Supporting Information

A. EXPERIMENTS

In the Appendix A, methodological information to obtain the data, data supporting some hypothesis and data used for the Bayesian calibration and to evaluate the predictive capacity of the DEB model were presented.

A.1. Experimental feeding level

Section "A.1." presents allometric relationship used to compute the fish mass from the length measurement. This fish mass was used to calculate the food quantity given for each fish.

In the experiments, feeding level was adjusted as a given ratio of the mass of the fish at the time of measurement. The fish weight was deduced from the measured standard length using allometric relationship calibrated on data obtained during previous experiments (2013).

$$W = (0.249 \times L)^{3.0} \quad (1)$$

A different equation, calibrated only on juvenile data (data acquired in our laboratory), was used to determine the weight of the small juveniles with a greater accuracy:

$$W = 0.0057 \times L^{3.235} \quad (2)$$

For both equations, the weight (W) was expressed in mg and the standard length (L) in mm. Adult food was composed of frozen chironomid larvae and provided for five consecutive days per week. Juveniles were fed with *Artemia* newly hatched every day.

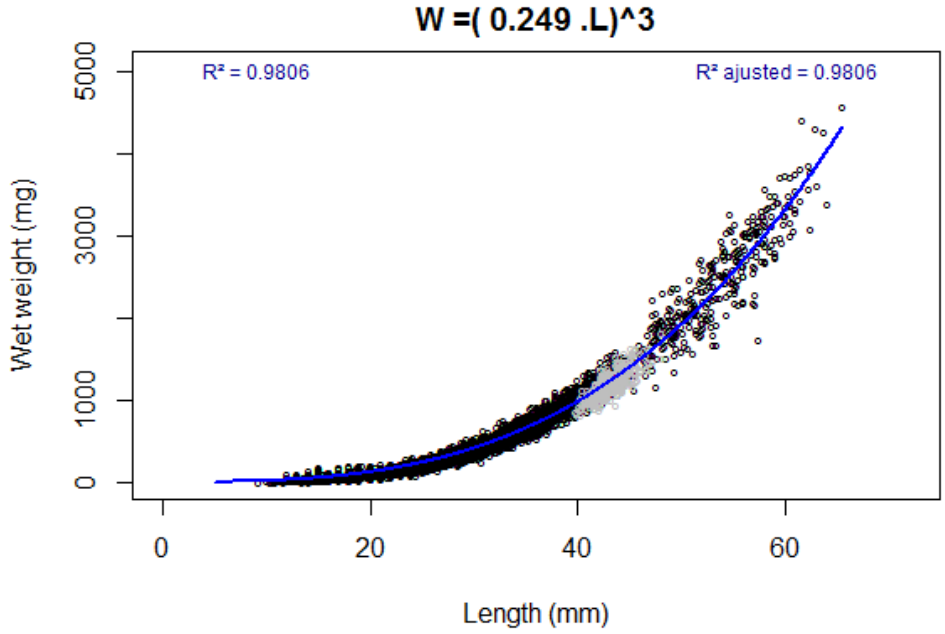


Fig. 1A. Length-Weight relationship in *G. aculeatus* (all stages). Grey points represent fish fed *ad-libitum* and not use for the model fitting.

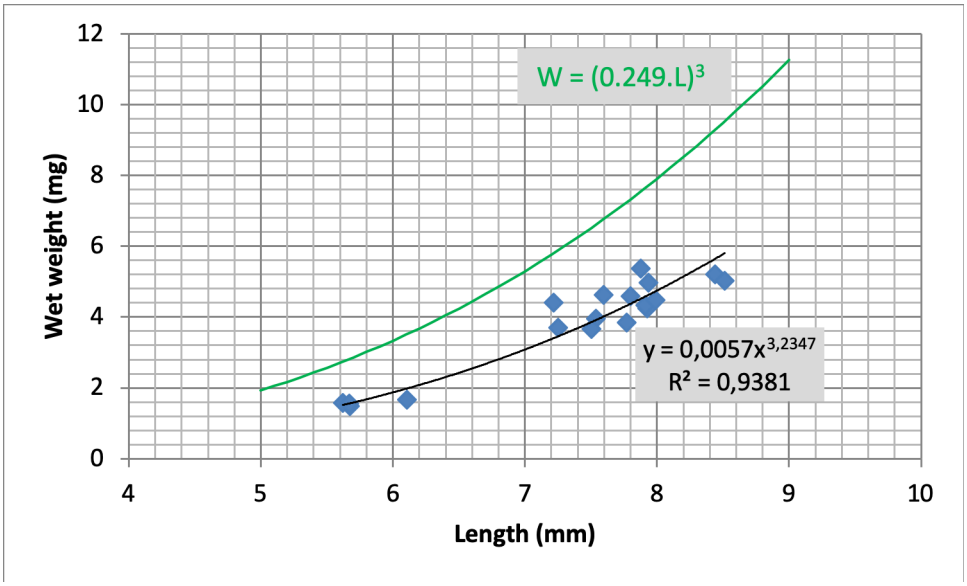


Fig. 2A. Length-Weight relationship for small juveniles of *G. aculeatus*. Green line represents the model fitted on the complete dataset (Fig. 1A).

A.2. Details of the experiments used to calibrate and evaluate the DEB model for the growth.

In this section, dataset of the experiment 2 was summarized in the table 1A. Table 2A provides the experimental conditions of the two experiments used to evaluate the predictive capacity of the DEB model for the growth.

Table 1A. Details of 43 groups of experiment 2 (indoor condition). The nominal and measured (mean ± S.D.) temperature is in °C; the feeding level corresponds of percentage in fish mass per day; the feeding corresponds to amount of *Artemia* given by one juvenile by day; the number of fishes corresponds in the size of groups (at the beginning and the end of the experiments) and, the starting date of the experiment.

Nominal temperature	Measured temperature	Feeding level (% of mass)	Feeding (in mg/juveniles)	Number of fishes (T0)	Number of fishes (end)	Date
7	7.5 ± 0.76	5	0.04 - 0.06	19	19	13/02/2012
7	7.5 ± 0.76	10	0.09 - 0.12	19	19	13/02/2012
7	7.5 ± 0.76	20	0.18 - 0.24	20	20	13/02/2012
7	7.5 ± 0.76	40	0.32 - 0.44	20	19	13/02/2012
7	7.5 ± 0.76	60	0.51 - 0.69	20	19	13/02/2012
7	7.5 ± 0.76	80	0.67 - 0.91	20	18	13/02/2012
15	14.92 ± 0.11	5	0.04 - 0.09	19	19	13/02/2012
15	14.92 ± 0.11	10	0.08 - 0.18	19	16	13/02/2012
15	14.92 ± 0.11	20	0.17 - 0.36	20	20	13/02/2012
15	14.92 ± 0.11	40	0.34 - 0.72	21	19	13/02/2012
15	14.92 ± 0.11	60	0.52 - 1.09	21	19	13/02/2012
10	8.5 ± 0.22	5	0.05 - 0.08	19	17	27/02/2012

10	8.5 ± 0.22	10	0.09 - 0.16	20	20	27/02/2012
10	8.5 ± 0.22	20	0.18 - 0.31	20	20	27/02/2012
10	8.5 ± 0.22	40	0.37 - 0.62	21	18	05/03/2012
10	8.5 ± 0.22	60	0.56 - 0.95	20	18	05/03/2012
13	13.56 ± 0.07	5	0.04 - 0.09	20	20	05/03/2012
13	13.56 ± 0.07	10	0.09 - 0.18	20	20	05/03/2012
13	13.56 ± 0.07	20	0.18 - 0.38	20	20	05/03/2012
13	13.56 ± 0.07	40	0.36 - 0.77	20	17	05/03/2012
13	13.56 ± 0.07	60	0.53 - 1.11	20	20	05/03/2012
13	13.56 ± 0.07	80	0.74 - 1.55	20	20	05/03/2012
19	19.78 ± 0.3	5	0.04 - 0.12	21	16	12/03/2012
19	19.78 ± 0.3	10	0.07 - 0.24	18	18	12/03/2012
19	19.78 ± 0.3	20	0.15 - 0.49	20	18	12/03/2012
19	19.78 ± 0.3	40	0.32 - 1.03	19	18	12/03/2012
19	19.78 ± 0.3	60	0.5 - 1.63	18	15	12/03/2012
19	19.78 ± 0.3	80	0.63 - 2.05	20	18	12/03/2012
22	22.25 ± 0.26	5	0.04 - 0.16	20	19	12/03/2012
22	22.25 ± 0.26	10	0.08 - 0.33	20	18	12/03/2012
22	22.25 ± 0.26	20	0.15 - 0.61	20	19	12/03/2012
22	22.25 ± 0.26	40	0.30 - 1.22	17	16	12/03/2012
22	22.25 ± 0.26	60	0.49 - 2.00	20	20	12/03/2012
22	22.25 ± 0.26	80	0.63 - 2.53	20	17	12/03/2012
10	9.8 ± 0.03	5	0.04 - 0.07	20	13	20/03/2012
10	9.8 ± 0.03	10	0.08 - 0.14	20	16	20/03/2012
10	9.8 ± 0.03	20	0.16 - 0.27	20	18	20/03/2012
10	9.8 ± 0.03	40	0.33 - 0.56	19	16	20/03/2012
10	9.8 ± 0.03	60	0.48 - 0.82	19	19	20/03/2012
14.5	15.7 ± 0.02	10	0.05 - 0.12	16	16	07/05/2011
14.5	15.7 ± 0.02	20	0.11 - 0.34	18	18	07/05/2011
14.5	15.7 ± 0.02	40	0.21 - 1.15	19	18	07/05/2011
14.5	15.7 ± 0.02	80	0.42 - 2.65	17	15	07/05/2011

Table 2A. Details of two experiments used to evaluate the predictive capacity. The temperature is in °C and corresponds to the temperature in °C (mean ± S.D.) during the experiments and the feeding corresponds to amount of *Artemia* in mg given by one juvenile by day with the periods associated.

Experiments	Feeding (in mg) per juveniles per day			Temperature
1 (May)	1 mg	0.8 mg	7 mg	13.3 ± 0.42
(n = 80)	(30 April - 6 May)	(7 - 13 May)	(14 May - end)	
2 (July)	8 mg	28 mg	56 mg	17.8 ± 0.66
(n = 120)	(12 - 17 July)	(18 - 24 July)	(24July - end)	

A.3. Length at maturity in males (Experiment 5)

In this section, Table 3A presents the data of the "Experiment 5: length at maturity of males" and Fig 3A presents the fit of a lognormal distribution on the observed cumulative frequency of mature males.

Table 3A. Number of males with gonads matures according to the total number of males classified by standard length [x ; x+2[in experiment 4.

Length classes [x ; x+2[(mm)	**21**	**23**	**25**	**27**	**29**	**31**	**33**	**35**	**37**	**39**	**41**	**43**	**45**	**47**	**49**
Nb males with mature gonads	0	0	0	0	0	4	7	12	11	9	7	3	5	2	0
Nb males	0	2	4	8	6	12	17	22	15	11	7	3	6	2	0

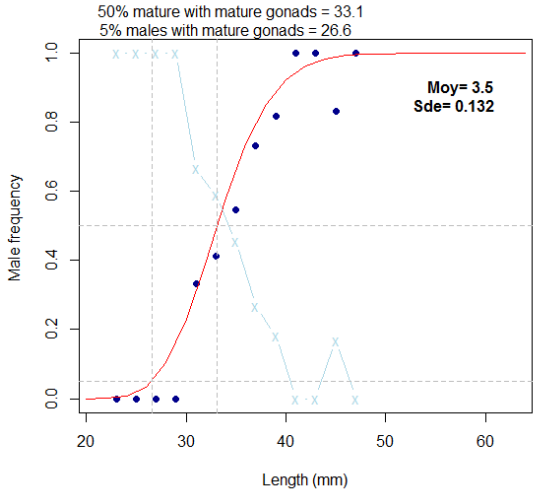


Fig. 3A. Frequency of male with mature gonads according to the length classes [x ; x+2[(mm). Red line represents the lognormal model fitted.

A.4. Sub-models for non-measured data

Figure 4A presents the von Bertalanffy growth model fitted to growth data measured on female adult of *G. aculeatus* (Data from the Experiment 3: growth of adults).

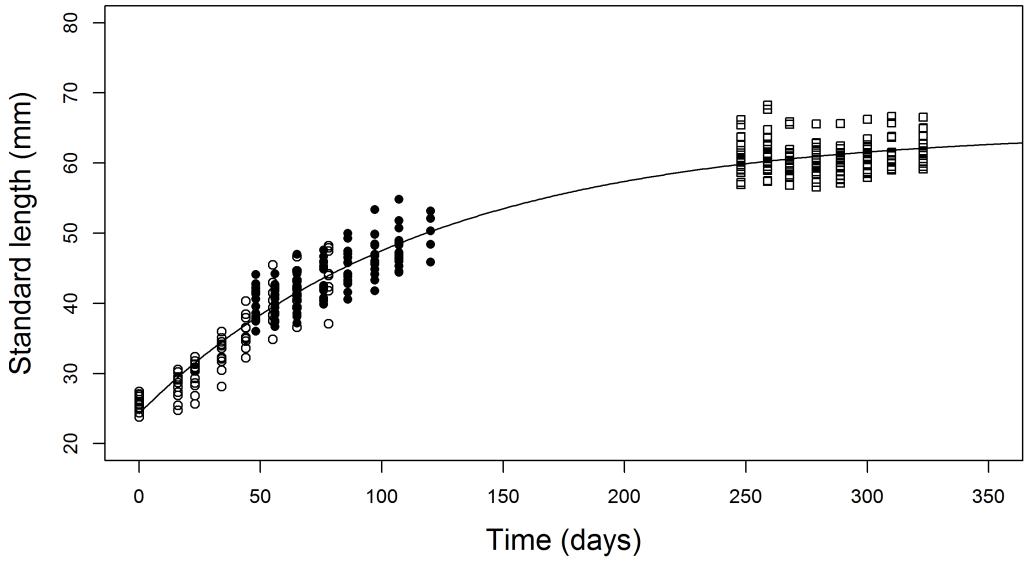


Fig. 4A. The von Bertalanffy growth model which predicts similar growth than the DEB model in *ad-libitum* condition for the experiment on females' fecundity. The fit were performed using data on adults' growth of *G. aculeatus* (only females).

○ represents the standard length (snout till end of caudal fin) of fishes of the small group. ● the medium group and □ the large group.

A.5. Feeding constants

Table 4A presents the energetic density of *Artemia*, *Chironomus* and *Mysis* which were used to convert the food mass (mg) provided to the fish in term of energy (J) and computes the Parameter *f*, the feeding ratio.

Table 4A. Description of the energetic density of *Artemia*, *Chironomus* and *Mysis* for fish.

Species	Energetic density	References
Nauplii artemia	22260 J/g dry weight	(Vanhaecke *et al.* 1983)
	88.2 to 90.9 % moisture (wet weight)-	(Watanabe *et al.* 1983)
	2326 J/g wet weight (2.33 J/mg)	
Chironomus larvae	87.9 ± 0.26 % water	(Bogut *et al.* 2007; Frouz & Matěna 2015)
	3730 J/g wet weight (3.730 J/mg)	(Cummins & Wuychec, 1971; Driver *et al.* 1974; Eggleton & Schramm Jr 2004)
Mysis spp	**3427 (3135 - 3720) J/g wet weight**	(Lasenby 1971)

Fig 5A present the relationship between a volume of a suspension of Nauplii artemia well-drained (ml) and the wet weight of Nauplii artemia (mg). This relationship was used to convert the volume of *Nauplii artemia* suspension provided to the fish at each feeding to a mass of *Nauplii artemia* and then to a quantity of energy (J).

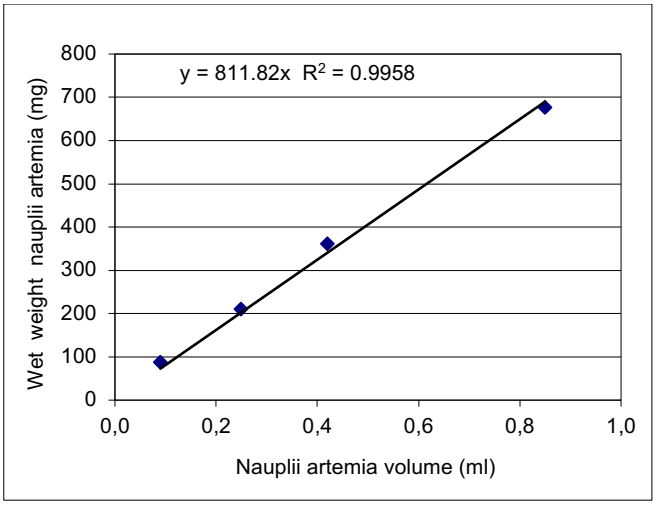


Fig. 5A. Relationship between the volume of a suspension of Nauplii artemia well-drained (ml) and the wet weight (mg)

B. THE DEB MODEL

This section presents all the equations of the DEB model (B1) and the parameter computed from the primary parameter (called "Compound parameters" B.2).

Section B.3 provides a comparison of the different models for temperature correction function to predict the daily consumption rate measured by Hovel *et al.* (2015) at different water temperatures.

Section B.4 provides a comparison of the DEB model and the model proposed by Hovel *et al.* (2015) to predict the maximal daily consumption rate (Cmax, J/g fish/d) according to the fish mass (mg).

Finally, Section B.5 provides the shape and parameters of the distribution assumed to the residual errors (likelihood) in the Bayesian calibration process.

B.1. Dynamic formulation of the model

Reserve density:

$$\frac{d[E]}{dt} = \frac{\{\dot{p}_{Am}\}}{L} \times (f - e) \text{ with } e = \frac{[E]}{[E_m]} \quad \text{(B.1)}$$

Where $\{\dot{p}_{Am}\}$ is the maximum surface-area specific assimilation rate (J mm^{-2} d^{-1}), L the structural length in mm, f the relative density of food, $[E]$ the reserve density and $[E_m]$ the maximal reserve density (J mm^{-3}).

Structural length: (B.2)

$$\frac{dL}{dt} = \frac{\dot{v}}{3*(e+g)} \times \left(e - \frac{L}{L_m}\right)$$

Where $\dot{v}$ is the energy conductance (mm d^{-1}), g the energy investment ratio (-) and L_m the maximum structural length (mm).

Maturity level:

$$\frac{dE_H}{dt} = \frac{(1-\kappa)\times(g\times[E])}{(g+e)} \times \left(\dot{v} \times L^2 + \dot{k}_M \times L^3\right) - \left(\dot{k}_J \times E_H\right)$$

$$\text{if } E_H < E_H^p \text{ else } \frac{dE_H}{dt} = 0 \qquad \text{(B.3)}$$

Where κ is the specific fraction of energy mobilized from reserve allocated to growth and somatic maintenance (-), $\dot{k}_M$ the somatic maintenance rate coefficient (d^{-1}), $\dot{k}_J$ the maturity maintenance rate (d^{-1}) and E_H^p the cumulated energy invested in maturity (J).

Cumulative number of eggs:

$$\frac{dR}{dt} = \frac{k_R}{E_0} \times \left(\frac{(1-\kappa)\times(g*E)}{(g+e)} \times \left(\dot{v} \times L^2 + \dot{k}_M \times L^3\right) - \left(\dot{k}_J \times E_H^p\right)\right) \qquad \text{(B.4)}$$

$$\text{if } E_H = E_H^p \text{ else } \frac{dR}{dt} = 0$$

Where $\frac{k_R}{E0}$ is the cost of an egg production with k_R the reproduction efficiency (-) and E_0 the initial reserve (J).

Parameters L_m, $[E_m]$, g and $\dot{k}_M$ are compounds parameters, computed with primary parameters (*see* Table I) and detailed below.

B.2. Compound parameters

Table 1B. Compound parameters (functions of primary energetic parameters)

Symbol	Unit	Formulation	Biological significance
L_m	mm	$L_m = \frac{\dot{v}}{\dot{k}_M \times g}$	Maximum structural length
$[E_m]$	J mm^{-3}	$[E_m] = \frac{\{\dot{p}_{Am}\}}{\dot{v}}$	Maximum reserve density
g	-	$g = \frac{[E_G]}{\kappa \times [E_m]}$	Energy investment ratio
$\dot{k}_M$	d^{-1}	$\dot{k}_M = \frac{[\dot{p}_M]}{[E_G]}$	Somatic maintenance rate coefficient

Where $[\dot{p}_M]$ is the volume somatic maintenance costs (J mm^{-3} d^{-1}) and $[E_G]$the cost of synthesis of a unit of structure (J mm^{-3}).

B.3. Sub-models for temperature correction function

Comparison of the different models for temperature correction function to predict the daily consumption rate (displayed as unitless proportions (range 0.0–1.0) when referenced to the maximum daily consumption rate at 23°C) measured by Hovel *et al.* (2015) at different water temperatures.

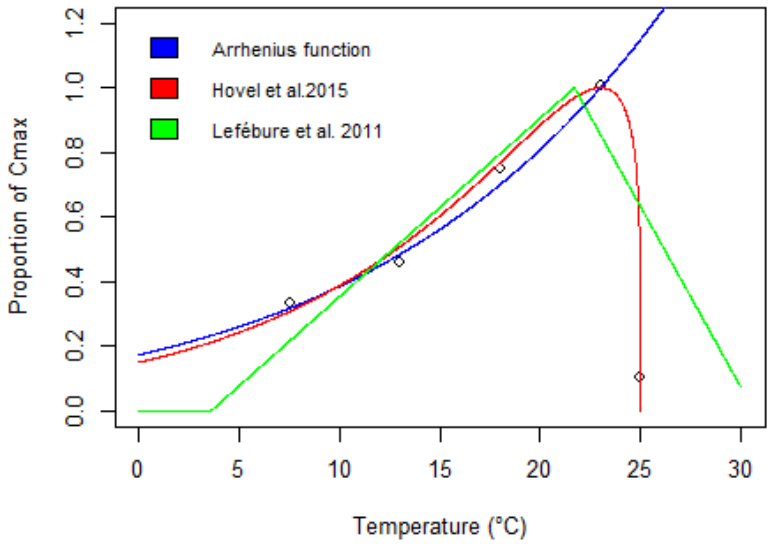


Fig. 1B. Comparison of three temperature correction functions. The points represents the observations done by Hovel *et al.* (2015) and were used to fit their model and the Arrhenius function. Lefébure *et al.* (2011) fitted their model on their own data.

B.4. feeding ratio

Maximal daily consumption rate: Cmax (J/g fish/d) according to the fish mass (mg)

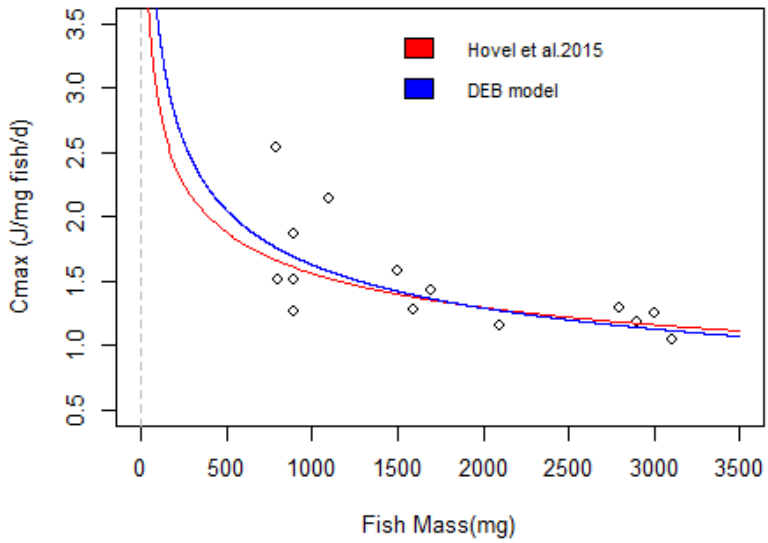


Fig. 2B. Comparison of the function relating Cmax (J/g fish/d) and the fish mass (g) in the DEB model and the model proposed by Hovel *et al.* (2015). The points represent the observations done by Hovel *et al.* (2015).

B.5. Distribution of the residual errors for the different data used

Table 2B. The observations (growth, reproduction, age at first feeding and length at maturity) assumed that the likelihood were associated with normally distributed residual errors. The standard deviation of the residual errors of the growth and reproduction was adjusted with a half normal distribution.

Likelihood	Distribution	S.D.
Growth	Normal	Sigma C
Reproduction	Poisson	-
Age at first feeding	Normal	1.5
Length at maturity	Normal	2.5

C. RESULTS

Section C presents: (i) the detailed results of the global sensitivity analysis using Sobol' methods, (ii) the posterior distributions of the parameters of the DEB model after the Bayesian calibration, (iii) Joint posterior distributions of the parameters of the DEB model, (iv) an analyses of the residual error of the calibrated DEB model for the egg production and (v) a comparison of the standard length predicted by the van Bertalanffy growth model and the DEB model for the initial length of the females used in the "Experiment 4: fecundity of females".

C.1. Sensitivity analysis of the DEB model

Sobol' sensitivity indices were estimated for the DEB model for **males** (Fig 1C) and for **females** (Fig 2C):

- the growth at 20, 100 and 650 days post fecundation (dpf): L20, L100 and L650, respectively
- the energy invested in maturity at 20, 50 and 150 dpf: M20, M50 and M150, respectively
- the energy invested in reproduction at 150, 400 and 650 dpf: R150, R400 and R650, respectively

The first order index is called FOI: variance contribution of one parameter

The total order index is called TI: main effect of one parameter and all its interactions with the other parameters

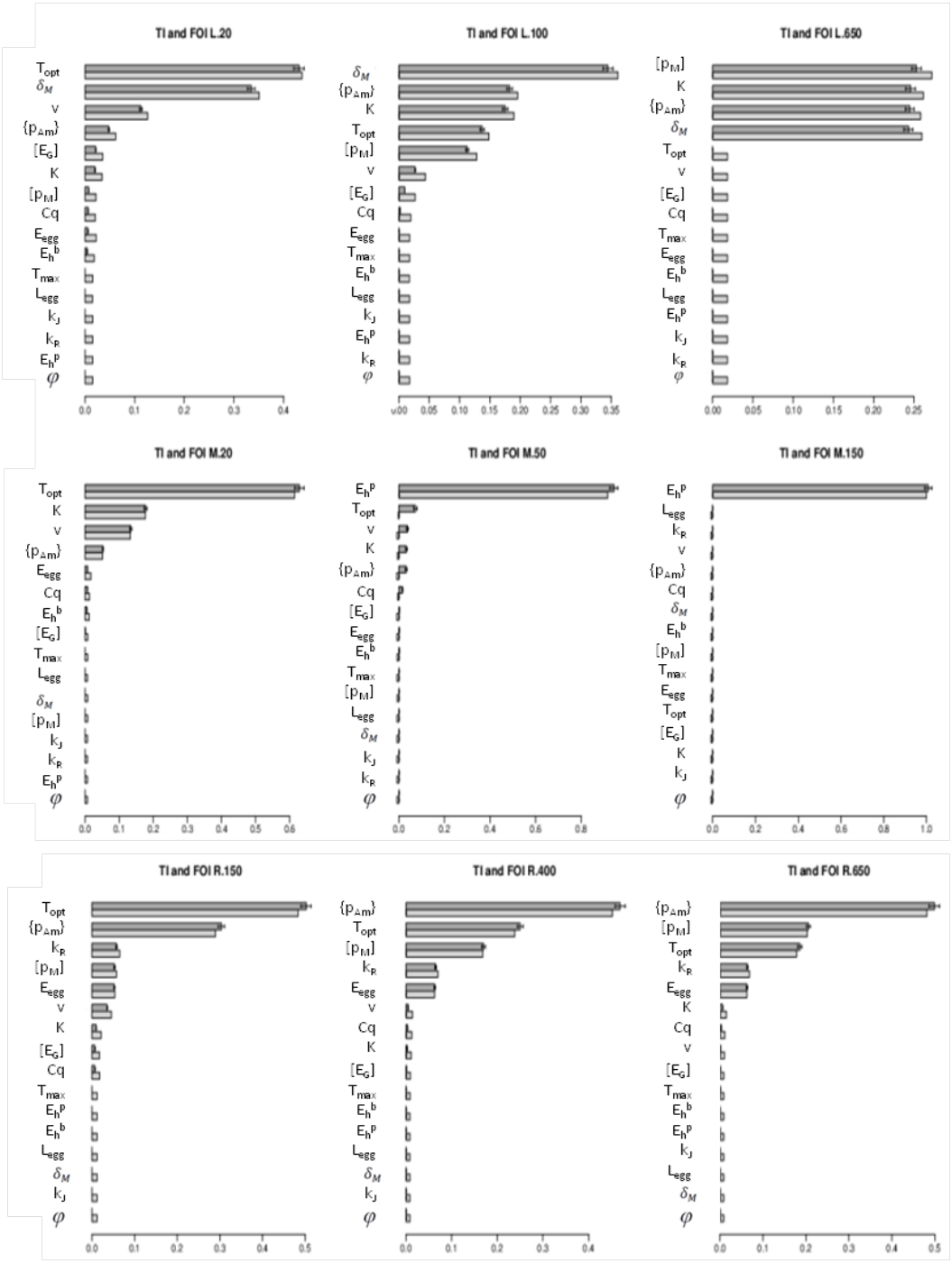


Fig. 1C. Sensitivity analysis of the DEB model for the **males**.

The Sobol' sensitivity indices are presented for the growth at 20. 100 and 650 dpf for the energy invested in maturity at 20, 50 and 150 dpf, and for the energy invested in reproduction at 150, 400 and 650 dpf. The water temperature was fixed at 20°C and the food was *ad-libitum* ($f = 1$). In this figure, E_{egg} corresponds to E_0.

The total order indices (TI) are presented in dark grey and first order indices (FOI) in light grey. Parameters were ordered according to the total order sensitivity indices.

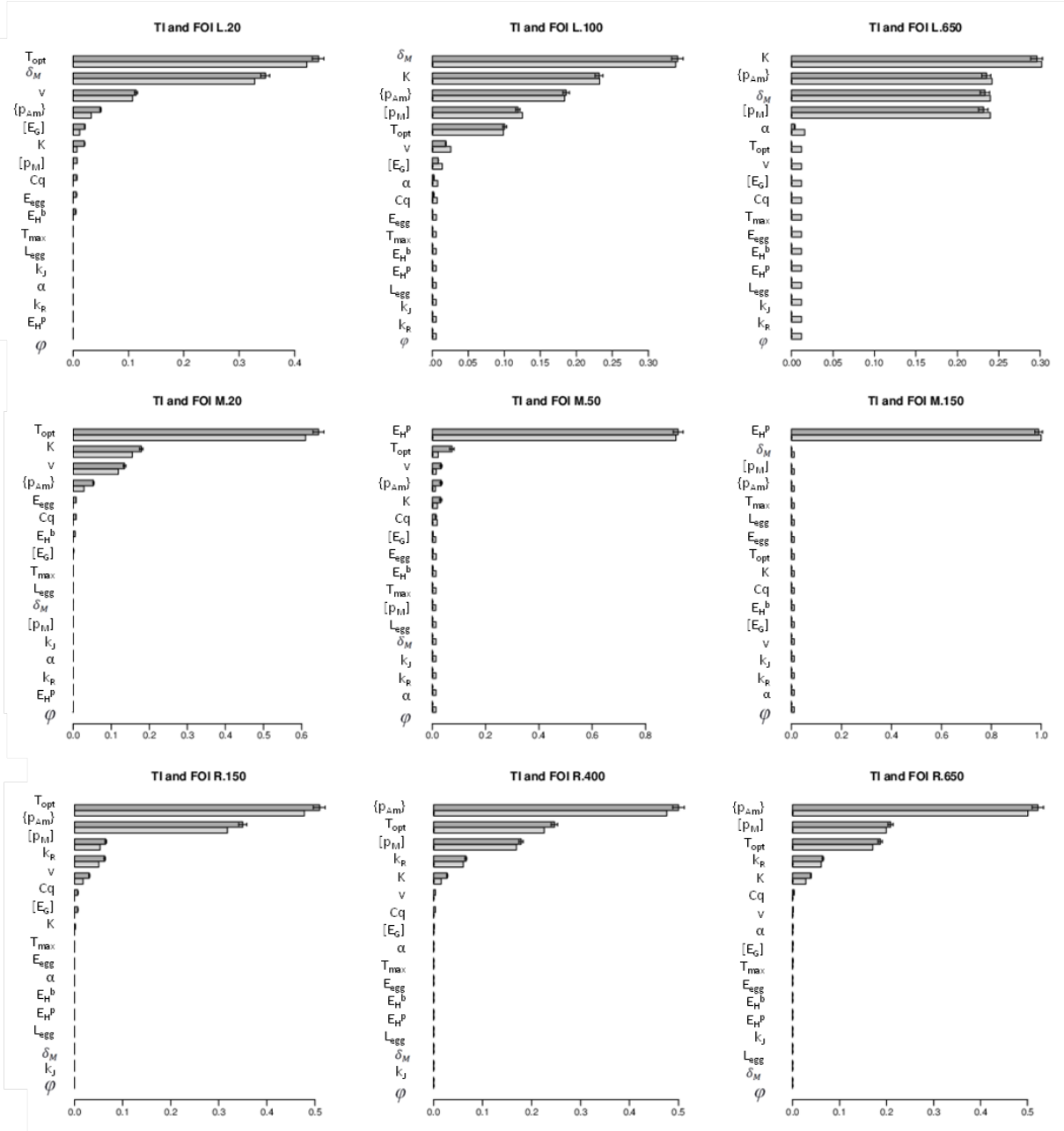


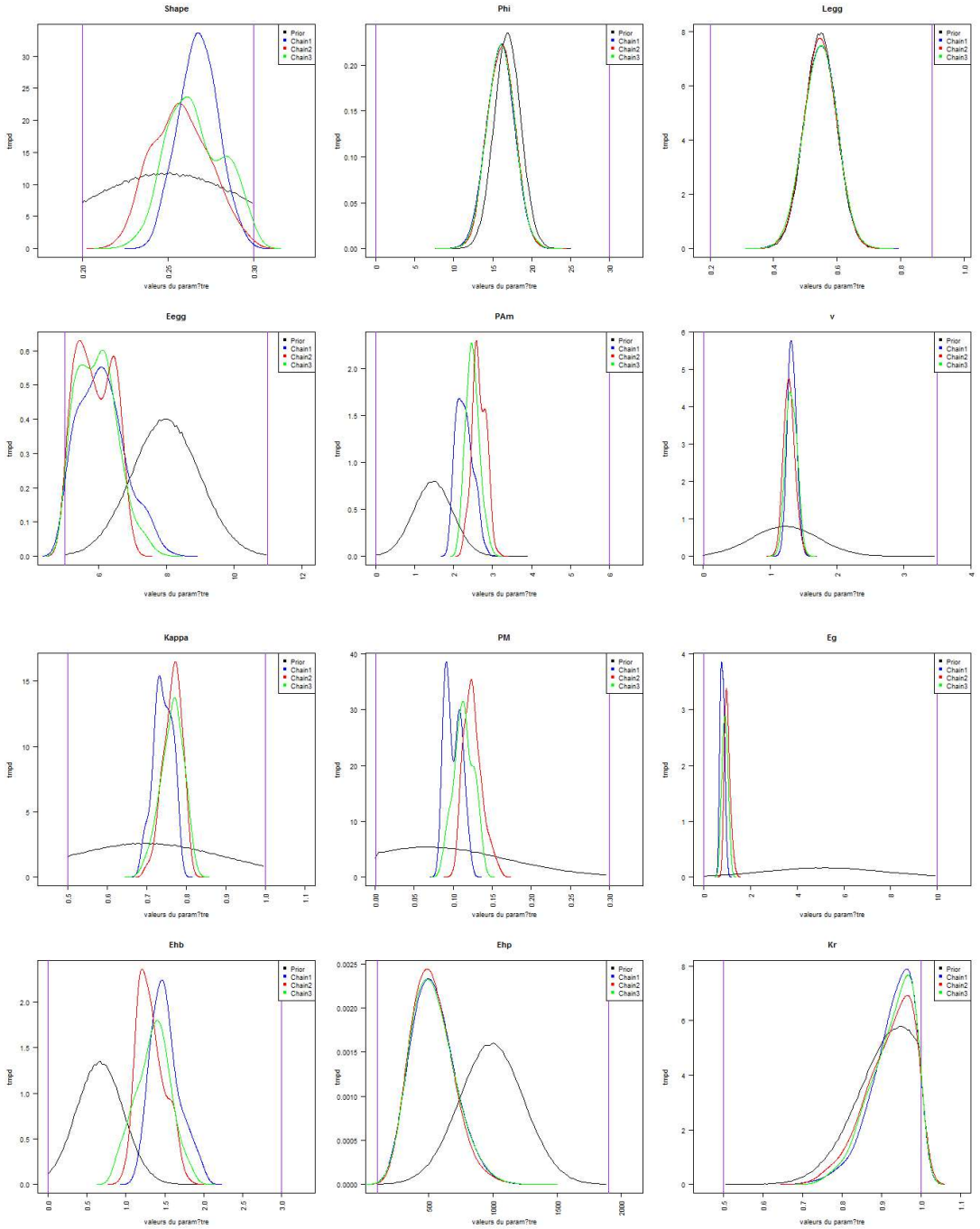
Fig. 2C. Sensitivity analysis of the DEB model for the **females**.

The Sobol' sensitivity indices are presented for the growth at 20, 100 and 650 dpf, for the energy invested in maturity at 20, 50 and 150 dpf, and for the cumulated number of eggs (reproduction) at 150, 400 and 650 dpf. The water temperature was fixed at 20°C and the food was *ad-libitum* (f = 1). In this figure, E_{egg} corresponds to E_0.

The total order indices (TI) are presented in dark grey and first order indices (FOI) in light grey. Parameters were ordered according to the total order sensitivity indices.

C.2. Posterior distributions of the parameters of the DEB model

For each parameter of DEB model, the *a priori* distribution (black line) is compared to the *a posteriori* distributions obtained by three independent calibration experiments (red, blue and green lines). Each color line corresponds of one chain of Monte-Carlo. These graphics allow us to assess if the parameter distributions are updated or not.



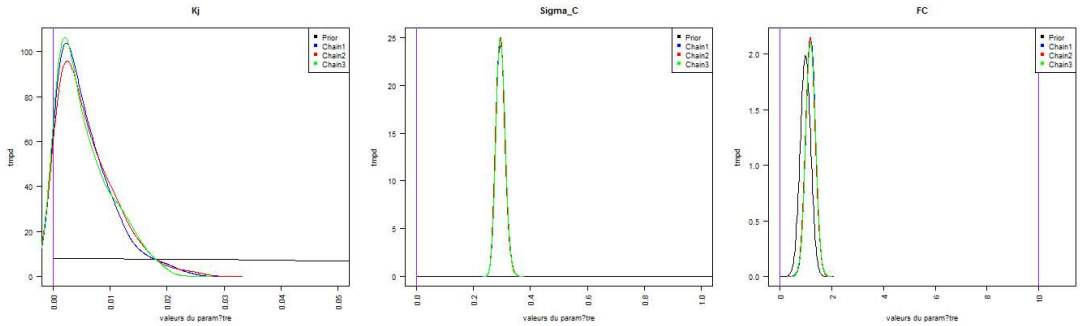


Fig. 3Ca. Comparison of *a priori* (black line) and *a posteriori* (red, blue and green lines) distribution for each parameter of DEB model. Each color line corresponds of one chain of Monte-Carlo. In this figure, E_{egg} corresponds to E_0.

C.3. Joint posterior distributions of the parameters of the DEB model

The fig 4C presents, in pairs, the joint posterior distributions of the parameters of the DEB model using a bivariate histogram. The grey levels represent the frequency: the higher the frequency is, the darker the grey level is.

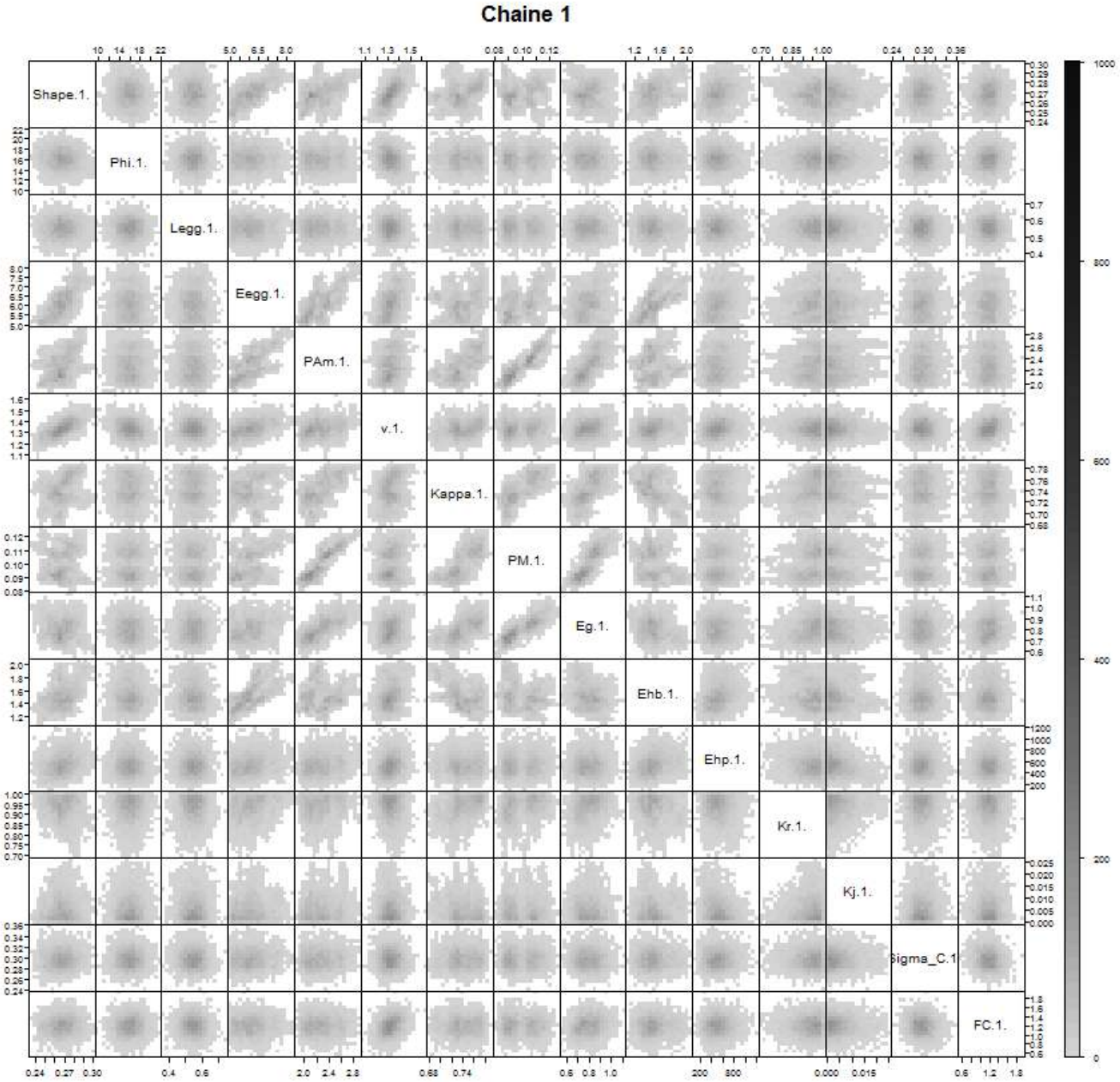


Fig. 4C. Scatter plot of the last 5.000 MCMC sample from the joint posterior distributions of the parameters of DEB model. In this figure, E_{egg} corresponds to E_0.

C.4. Relative residual of the clutch size of the DEB model

Figure 5C presents the relative residual error of the DEB model predictions for the clutch size "Experiment 4: fecundity of females" according to the water temperature and female length. These residual analyses were conducted to better understand which factors are responsible for the prediction errors.

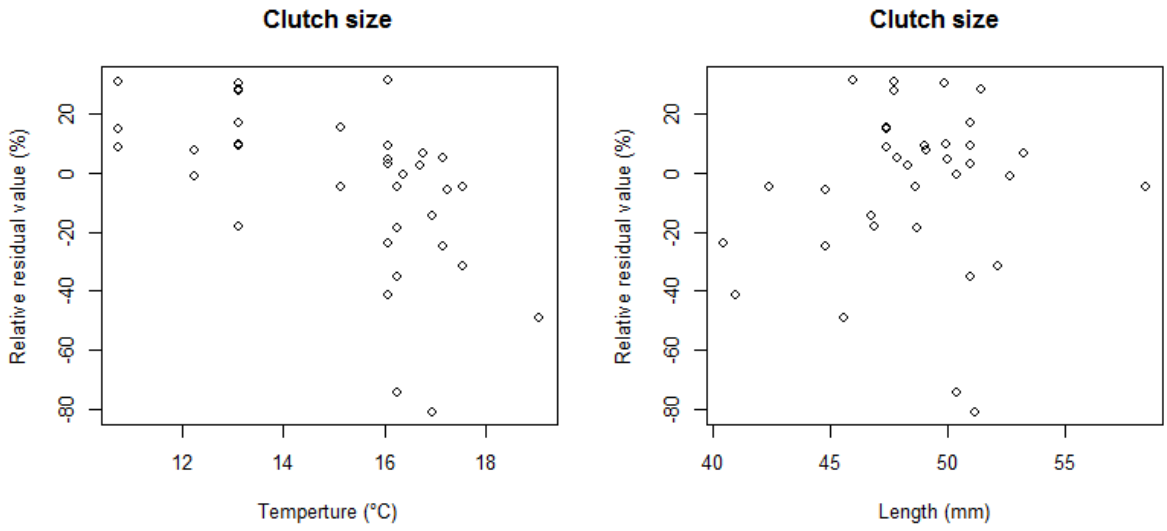


Fig. 5C. Relative residual values on the clutch size according to the water temperature (°C) and the spawning length of the females.

C.5. Comparison of the standard length predicted in experiment 4

Table 4C and Figure 6C present a comparison of the standard length predicted by the van Bertalanffy growth model and the DEB model for the initial length of the females used in the "Experiment 4: fecundity of females".

Table 4C. Comparison between the standard lengths predicted by the van Bertalanffy growth model (column 2) and by the DEB model (column 3). The column 1 is le number of female and the column 4, the difference in percentage between the columns 2 and 3.

NB F	T_{BV}	T_{DEB}	ratio %
1	39,69	39,25	1,121
2	46,63	46,48	0,323
3	48,67	48,39	0,579
4	37,91	37,53	1,013
5	43,62	43,36	0,600
6	48,11	47,94	0,355
7	49,34	49,07	0,550
8	49,34	49,07	0,550
9	37,45	37,04	1,107
10	42,51	41,7	1,942

11	42,51	41,95	1,335
12	44,5	44,06	0,999
13	50,6	49,18	2,887
14	45,84	45,55	0,637
15	49,34	49,07	0,550
16	48,53	48,39	0,289
17	43,62	42,76	2,011
18	44,5	45,46	-2,112
19	44,68	45,49	-1,781
20	46,27	45,85	0,916
21	50,84	51,31	-0,916
22	46,63	47,21	-1,229
23	44,33	44,63	-0,672
24	46,78	47,1	-0,679
25	47,68	48,07	-0,811
26	47,82	48,2	-0,788
27	45,35	45,62	-0,592
28	49,47	49,88	-0,822
29	49,07	49,36	-0,588
30	46,47	46,44	0,065
31	45,02	45,03	-0,022
32	46,32	45,93	0,849
33	51,75	51,77	-0,039
34	50,72	50,33	0,775
35	57,75	57,72	0,052
		Mean	**0,242**

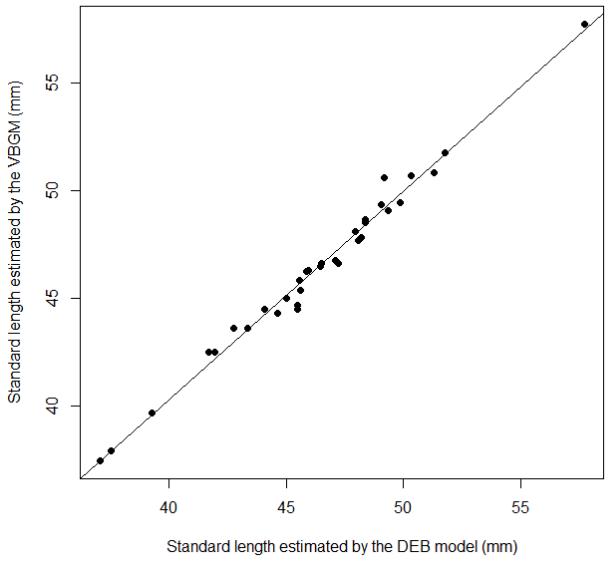


Fig 6C. Relationship between the standard lengths predict by the van Bertalanffy growth model and by the DEB model.

D. LIFE HISTORY

Table 1D presents values reported in literature for different stickleback populations regarding the maximal physical length, length at maturity, and egg production (number of eggs for a given length in mm).

Table 1D. Life history data for three-spined stickleback

Location	Life - style	Maximal length (mean ± S.E.)		Length at maturity (mean ± S.E.)		Reproduction (females)		References
		Females	Males	Females	Males	Mean females length	Mean spawn size	
All locations	All forms			39.6 ± 1.46 mm				(Baker 1994)
Alaska	Lake-resident	49.4 ± 4.8 mm (mean±S.D.)						(Karve *et al.* 2008)
	Anadromous	69.2 ± 3.2 mm (mean±S.D.)						
	Anadromous	68.94 ± 0.3 mm	64.48 ± 0.27 mm					(Aguirre *et al.* 2008)
Bristish colombia	Anadromous	60.95 ± 3.31 mm	57.06 ± 1.81 mm					(Kitano *et al.* 2007)
	Stream-resident	58.70 ± 2.76 mm	50.41 ± 3.53 mm					
	Hybrid river	49.10 ± 3.44 mm	49.41 ± 3.79 mm					
	Lake-resident	51.73 ± 4.91 mm	50.27 ± 3.12 mm					
	Fresh water (all forms)	67.18 ± 2.74 mm	65.42 ± 2.15 mm					(Moodie & Reimchen 1976)

	Lake-resident	60 mm				51 mm	105	(Bell & Foster 1994)
France	All forms	57.4 ± 2.2 mm		37.86 ± 1.75 mm				(Bell & Foster 1994)
	Anadromous					41 mm	134	(Bell & Foster 1994)
England					40 mm			(Wootton 1976)
Japan	Anadromous	88 mm				83 mm	450	(Bell & Foster 1994)
	Lake-resident	70 mm				62 mm	226	
	Stream-resident	58-61 mm		32-39 mm		51 mm	145	
	Stream-resident	85 mm		47 mm		57 mm	172	
	River (low plated morph)	64.8 mm			45 mm			(Mori & Nagoshi 1987)
	Anadromous	82.9 ± 2.71 mm	75.88 ± 2.64 mm					(Kitano *et al.* 2007)
		80.68 ± 2.96 mm	74.46 ± 2.35 mm					
	Stream-resident	62.45 ± 5.59 mm	57.06 ± 3.72 mm					
		63.16 ± 4.14 mm	57.37 ± 4.14 mm					
	Marine - resident	67.14 ± 2.57 mm	61.6 ± 2.17 mm					
		65.86 ± 3.69 mm	59.24 ± 2.59 mm					
Quebec	Lake-resident	67 mm				56 mm	88	(Bell & Foster 1994)
	Marine-resident	71 mm				61 mm	265	
	Anadromous	70 mm				64 mm	366	

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