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QUANTIFICATION OF THE SINUSOIDAL TRAJECTORY IN TISSUE MASS AND CONDITION INDICES OF A BIVALVE (*EGERIA RADIATA*) IN THE CROSS RIVER, NIGERIA*

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ABSTRACT

Variation in monthly values of dry tissue mass (DTM) and two different types of condition indices of the bivalve *Egeria radiata* (Lamarck, 1804) was studied for 32 consecutive months. To quantify the seasonal trajectory of variation these data were fitted to one- and two-compartment sinusoidal models; and also to a quadratic, cubic and quartic models. The cyclic events in the variation of the DTM and both indices of condition were adequately described by the one-compartment sinusoidal model whose parameters are biologically interpretable. The fit of the data is progressively improved as one moves from the quadratic through the cubic to the quartic model whose fit was best. Although biological meaning could be found for the one-compartment sinusoidal model, the biological meaning of the coefficients of the parabolic-based models are obscure. Multiple regression analysis shows that of all the four environmental parameters (temperature, salinity, pH and phytoplankton) tested, temperature has the greatest effect on DTM and one of the condition indices, while pH has the greatest impact on the other condition index. This implies that the two indices are not only intrinsically different, but that they respond to different sets of factors. Inter- and intra-specific comparison of the many recommended 'standard' indices of condition found in the literature, especially with regard to their innate sensitivity to seasonal variation in internal (e.g. state of gravidity) and external (physicochemical parameters of water) factors is necessary.

INTRODUCTION

Grave (1912) was probably the first to utilise a ratio (100*meat volume/shell cavity volume) to express the 'fatness' of a bivalve species. Today, there are many such ratios under the generic name of condition index. Their general characteristics have been reviewed by Mann (1978) and Lucas & Beninger (1985) while Lawrence & Scott (1982), Davenport & Chen (1987), Crosby & Gale (1990) and Rainer & Mann (1992) compared various methods of computation and standardisation.

Seasonal variations in the tissue mass or any condition index of many bivalves follow a wave form or a closely related pattern. Such patterns have been found useful for economic purposes in describing the period when harvesting could give maximum meat yields (Nair & Nair, 1987), for ecological purposes in elucidating the spawning period (Etim, 1990), and for the biomonitoring of pollution and environmental stress (Marcus, Scott & Heizer, 1989), and disease condition (Sastry, 1979). Often, the description of the seasonal variation in the condition index and tissue mass of bivalves has been qualitative. Fitting a periodic regression model (Batschelet, 1981; Loesch & Evans, 1994) to such data could confer a statistical predictive power and also render it more amenable to further quantitative analysis. Fitting a linear regression to a scatter plot enables one to compare quantitatively two or more sets. Equally, fitting a periodic regression to data on seasonal patterns of condition index of bivalve could serve as a basis in quantitative comparison of the nature of the cyclic events of the bivalve condition. The aim of this work is to explore the mathematical plausibility of fitting a basic sinusoidal, two compartment sinusoidal, and polynomial models to the data on the monthly variation in tissue mass and condition index of the bivalve *Egeria radiata* (Lamarck, 1804).

Egeria radiata is of both ecological and economic importance. It is a fresh water donacid bivalve endemic to the West African subregion. It is a gonochoristic species which spawns once in a year during the peak of the rainy season (June to October). The species is abundant in many large rivers e.g. Volta (Ghana), Sanaga (Cameroon), and Cross (Nigeria) rivers. It supports a rich and thriving artisanal fisheries wherever it is found. Several aspects of its biology have been documented e.g. general biology and gross anatomy (Purchon, 1964), population dynamics and fisheries (Etim & Brey, 1994; Moses, 1990), and reproduction cycle (Etim, 1996). In this study, the species is used in demonstrating the mathematical feasibility and utility of adopting a quantitative approach in elucidating the seasonal patterns in variation of tissue mass and condition indices of bivalves.

MATERIALS AND METHODS

Clams were obtained from artisanal fishermen in the Cross River (~Long. 8°4'E, Lat. 5°11'N), Nigeria. Monthly samples of 10 to 20 specimens whose lengths (maximum anterio-posterior dimension) ranged between 70.0 mm and 73.0 mm were bought between February 1987 and September 1989. The shell-free dry mass of each specimen was determined by oven-drying the tissue at 60°C for 72 hours. The monthly average shell-free dry mass was then plotted against time to give the pattern of seasonal variation from which the spawning season of the species could be deduced. Data on the monthly variation in bottom water temperature, salinity, phytoplankton counts, and pH were as recorded in Etim (1990) and Etim & Taege (1993).

First, a multiple regression of the dry tissue mass (DTM) against temperature (temp), salinity (sal), phytoplankton count (phyto), and pH was computed in order to assess the relative importance of the influence of each of these on the dependent variable.

$$\mathrm{DTM} = a + b_1\,\mathrm{temp} + b_2\,\mathrm{sal} + b_3\,\mathrm{time} + b_4\,\mathrm{phyto} + b_5\,\mathrm{pH} \quad (1)$$

where a is the constant and b values are the multiple regression coefficients.

The following condition indices were computed:

(i) Dry tissue mass/Dry shell mass

This is the index recommended by Lucas & Beninger (1985) and is herein referred to as condition index-1 (CI-1).

(ii) 1000(Dry tissue mass/Shell cavity volume)

This is the index recommended by Crosby & Gale (1990) and is herein referred to as condition index-2 (CI-2).

To quantify the cyclic event, nonlinear regression models were iteratively fitted to the monthly data on DTM using the Quasi-Newton algorithm (Press, Flannery, Teukolsky & Vetting, 1986) available on Systat (1992). The Quasi-Newton procedure (which yielded the same results as the Simplex algorithm) was preferred because it was faster.

The basic sinusoidal model used is

$$\mathrm{DTM} = M_o + A\cos 2\pi t + B\sin 2\pi t \quad (2)$$

where DTM is the monthly dry tissue mass (=shell free dry mass), t is the time of sample collection expressed in years, M_o is the mesor, while A and B are the model constants which were determined empirically.

In its alternative form, it follows that

$$\mathrm{DTM} = M_o + h\cos 2\pi(t = t_o) \quad (3)$$

where h is the amplitude of sinusoidal variation, and t_o is the acrophase.

The two component sinusoidal model takes the form

$$\mathrm{DTM} = M_o + A_1\cos 2\pi t + B_1\sin 2\pi t + A_2\cos 4\pi t + B_2\sin 4\pi t \quad (4)$$

The dependent variable in equations 2, 3 and 4 were in turn replaced with CI-1, CI-2.

For further exploratory purposes, the data on DTM was also fitted to a basic quadratic model.

$$\mathrm{DTM} = M_o + AT + Bt^2 \quad (5)$$

The addition of an extra term would yield cubic and quartic models successively as follows:

$$\mathrm{DTM} = M_o + At + Bt^2 + Ct^3 \quad (6)$$

$$\mathrm{DTM} = M_o + At + Bt^2 + Ct^3 + Ct^4 \quad (7)$$

Evaluation of models

To assess the models used in this study, we computed the residuals after having estimated the parameters of the model. By definition, the residual is the difference between the actual data used for the estimation of the model coefficients and the corresponding predicted values derived from the model itself. The coefficiency of determination r^2 which indicates the proportion of the variance in the data explained by the model was used as a measure of goodness of fit.

RESULTS

Table 1 shows the results of the multiple regression analysis of monthly DTM against corresponding values of environmental temperatures, salinity, phytoplankton counts and pH. Both the partial regression coefficient (Coef.) and the standard partial regression coefficients (Std. Coef.) are shown together with the standard error (std. error) of estimate. Additionally, tolerance (one minus the squared multiple correlation between each predictor and the remaining predictors in the equation) values are given. Tolerance values close to zero indicate that some predictors are highly intercorrelated; a situation which can lead to inflated standard errors of the regression coefficient, reduced associated t statistic, and may even compromise computational accuracy. Our tolerance values indicate a lack of such multicolinearity. The standardised

Table 1. Multiple Regression analysis of dry tissue mass (DTM) or condition index (dependent variable) against environmental temperatures (temp), salinity (sal), phytoplankton counts (phyto), and pH (independent variable). Var = variable; Coef = partial coefficient of multiple regression; Std Error = standard error of estimate, Std Coef = Standard partial regression coefficient; Toler = Tolerance; r^2 = coefficient of multiple determination; const = constant.

(a) Dependent variable = DTM, N = 32, $r^2 = 0.613$, $P < 0.0005$

Var	Coef	Std Error	Std Coef	Toler	P (2 tail)
Const.	−6.79	3.622	0.000	—	0.071
Temp	0.169	0.134	0.400	0.141	0.219
Sal	−8.216	1.908	−1.162	0.197	0.000
Phyto	0.000	0.000	0.171	0.374	0.389
pH	1.340	0.605	0.396	0.448	0.035

(b) Dependent variable = Condition index-1 (CI-1), N = 32, $r^2 = 0.561$, $P < 0.0005$

Var	Coef	Std Error	Std Coef	Toler	P (2 tail)
Const.	−9.973	7.856	0.000	—	0.215
Temp	0.283	0.292	0.329	0.141	0.340
Sal	−15.879	4.138	−1.104	0.197	0.001
Phyto	0.001	0.0001	0.164	0.374	0.438
pH	2.228	1.312	0.324	0.448	0.101

(c) Dependent variable = Condition index-2 (CI-2), N = 32, $r^2 = 0.655$, $P < 0.0005$

Var	Coef	Std Error	Std Coef	Toler	P (2 tail)
Const.	−19.420	8.680	0.000	—	0.034
Temp	0.328	0.322	0.306	0.141	0.318
Sal	−20.017	4.573	−1.116	0.197	0.000
Phyto	0.001	0.001	0.231	0.374	0.221
pH	4.000	1.450	0.466	0.448	0.010

partial regression coefficients are free of the original measurement scale, thus their magnitudes can be directly compared to show the relative standardised strengths of the effect of several independent variables on the same dependent variable (Sokal & Rohlf, 1995). *Ipso facto*, it follows that of all the four environmental parameters tested, temperature has the most profound effect on DTM, followed by pH and phytoplankton counts, with salinity having the least effect. The comparatively low impact of salinity is understandable, since the water at the sampling station and throughout the range of distribution of the clam is freshwater (<0.6 ppt) year-round. This order in relative importance of the different environmental factors is not changed even when DTM is replaced with CI-1 as the dependent variable (Table 1a, b). But with CI-2 as the dependent variable, pH exhibits the greatest impact (Table 1c).

There is a marked seasonal variation in the dry tissue mass and condition indices of the clam (Fig. 1). Table 2 shows that the fit of the basic sinusoidal model to each year's data was significant ($p < 0.0005$). Thus, the null hypothesis that the data is not a function of year is not accepted. Despite the monthly variation, the mesors (M_o) (which are indicators of annual mean level) are similar. This implies a corresponding similarity in the inter-annual variation in factors which induces the tissue variation in the first instance. The fall in DTM and condition between June and October implies that the organism spawns during this period (Etim, 1990; Etim & Taege, 1993).

The variation of the DTM or condition index with time was explained by a fit of the

Table 2. Parameters of the basic sinusoidal model Y = Mo + A cos 2π t + B sin 2π t fitted to the monthly data on dry tissue mass (DTM). M_0 is the mesor which is annual mean of DTM, A and B are empirical constants. r^2 is the coefficient of determination.

Year	No. of months	M_0	A	B	r^2	P
1987	11	3.925	−1.048	0.893	0.753	<0.0005
1988	12	4.243	−1.57	0.059	0.808	<0.0005
1989	9	3.999	−1.211	0.303	0.643	<0.0005
All years	32	4.037	−1.130	0.869	0.736	<0.0005

data to the one-compartment sinusoidal model whose coefficients were amenable to biological interpretation. Although the explained variance was higher when a two compartment sinusoidal model was employed (see r^2 values in Fig. 1: a-1 and a-2), difficulties arise in imputing biological meaning to the coefficients. For instance, while the one compartment sinusoidal model carries a period of one year, the two compartment sinusoidal model implies a period of 6 months. The amplitude h $(=A^2 + B^2)^{1/2}$ of the graph and the time t_o $(=1/2p)\tan^{-1}(B/A)$ when the maximum dependent variable occurs could easily be computed for the one compartment sinusoidal model. However, the biological interpretation of t_o, for instance, becomes difficult when the two compartment sinusoidal model is fitted to data.

Each of the three parabolic-based equations were highly significant (ANOVA: $P < 0.0005$). There is a gradual improvement in the value of r^2 as one moves from a fit of the data to the simple quadratic through the cubic to the quartic. And, as shown by visual inspection of the curves in Fig. 2, the predictive power of the model is also greatly enhanced with each term added to the basic quadratic model. However, this improvement of the fit as a consequence of an additional extra term to the basic model collapsed at the quintic model (r^2 = 0.348, graph not shown). Additionally, biological interpretation of these parabolic-based coefficients is not feasible.

DISCUSSION

There are more than twenty different types of condition indices used in both bivalve research and commercial practice. Depending on the variables used, condition indices can be classified into morphometric, biochemical or physiological (Mann, 1978). Alternatively, they can be classified either as static (determined at a single point in time), or dynamic (determined over a period of time to give information about physiological changes in the individual comprising the population) (Lucas & Benninger, 1985). Many authors have proposed a 'standard' or 'recommended' index in an attempt to facilitate comparability of results. However, there is no consensus recommendation. For instance, Lawrence & Scott (1982)

Figure 1. *Egeria radiata.* (a-1) Observed monthly dry tissue mass (solid lines) of *E. radiata* with superimposed predicted values (broken lines) derived from the model DTM = 4.037 + 1.130 cos 2πt + 0.869 sin 2πt, N = 32, r^2 = 0.736, P < 0.0005.
(a-2) Observed monthly dry tissue mass (solid lines) of *E. radiata* with superimposed predicted values (broken lines) derived from the model DTM = 4.021 + 1.146 cos 2πt + 0.896 sin 2πt + 0.083 cos 4πt + 0.246 sin 4πt, N = 32, r^2 = 0.763, P < 0.0005.
(b-1) Monthly variation in condition index-1 (CI-1) (solid lines) with superimposed predicted curve (broken line) derived from the one-compartment sinusoidal model CI-1 = 7.489 − 2.445 cos 2πt + 1.536 sin 2πt, N = 32; r^2 = 0.734, P < 0.0005.
(b-2) Monthly variation in condition index-1 (CI-1) (solid line) with superimposed predicted curve (broken line) derived from the two-compartment sinusoidal model CI-1 = 7.464 − 2.446 cos 2πt + 1.598 sin 2πt + 0.440 cos 4πt + 0.363 sin 4πt, N = 32; r^2 = 0.764, P < 0.0005.
(c-1) Solid line shows the monthly changes in condition index-2 (CI-2) of *E. radiata* while broken line is the predicted value as derived from a one-compartment sinusoidal model CI-2 = 9.805 − 2.829 cos 2πt + 2.430 sin 2πt, N = 32; r^2 = 0.783, P < 0.0005.
(c-2) Solid line shows the monthly changes in condition index-2 (CI-2) of *E. radiata* while broken line is the predicted value as derived from a two-compartment sinusoidal model CI-2 = 9.741 − 2.911 cos 2πt + 2.517 sin 2πt + 0.043 cos 4πt + 0.959 sin 4πt, N = 32; r^2 = 0.839, P < 0.0005.

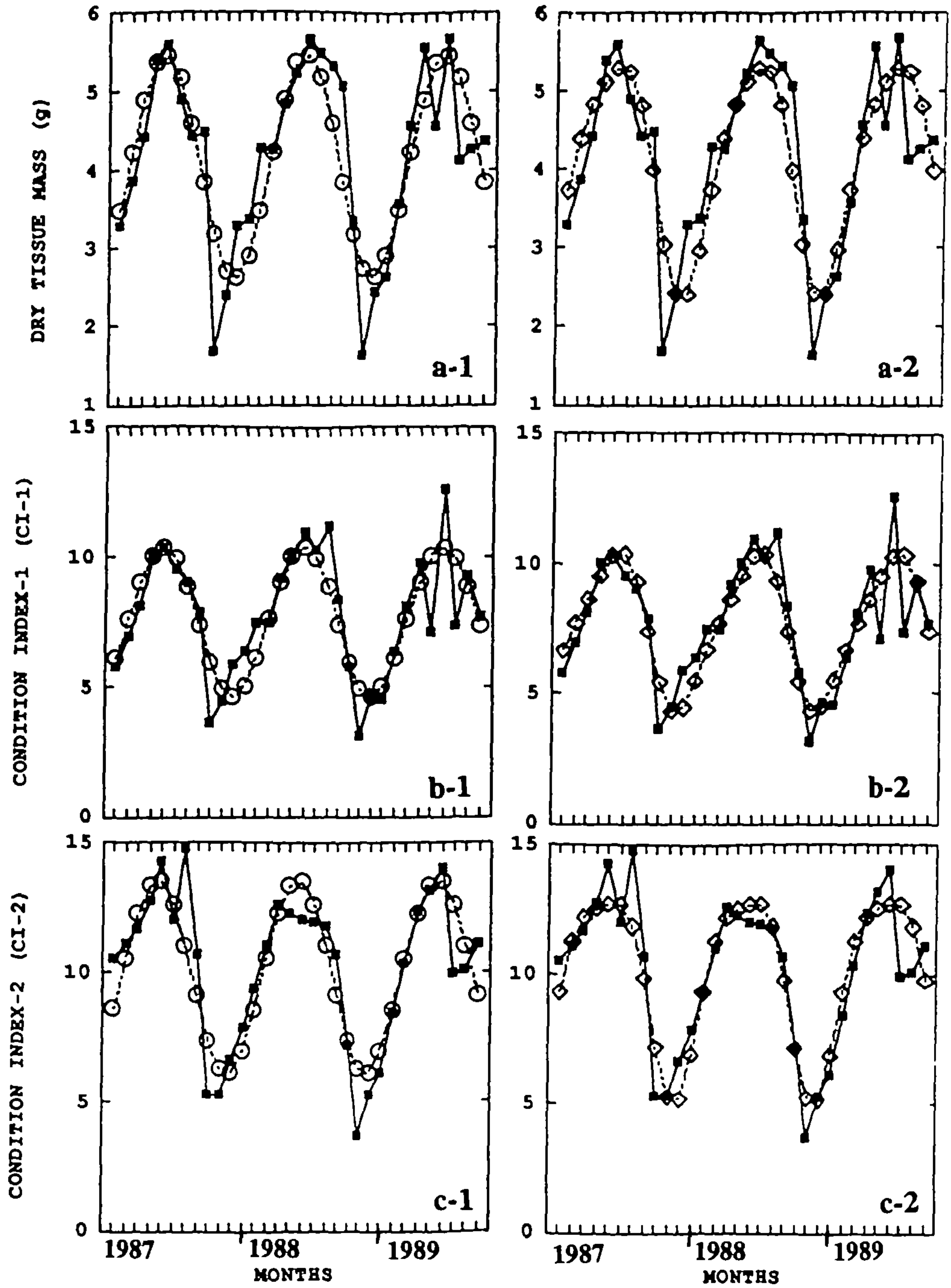
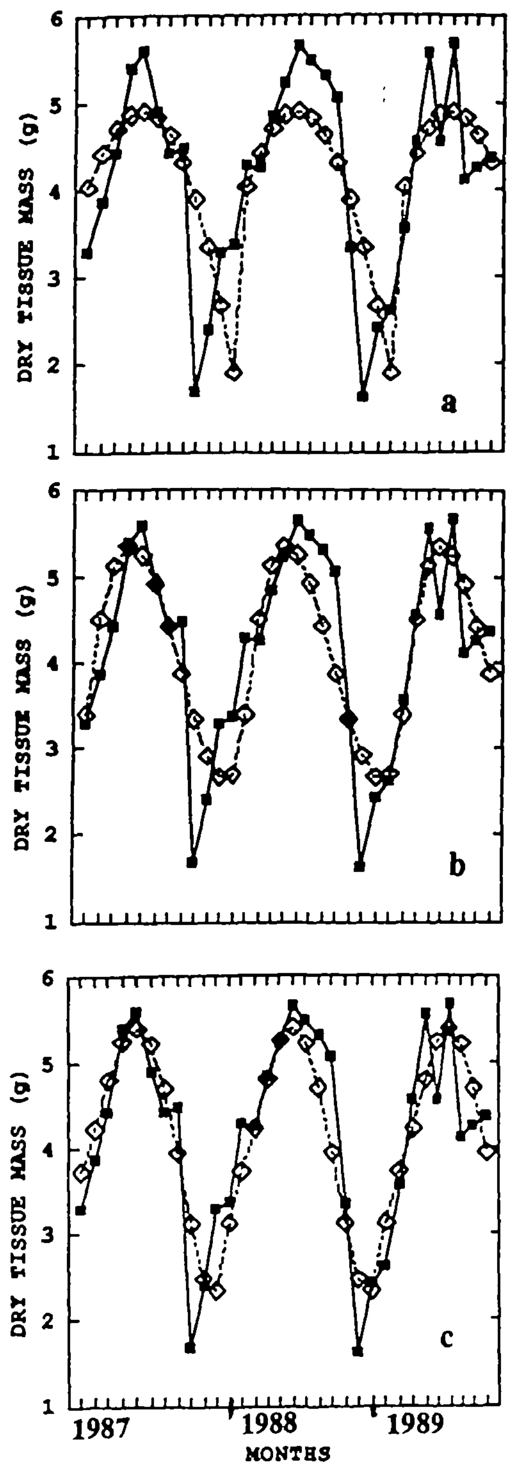

DRY TISSUE MASS (g)
CONDITION INDEX-1 (CI-1)
CONDITION INDEX-2 (CI-2)
a-1
a-2
b-1
b-2
c-1
c-2
1987
1988
1989
MONTHS

Figure 2. *Egeria radiata.* Monthly variation in dry tissue mass of *E. radiata* (solid lines) with superimposed predicted values derived from
(a) a quadratic model $DTM = 3.531 + 6.821t - 8.448t^2$, $N = 32$; $r^2 = 0.548$, $P < 0.0005$.
(b) a cubic model $DTM = 1.713 + 24.029t - 47.412t^2 + 24.363t^3$, $N = 32$; $r^2 = 0.692$, $P < 0.0005$.
(c) a quartic model $DTM = 3.624 - 2.437t + 54.477t^2 - 120.405t^3 + 67.869t^4$, $N = 32$; $r^2 = 0.755$.



recommended 100(dry meat weight)/(internal cavity volume) because the technique is simple and time efficient. Davenport & Chen (1987) compared seven different indices and recommended 100(cooked meat weight)/(cooked meat weight + shell weight) because it was the most accurate and least variable. Beninger & Lucas (1984) found a close correspondence between the Dry tissue weight/Dry shell weight and the Ash-free dry weight/Dry shell weight indices and suggested the use of the former which is more easily measured. Crosby & Gayle (1990) compared three different indices of condition before recommending 1000(dry soft tissue mass)/(internal shell cavity capacity) because it has fewer measuring errors, a lower coefficient of variation and is the easiest and fastest to use. Rainer & Mann (1992) recommended indices based on volume and shell mass viz: 100(dry meat weight)/(shell cavity volume); 100(dry meat weight)/(dry shell weight). There are differences not only in the computation of condition index but also in the procedure for measuring the denominator and numerator. For example, there are about five different methods for measuring the internal volume of the bivalve: (a) the difference between the volume of water displaced by a whole live animal and that displaced by the shell, (b) the weight of a closed live bivalve in water is subtracted from its weight in air to have the total volume of the bivalve. The weight of the two shells in water is subtracted from the weight in air to give the volume of the shell material. Then the internal shell cavity volume is obtained as the difference between the total volume of the claim and the volume of the shell material (Quayle, 1950). This procedure is based on the Archimedes principle, (c) the shell cavity volume is also determined by subtracting the weight of the shell in air from the total weight of the whole animal in air (Lawrence & Scott, 1982). The underlying principle here being that there is a 1:1 ratio between the cavity volume and the mass of its contents, (d) by noting the volume of water from a burette required to fill the two shell valves (Etim, 1990), (e) from the weight of sand that fills the two shells; given the density of the sand the weight could be converted to volume, (f) Emmett, Thompson & Popham (1987) even used the volume of the whole animal instead of its internal volume. Since the precision and accuracy of each of these are not the same, inter-comparisons might not be valid. Crosby and Gale (1990) showed statistically that although condition indices employing (a) and (b) could be comparable, that employing shell weight as the denominator is different.

Condition index, which is assumed to be an indicator of the physiological state of the bivalve, is affected by many factors e.g. internal (state of gravidity, degree of parasitism, etc.) and external (temperature, salinity, food availability, etc.). Yet, all the different indices recommended as standards are based on ease of measurement, potential precision in measuring the components, and on statistical comparison of variance components, rather than on the innate sensitivity of the index to these factors that impact on the life of the bivalve itself. For instance, our results have shown that the 3 conditions used in this work are not equally sensitive to the same set of factors. While the seasonal variation in DTM indicates a dribble spawning (*sensu* Newell, Hilbish, Koehn & Newell, 1982 and Schmitzer, Dupaul & Kirkley, 1991) phenomenon during May 1989, the CI-2 indicates its occurrence in July 1987 and CI-1 does not seem to reflect such occurrence. Additionally, our multiple regression analysis shows that DTM and CI-1 are more affected by seasonal variations in temperature (Table 1a and b) while Table 1c shows that it is the pH that has the most profound effect on CI-2. Thus these indices are intrinsically different; for while CI-2 measures the amount of space which the tissue could occupy, CI-1 gives an indication of the proportion of the total weight contributed by the shell and tissue.

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