected weights of the Akaike Information Criterion (*Wi AICc*). Size-weight relationship was estimating by a power model. A total of 201 individuals were collected. Females presented larger sizes than males. The best-fit models were two-segment and threshold. The allometry was principally isometric ($b = 1$) and negative allometric ($b < 1$) for the first and second segments, respectively. The size-weight relationship showed a negative allometry ($b < 3$). We assume the inflection points of the best models show morphometric changes related to use of habit as feeding, protection against predators, and mating behavior.

Keywords: Akaike, isometric, inflection point, chelae, morphometric relationship.

INTRODUCTION

Freshwater crabs comprise 1,400 species included in five families: Potamidae (551 spp.), Gecarcinucidae (372 spp.), Pseudothelphusidae (271 spp.), Potamonautidae (152 spp.), Trichodactylidae (48 spp.). Pseudothelphusidae and Trichodactylidae inhabit Neotropical regions (Wehrtmann et al., 2019). Pseudothelphusidae species are distributed from Mexico to tributaries of the Amazon River (Peru), including a large part of the Antilles (Poettinger et al., 2016).

The genus *Hypolobocera* is included in Pseudothelphusidae and presents 39 species with omnivorous habits (especially detritus), used as bioindicators (Campos & Rodríguez, 1995; Mamian & Zamora, 2016; Ramos-Tafur & Ríos, 2007). *Hypolobocera aequatorialis* is a freshwater crab species native to Ecuador, and its distribution includes the western Andes Mountain range, on the eastern and western slopes (Rodríguez & von Sternberg, 1998; Takeda et al., 2014).

Studies on freshwater crabs are limited, being mainly taxonomic and systematic reviews, as well as the record of new congener species (Acevedo & Campos, 2015; Arias et al., 2015; Campos, 1989; Campos & Rodríguez, 1995; Ramos-Tafur, 2006; Rivera-Pérez et al., 2021, 2022; Takeda et al., 2014). In general, crab species show different allometry patterns related to key stages of ontogenetic development such as sexual dimorphism and sexual maturity (Fadlaoui et al., 2019; Hartnoll, 1974, 1978).

Allometry represents variations in the proportion of body structures (i.e., organs or tissues), and their possible changes compared to the body dimensions (Hartnoll, 2012; Zambrano, 2021). The objective of this work is to determine the allometry of *H. aequatorialis* collected in Ecuador, which could be used for further understanding biology aspects such as reproductive traits.

MATERIALS AND METHODS

Field sampling was realized in the Pintohuayco site, located in the Canton of Alausi, Province of Chimborazo, during May and June 2022 (Fig. 1). Individuals were captured manually and their morphometric variables were recorded using a plastic caliper (accuracy = 0.05 mm). The width, length, and height of the carapace (CW, CL, CH, respectively) and chelae (ChW, ChL, ChH, respectively) were measured. The abdomen width (AW) was recorded only in females because this morphometric variable could show evident changes associated with the sexual maturity. Total weight was recorded using a digital scale (0.1 g. accuracy)(Zambrano & Olivares, 2020). The data base was uploaded to Mendeley Data (Yánez & Zambrano, 2022).

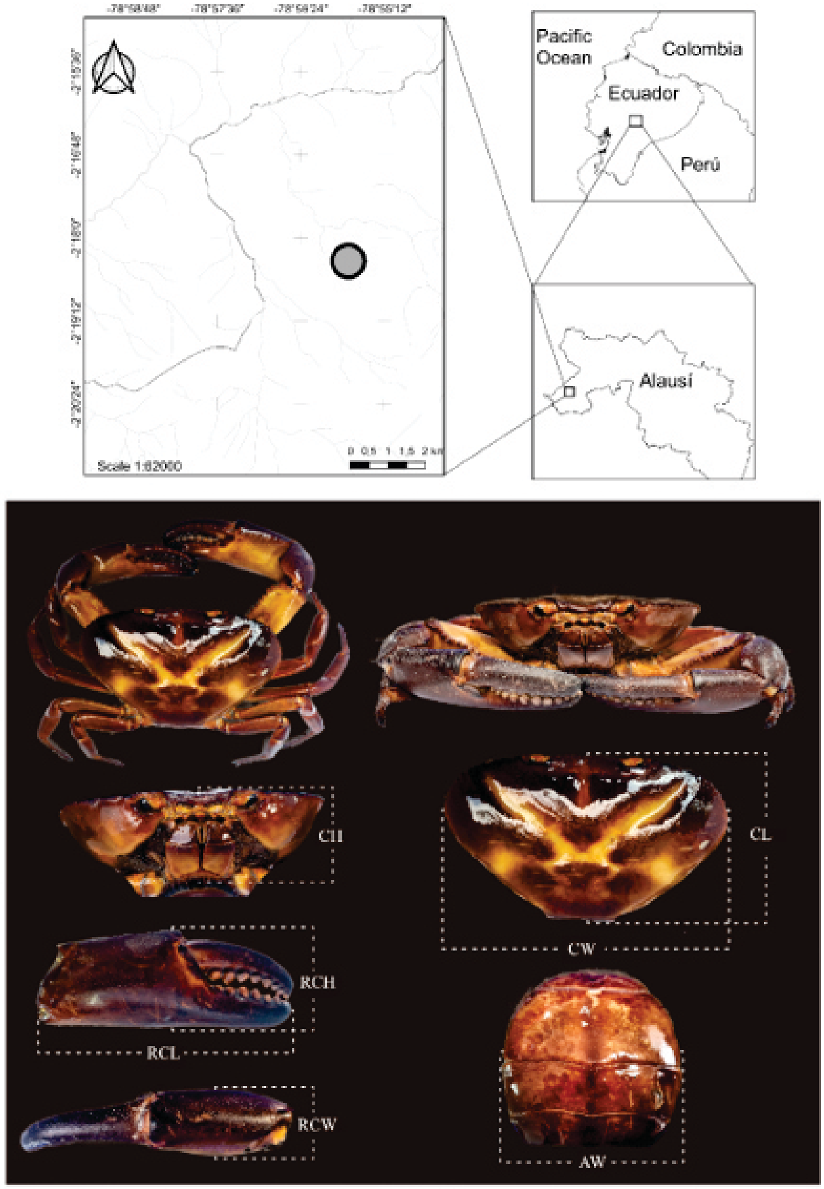

Figure 1. Sampling site and specimen of *Hypolobocera aequatorialis*, collected in the Pintohuayco site, Canton of Alausí, Province of Chimborazo, Ecuador. Morphometric variables recorded: carapace height, length and width (CH, CL, CW, respectively). Right chela length, height, and width (RCL, RCH, RCW, respectively). Abdomen width (AW) in females.

Two random decimals were created from a uniform distribution and added to raw data (Sanvicente-Añorve et al., 2003; Zambrano & Ramos, 2020). That procedure was developed to improve data presentation and the model fit. Mean sizes and the standard deviation were reported by sex. Data were transformed using natural logarithm (ln) for reducing their variability, improve the visualization of possible subsets, and increase the fit of the models. Linear model ($lny=ln\ a+b * lnx$), thresholds ($lny=ln\ a_1+ b * ln(x)\ \ if\ (x)<B$; $lny=ln\ a_2+b * ln(x)\ \ if\ (x)>B$) and two segments ($lny=ln\ a_1+b_1 * ln(x)\ \ if\ (x)<B;\ lny=ln\ a_2+ b_2 * \ln(x)\ \ if\ (x)>B$) were fitted assuming additive error. (Arvizu-Merín et al., 2021; Leyva-Vázquez et al., 2022).

Linear and threshold models were fitted in Stata version 17. Two segments model was fitted in Excel using the algorithm from Neter et al. (1996) and the breakpoint (*B*) used was estimated by the threshold model. Parameters of the models were "*a*" and "*b*" intercept, and slope, respectively. Allometry level corresponded to slope values: when $b > 1$ allometry is positive; if $b < 1$ allometry is negative; and if $b = 1$ means isometry (Hartnoll, 1978, 2012; Mayrat, 2012).

Bias-corrected Akaike Information Criterion (AIC_c) was applied because $n/k < 40$, where n is the data number and k is the number of model parameters (Sugiura, 1978). The best model was selected considering the highest Akaike weight value ($W_i\ AIC_c$). Equations and procedure were described in Burnham and Anderson (2002), among other works.

Size-weight relationship was estimating by the power model ($Y = a\, x^b$) fitted to raw data, assuming additive error. The analysis was run in Stata version 17 using the command *nl pfun2*: *y x* (Salgado-Ugarte et al., 2000; Salgado-Ugarte & Saito-Quezada, 2020). The slope value (*b*) indicated the allometry level: positive $b > 3$, negative $b < 3$, and isometry $b = 3$ (Froese, 2006; Froese et al., 2011).

RESULTS

A total of 201 individuals of *H. aequatorialis* were collected of which 50.1% were females. Mean sizes were 23.63 mm CW (S.D. ± 14.36 mm), 17.08 mm CL (SD ± 9.70), 9.82 mm CH (SD ± 5.88) in females and 21.22 mm CW (SD ± 9.61), 15.51 mm CL (SD ± 6.49), 8.93 mm CH (SD ± 3.90) in males. The best model was two-segments (*Wi AICc* > 70 %).

In males, the relationships CW vs. RCL and CW vs. LCW indicated that the best model is thresholds (*Wi AICc* = 60 to 70%). For CW vs. LCL the *Wi AICc* values were similar between threshold and linear models; in this case, the former was selected as the best due to congruency with the other relationships (Table I).

In females, the threshold was the second-best model (*Wi AICc* = 60 to 70%). For CL vs. RCL the *Wi AICc* values were similar between threshold model and two-segments; in this case, the dormer was selected considering model parsimony. Linear model presented a *Wi AICc* value of 99% only in CH vs RCW (Table I).

Table I. Akaike weights values (*Wi* AIC_c) estimated for models fitted to morphometric variables of *Hypolobocera aequatorialis* collected in Pintohuayco site, Province of Chimborazo, Ecuador. Carapace width, length, and height (CW, CL, and CH, respectively). Right chela length, height, and width (RCL, RCH, RCW, respectively) and left (LCL, LCH, LCW, respectively).

Models			W_i AIC_c females	W_i AIC_c males	Models		*Wi* *AICc* females	*Wi* *AICc* males
CW vs	RCL	Linear	0.07	18.39	LCL	Linear	0	40.33
		Threshold	64.45	65.72		Threshold	0.01	38.54
		Two segments	35.48	15.9		Two segments	99.99	21.13
	RCH	Linear	0	0	LCH	Linear	0	0
		Threshold	1.02	0		Threshold	12.07	8.92
		Two segments	98.98	100		Two segments	87.93	91.08
	RCW	Linear	0.04	0	LCW	Linear	0	0
		Threshold	64.48	6.43		Threshold	0	64.59
		Two segments	35.49	93.57		Two segments	100	35.41
CL vs	RCL	Linear	13.68	7.35	LCL	Linear	0.07	10.43
		Threshold	43.34	17.23		Threshold	0.7	19.9
		Two segments	42.98	75.42		Two segments	99.24	69.67
	RCH	Linear	0	0	LCH	Linear	0	0
		Threshold	2.78	0.98		Threshold	11.46	0.31
		Two segments	97.22	99.02		Two segments	88.54	99.69
	RCW	Linear	0.46	0	LCW	Linear	0	0
		Threshold	33.24	11.87		Threshold	0.67	12.59
		Two segments	66.3	88.13		Two segments	99.34	87.41
CH vs	RCL	Linear	0.03	0	LCL	Linear	1.39	1.7
		Threshold	97.28	32.76		Threshold	11.01	36.85
		Two segments	2.69	67.24		Two segments	88.83	61.45
	RCH	Linear	0	0	LCH	Linear	0.14	0
		Threshold	84.93	0.1		Threshold	0.96	0.71
		Two segments	15.07	99.9		Two segments	98.91	99.29
	RCW	Linear	99.97	0	LCW	Linear	0.83	0
		Threshold	0.03	4.45		Threshold	3.7	44.25
		Two segments	0	95.55		Two segments	95.63	55.75
CW vs	AW	Linear	0.19					
		Threshold	58.97					
		Two segments	40.83					
CH vs	AW	Lineal	2.6					
		Threshold	68					
		Two segments	29.4					
CL vs	AW	Linear	1.01					
		Threshold	53.59					
		Two segments	45.39					

The relationships of carapace vs. chelae size isometric in the first segment ($b = 1$) and negative allometry in the second ($b < 1$). Negative allometry was observed in the first segment for the relationships CW, CL, CH vs. RCW. In females, the allometry of the carapace vs. left chelae was mainly negative while considering the abdomen it was positive (Table II).

Table II. Regression parameters in morphometric relationships of *Hypolobocera aequatorialis* collected in the Pintohuayco site, Province of Chimborazo, Ecuador. Carapace width, length, and height (CW, CL and CH, respectively). Right chela length, height, and width (RCL, RCH RCW, respectively) and left (LCL. LCH. LCW. respectively). Abdomen width (AW)

Models				Regression parameters				
				a_1	b_1	a_2	b_2	B
CW vs.	RCL	F	Threshold	-0.66	1.13	-0.80		2.4
		M	Threshold	-0.69	1.13	-0.75		2.27
	RCH	F	Two segments	-1.49	1.05	1.38	-0.08	2.36
		M	Two segments	-1.99	1.2	0.74	0.20	2.57
	RCW	F	Threshold	0.16	0.53	0.03		2.36
		F	Two segments	1.11	0.57	-0.20	0.90	3.32
	LCH	F	Two segments	-1.03	0.93	1.13	0.11	2.4
		M	Two segments	-1.44	0.96	0.13	0.45	2.5
	LCW	F	Two segments	-0.95	0.84	1.39	-0.01	2.51
		M	Two segments	-0.06	0.49	0.42	0.35	2.3
CL vs.	RCL	F	Threshold	-0.35	1.09	-2.29		2.67
		M	Two segments	-0.71	1.24	0.93	0.44	2.04
	RCH	F	Two segments	-1.18	1.06	1.25	-0.03	2.11
		M	Two segments	-1.29	1.1	1.54	-0.18	2.08
	RCW	F	Two segments	0.13	0.56	0.90	0.23	2.15
		M	Two segments	-0.16	0.6	0.54	0.32	2.89
	LCL	F	Two segments	0.92	0.69	-0.2	1.01	2.99
		M	Threshold	-0.48	1.15	-0.56		2.04
	LCH	F	Two segments	-0.39	0.81	0.98	0.2	2.07
		M	Two segments	-1.45	1.06	0.45	0.35	2.25
	LCW	F	Two segments	-0.53	0.79	1.32	0.02	2.17
		M	Two segments	-0.09	0.55	1.35	-0.08	2.08
CH vs.	RCL	F	Threshold	0.32	1.14	0.14		1.7
		M	Two segments	0.05	1.2	0.69	0.85	1.49
	RCH	F	Threshold	-0.04	0.92	-0.26		1.39
		M	Two segments	-0.59	1.06	1.15	0.05	1.5
	RCW	F	Linear	0.69	0.45			
		M	Two segments	0.14	0.61	0.8	0.28	2.38
	LCL	F	Two segments	0.27	1.07	0.74	0.82	2.14
		M	Two segments	0.22	1.08	1.16	0.45	1.35
	LCH	F	Two segments	0.15	0.77	0.39	0.71	1.63
		M	Two segments	-0.28	0.82	0.76	0.32	1.53
	LCW	F	Two segments	0.04	0.97	0.22	0.77	2.06
		M	Two segments	0.29	0.52	0.92	0.22	2.06
CW vs.	AW	F	Threshold	-1.24	1.15	-1.45		2.3
CL vs.	AW	F	Threshold	-0.81	1.02	-0.64		2.67
CH vs.	AW	F	Threshold	-0.18	1.11	-0.34		1.39

In males, two different data subsets were observed in most relationships. The breakpoint (*B*) corresponded to 11.22 mm CW (9.68-13.07 mm CW), 9.30 mm CL (7.69-17.99 mm CL), 5.58 mm CH (3.86-10.80 mm CH). The subsets are hardly noticeable in the length relationships of carapace to chelae (Fig. 1S).

In females, data subsets were scarcely different, and the most notorious was in the relationships RCW vs. CW and RCW vs. CL (Fig. 3). The breakpoints were 12.94 mm CW (10.59-27.66 mm CW), 10.59 mm CL (7.92-19.89 mm CL), and 5.95 mm CH (4.01-8.50 mm CH) for chelae (Fig. 2S); 9.97 mm CW, 14.44 mm CL, 4.01 mm CH for abdomen (Fig. 2S).

The size-weight relationships showed a negative allometry ($b < 3$) and a coefficient of determination close to unity (Table III). The power model presented a good fit although female individuals with medium sizes were not recorded in samples (Fig. 2).

Table III. Size-weight relationship of *Hypolobocera aequatorialis* collected in the Pintohuayco site, Province of Chimborazo, Ecuador. Carapace width, length, and height (CW, CH, and CL, respectively). Abdomen width (AW).

Sex	Relationship	Regression parameters			95% Confidence Intervals			
		a	b	r^2	$a_{(min)}$	$a_{(max)}$	$b_{(min)}$	$b_{(max)}$
Females	CW vs. Weight	0.0013	2.59	0.99	0.0012	0.0015	2.56	2.62
	CL vs. Weight	0.0016	2.80	0.99	0.0012	0.0019	2.75	2.85
	CH vs. Weight	0.013	2.64	0.99	0.01	0.0160	2.58	2.70
Males	CW vs. Weight	0.0008	2.71	0.98	0.0004	0.0012	2.58	2.85
	CL vs. Weight	0.013	2.16	0.97	0.0078	0.019	2.03	2.29
	CH vs. Weight	0.0067	2.83	0.97	0.0031	0.01	2.62	3.03

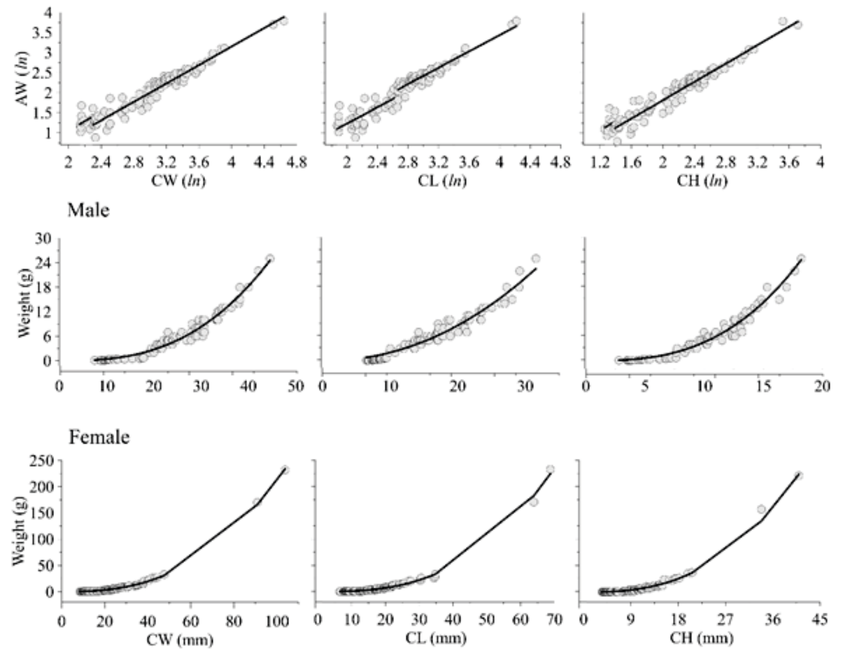

Figure 2. Relathionships between abdomen width, weigth and carapace size of *Hypolobocera aequatorialis* collected in the Pintohuayco site, Canton of Alausí, Province of Chimborazo, Ecuador. Carapace width, length, and height (CW, CL and CH, respectively). Abdomen width (AW) in females.

DISCUSSION

Mean sizes were similar between sexes, but females presented the highest values. Similar sizes are common between sexes for *Hypolobocera* e.g., *H. alata*: males = 20.4 mm CW, females = 21 mm CW; *H. buenaventurensis*: males = 32.6 mm CW and females 39.42 mm CW (Acevedo & Campos, 2015; Ramos-Tafur, 2006).

Other crab species show similar mean sizes between sexes. *Neostrengeria charalensis*: males = 43.5 mm CW, females = 48 mm CW(Campos et al., 2018); *Ucides occidentalis*: males = 68.83 mm CW, females = 77.83 mm CW; *Calappa convexa*: males = 72.8 mm CW, females = 75.7 mm CW; *Menippe frontalis*: males = 92.84 mm CW, females = 93.41 mm CW; *Cardisoma guanhumi*: males = 57 mm CW, females = 5.6 mm CW (Ayón-Parente & Hendrickx, 2001; Campos et al., 2018; Lima et al., 2021; Zambrano & Meiners, 2018; Zambrano & Ramos, 2020). That could indicated that there is not a sexual dimorphism related to the mean size of *H. aequatorialis*, but females would be larger in size.

Morphometric relationships showed two data subsets which were represented principally by the two-segment model. That indicates a morphological change in the body proportions of *H. aequatorialis* during the development, which is more evident in males. In other crab species, the breakpoint is used as indicator of the size at sexual morphometric maturity, for example: *Cardisoma crassum*, *Callinectes arcuatus*, *M. frontalis, M. mercenaria*, female of *Pinnaxodes gigas* (Aragón-Noriega et al., 2019; Crowley et al., 2018; Ortega-Lizárraga et al., 2016; Zambrano & Olivares, 2020; Zambrano & Ramos, 2020).

We pose that morphometric changes represented by the breakpoint are related to: feeding, protecting against predators, and mating behaviour. Nevertheless, the breakpoint could be associated to sexual maturity; assesment of reproductive studies are needed to suport such assertions.

Allometric growth of *H. aequatorialis* was mainly isometric in the first data subset and negative in the second one. That has been observed in other crab species such as *M. frontalis*, *Mecataleptodius parvulus* and juveniles of *Potamon algeriense* (Chellegatti et al., 2021; Fadlaoui et al., 2019; Zambrano & Ramos, 2020). Mariappan et al. (2000) emphasize that heterochelia could be associated with distintict functions; larger chelae could be associated with courtship and smaller with feeding. On the other hand, Hartnoll (2012) mentions that a higher growth rate in chelae is associated with male crabs for a higher probability of breeding.

In females of *H. aequatorialis*, the allometry level could be related to feeding habits. That is, they develop chelae only to be able to grab and break the organic matter of its environment. In *Hypolobocera* species, no reports were found about the reproductive behavior (e.g., courtship, fights), which requires further development of the chelae in relation to the body, and it is principally associated to males. The males sampled were relatively young therefore we could not observe a positive allometry level as expected.

The positive allometry in females, considering the abdomen width, is related to increasing their capacity to carry the ovigerous mass. Hartnoll (2012) mentions that the positive allometry is produced by the morphometric sexual maturity of females, where priority is given to abdominal growth because it is the structure that carry the eggs after the fertilization.

Size-weight relationship showed a negative allometry in *H. aequatorialis*. This coincides with the reports in females of *Menippe frontalis*, *C. crassum, U. occidentalis*, *C. danae, C. ornatus* and *Achelous gibbesii* (Ariza et al., 2018; Vega et al., 2018; Zambrano & Ramos, 2020). We pose that negative allometry is related to reproductive aspects. In this sense, a large female may have a greater carrying capacity of the ovigerous mass, and having a low individual weight could consume less energy for movement. On the other hand, the additional burden of carrying offspring is offset by negative allometry. In the case of males, the individuals were small, and they allocate energy to grow, rather than to gain weight.

Hypolobocera aequatorialis presents mean sizes similar between sexes, but the females showed the major maximum size. There are changes in the level of allometry in accordance with the size of the individuals, which are more noticeable in males. Those changes are represented with two-segment models. The size-weight relationship shows a negative slope, related to the size of the male individuals and to reproduction in the females.

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SUPPLEMENTARY MATERIAL

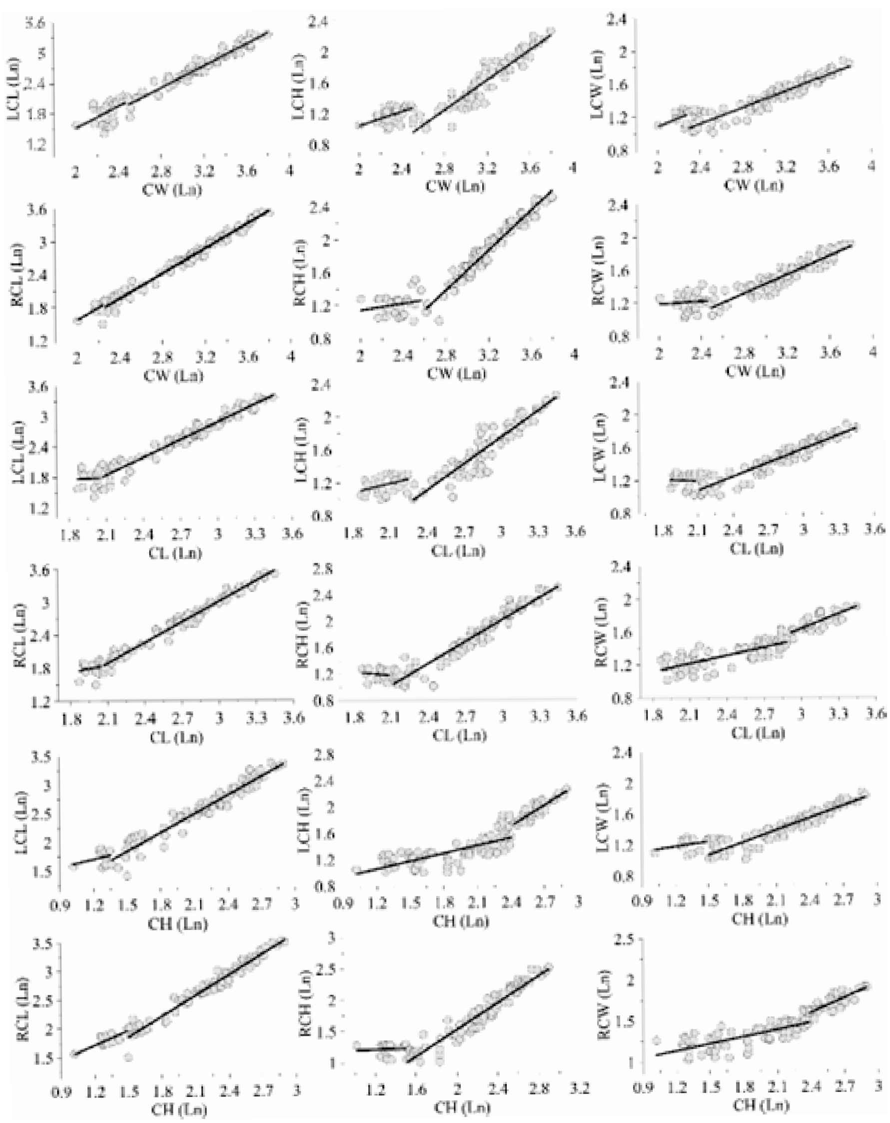

Figure 1S. Morphometric relationships in males of *Hypolobocera aequatorialis* collected in the Pintohuayco site, Canton of Alausí, Province of Chimborazo, Ecuador. Carapace width, length, and height (CW, CL, and CH, respectively). Right chela length, height, and width (RCL, RCH, RCW, respectively) and left (LCL, LCH, LCW, respectively).

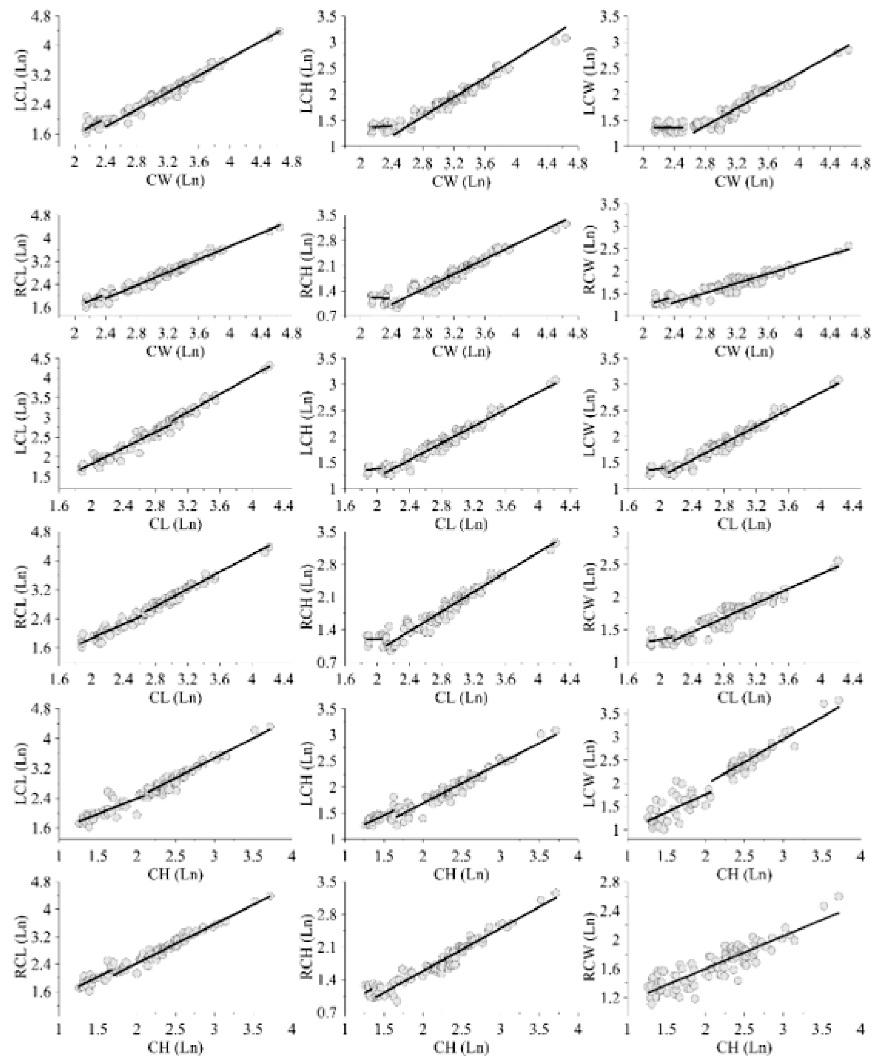

Figure 2S. Morphometric relationships in females *Hypolobocera aequatorialis* collected in the Pintohuayco site, Canton of Alausí, Province of Chimborazo, Ecuador. Carapace width, length, and height (CW, CL, and CH, respectively). Right chela length, height, and width (RCL, RCH, RCW, respectively) and left (LCL, LCH, LCW, respectively).