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A COMPARISON OF METHODS FOR CALCULATING CONDITION INDEX IN EASTERN OYSTERS, *CRASSOSTREA VIRGINICA* (GMELIN, 1791)

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ABSTRACT A number of techniques have been reported to estimate condition index in oysters and other bivalve molluscs. We report and compare condition index, estimated by three different methods, for oysters collected from a single reef in the James River, Virginia over a four week period in the summer of 1987. Two indices express condition as a ratio of dry meat weight to shell cavity volume, but differ in methods of estimating shell cavity volume. A third method expresses condition as a ratio of dry meat weight to dry shell weight. Within the size range 36–96 mm length there is no effect of size on index values. We suggest that indices based on both shell cavity volume and shell weight have utility in reflecting biochemical or nutritive status; however, intercalibration is difficult and comparisons of data from different authors and locations limited in scope.

KEY WORDS: bivalve, condition index, oyster, clam, mussel

INTRODUCTION

A number of techniques have been reported to estimate condition index in oysters and other bivalve molluscs. Recent reviews include Mann (1978), Lucas and Beninger (1985), Bodoy, Prou and Berthome (1986), Davenport and Chen (1987), and Crosby and Gale (1990). Collectively, these contributions illustrate the abundance of indices used, the lack of consistent methods, and the difficulty in comparing published material. Mann (1978) included discussion of volumetric and gravimetric meat-to-shell ratios, biochemical and physiological indices, and a comparison of biochemical and gravimetric indices. Lucas and Beninger (1985) offered a comprehensive review of "static", physiological, biochemical, and "dynamic" indices. All of the above discuss indices based on measurement of dry tissue weight, shell cavity volume and shell dry weight. In this contribution we compared three methods based on dry meat : shell cavity volume ratios and dry meat : dry shell weight ratios, and discuss their utility in comparison with gross biochemical indices.

METHODS

Oysters, *Crassostrea virginica* Gmelin, were collected from Horsehead reef in the James River, Virginia. Sampling locations were randomly selected from a uniform grid overlaying the reef. Samples were collected at weekly intervals from 1 July to 29 July, 1988, using a 60 cm oyster dredge with 7.5 cm teeth. Tows were not replicated. A one half bushel subsample was haphazardly taken from the collected material, sorted and all whole oysters were retained. Twenty five oysters, selected randomly and without regard to size, were removed for estimation of condition index.

All animals were measured for length (defined as the longest dimension measured from the hinge) to facilitate subsequent examination of size versus index relationships. The overall size range for the entire study was 36–96 mm length. The following relationships were used to estimate condition index (Ci):

$$\text{Ci} = (\text{dry meat weight} \times 100/\text{shell cavity volume}) \quad (1)$$

$$\text{Ci} = (\text{dry meat weight} \times 100/\text{dry shell weight.}) \quad (2)$$

Equation 1 is that of Hopkins as described in Higgins (1938). When the resultant value is multiplied by ten it is the volumetric index (Ci-vol) of Crosby and Gale (1990). Equation 2 is the relationship used by Walne and Mann (1975) and is similar to the shell weight index (Ci-shell) of Crosby and Gale (1990) with the exception that the meat:shell ratio here is multiplied by 100 rather than 1000.

Shell cavity volume was estimated from the difference between the volume of water displaced by the live animal, after removal of attached epifauna and debris, and the volume displaced by the clean, separate valves after removal of the meat. Displacement was estimated using two different methods. Individual oysters were placed in a water filled container equipped with an overflow pipe. Surface tension around the exposed surface of the water moderates the flow of water and is a potential source of error. It is this moderating force which has led us to label this a passive method. Passive methods were also used by Hopkins (1938) and Crosby and Gale (1990). Condition index calculated by equation 1 using these data will be referred to as volumetric and passive, abbreviated to Ci-vol-p, to conform with Crosby and Gale (1990). Individual oysters were then transferred to a second, cylindrical chamber fitted with a piston inserted from above after addition of the oyster, which came to rest against a stop. Displaced water moved through a small bore hole in the piston into a graduated glass buret attached to the piston. The displaced water volume was the calculated difference of the calibrated buret measurement before and after addition of the oyster. Errors due to surface tension by this method are markedly reduced by comparison with the former method. Condition index calculated by equation 1 using this data will be referred to as volumetric and active, abbreviated to Ci-vol-a. All measurements were replicated three times for each individual animal.

Dry meat weight and dry shell weights were estimated after drying to constant weight at 100°C in tared pans. Condition index calculated by equation 2 using this data will be referred to as shell weight indices, abbreviated to Ci-shell.

RESULTS

The descriptors of oyster size (whole animal volume, dry meat weight, shell cavity volume, and shell length) of the animals examined are shown in Table 1. The regression relationships between condition indices (Ci-vol-p, Ci-vol-a, and Ci-shell) and both

TABLE 1.

Size range of animals examined.

Whole animal displacement volume	(V) 6–73 ml
Shell length	(L) 39–96 mm.
Shell displacement volume	4–44 ml
Shell cavity volume (V − D)	2–26 ml
Meat dry weight	0.3–2.0 g
Shell dry weight	10–110 g

Letters in parentheses indicate descriptor variable name in Table 2.

whole animal volume and length, that is size descriptors not used in condition index calculation, are given in Table 2. In all comparisons very low r^2 values indicate a large scatter of points about the line and slopes that are not significantly different from zero. No relationship between size and condition is observed. Consequently, all data obtained by one method at one date are pooled (n = 25 per week) and plotted as Figure 1, a bar histogram, to examine variation in index over time by all methods. The similarity in temporal trend is evident regardless of the index in use.

Figures 2A and 2B illustrate, respectively, comparisons of Ci-vol-p versus Ci-vol-a, and both Ci-vol-p and Ci-vol-a versus Ci-shell using all 125 individual values collected during the study period. The lack of correlation between Ci-vol-p and Ci-vol-a is unsettling given that they differ only in the method of volume estimation and suggest measuring error in one or both methods. Only the plot of Ci-vol-p versus Ci-shell exhibits a slope significantly different than zero ($p < 0.001$). The accompanying r^2 value of 0.209 suggests a modest predictive capability for this relationship.

DISCUSSION

Condition indices based on both shell weight and shell cavity volumes have limitations. Shell weight indices do not account for possible changes in shell volume caused by changes in shell shape or thickness. Shell cavity volume indices for oysters are only valid if specimens of the same age are used because oysters from overcrowded natural reefs and young oysters are usually flat, with little space between the valves (Galtsoff 1964). Oysters are notably ecomorphic, volume condition index values from these animals are comparatively high because the soft tissues occupy almost the entire shell cavity. The lack of relationship between Ci-vol-p and Ci-vol-a in the present study suggests that error in measurement of volume, especially so in passive systems where surface tension problems in large bore measuring containers may result in errors that are a significant fraction of the reading, may be a more widespread and significant problem than previously appreciated. Finally, uncoupled growth of tissue and shell may be quite typical for healthy oysters, resulting in reduced condition values that do not accurately reflect nutritional or physiological status of the oyster (see discussion in Hilbish 1986). Indeed, all condition indices will vary due to seasonally related changes in growth of the animals under study and have been used as descriptors of such change.

TABLE 2.

Linear regressions of relationships between Ci-vol-p, Ci-vol-a, and Ci-shell when plotted respectively against volume, V, and length, L, as listed in Table 1.

y	x	m	c	p	r^2
Ci-vol-p	V	0.014	7.715	0.765	0.001
Ci-vol-p	L	−0.031	9.44	0.629	0.002
Ci-vol-a	V	−0.052	9.792	0.076	0.003
Ci-vol-a	L	0.040	4.936	0.927	0.003
Ci-shell	V	−0.005	2.173	0.300	0.009
Ci-shell	L	−0.005	2.351	0.305	0.008

All relationships as y = mx + c where y is Ci value and x is V or L. N = 125 oysters in all cases; 25 each on July 1, July 8, July 15, July 22, and July 29, 1987.

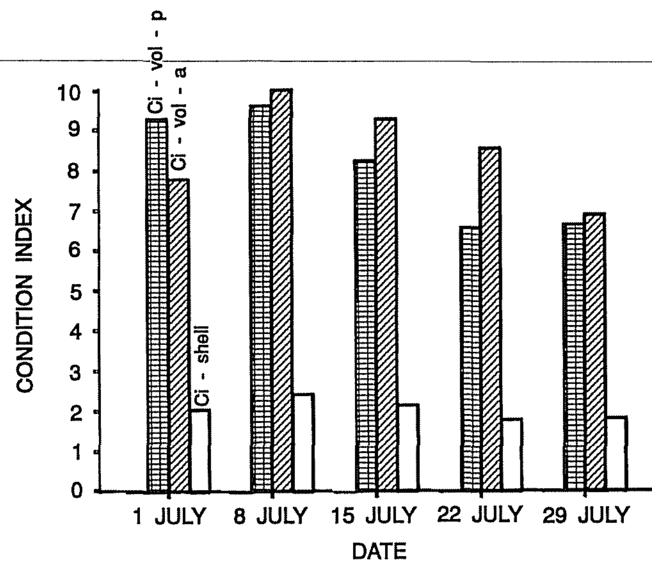

Figure 1. A comparison of mean condition index (of 25 animals) assessed as Ci-vol-p, Ci-vol-a and Ci-shell at weekly intervals during the period July 1–29, 1988.

In their recent review Crosby and Gale (1990) examine the following indices:

Ci-vol = dry soft tissue weight (g) × 1000/internal shell cavity vol (ml)

Ci-grav = dry soft tissue weight (g) × 1000/internal shell cavity capacity (g)

Ci-shell = dry soft tissue weight (g) × 1000/dry shell weight (g)

In their discussion Crosby and Gale (1990) state that Ci-shell "is an "absolute" index (as opposed to a relative index such as Ci-vol and Ci-grav) comparing metabolism directed towards calcification processes and metabolism focused towards somatic and gametic processes of glycogen storage, protein synthesis, and vitellogenesis. Ci-shell is not, then, an index of nutritive status and should not be used as an indicator of recent catabolic or anabolic activity within a bivalve." We disagree with this conclusion and suggest that all three have utility as indices of nutritive stress. The processes of glycogen storage and catabolism, protein synthesis and possible utilization in respiratory pathways with resultant ammonia excretion, and balance between somatic and gametic processes are all affected by short term stress and continually adjusted by anabolic and catabolic pathways (see Gabbott 1975). If condi-

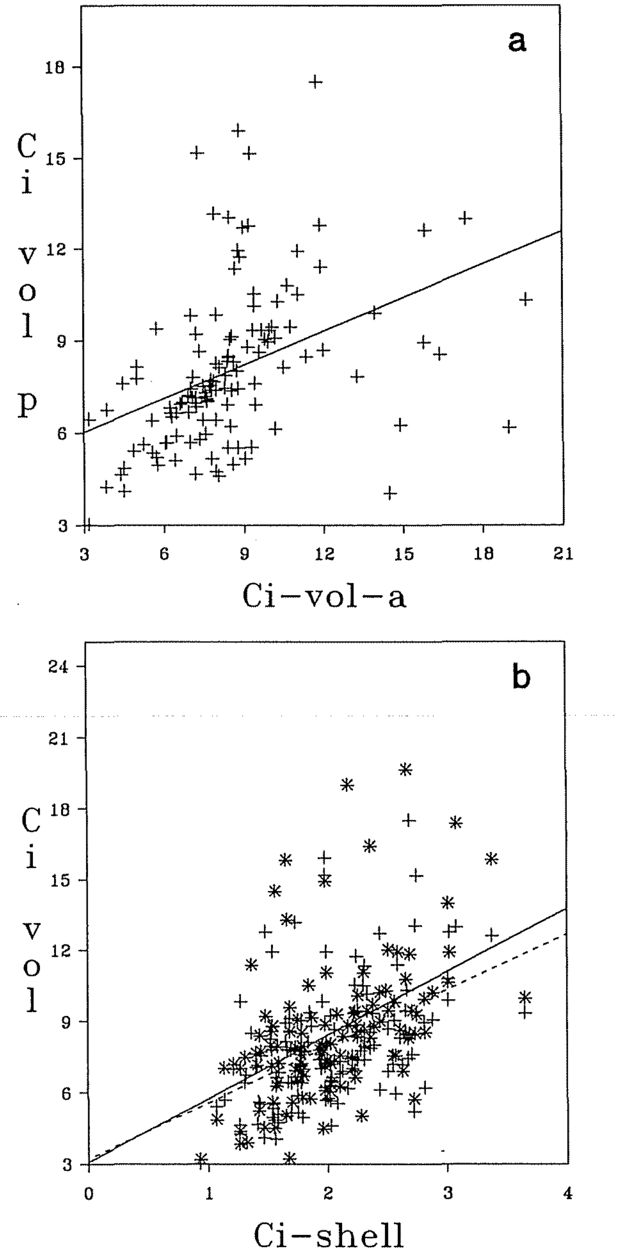

Figure 2. A comparison of (a) Ci-vol-p versus Ci-vol-a ($r^2 = 0.032$, p = 0.967), and (b), both Ci-vol-p versus Ci-shell (+, ——; $r^2 = 0.209$, p < 0.001) and Ci-vol-a versus Ci-shell (*, - - -; $r^2 = 0.000$, p = 0.850) as individual values obtained from 125 animals collected in equal groups of 25 at weekly intervals during the period July 1–29, 1988.

tion is defined as "the ability of an animal to withstand an adverse environmental stress, be this physical, chemical or biological" (Mann 1978), and stress as "a measurable alteration of a physiological, or behavioural, or biochemical, or cytological, steady-state which is induced by environmental change, and which renders the individual (or the population, or the community) more vulnerable to further environmental change" (Bayne 1975), then the obvious requirement of any "static" [sensu Lucas and Beninger (1985)] condition index ratio is to provide a stable denominator to compare with a sensitive numerator. In this instance shell weight is as useful as cavity volume. Both are considered to increase over time as the animals grows but are essentially immune from decreases in value, with the exception of possible minor weight loss due to abrasion or boring organisms.

If, in presenting a quantitative condition index, the intent is to examine short term stress effects or nutritive status then it would arguably be more appropriate to ignore indices based on tissue weight : shell cavity volume or tissue weight : shell weight ratios and use one of the biochemical indices reviewed in Mann (1978) or the one of the "dynamic" indices offered by Lucas and Beninger (1985). Mann (1978) discusses the use of percentage carbohydrate content [equivalent to the glycogen content as discussed by Ingle (1949), Walne (1970) and Gabbott and Stevenson (1974)], carbohydrate : nitrogen ratio (as an index of stored respiratory substrate compared to somatic tissue), carbon : nitrogen ratio (total organic content compared to somatic tissue) or percentage organic content. All of these biochemical indices have been used and compared to one or both of Ci-vol (dry meat weight : shell cavity volume) and Ci-shell (dry meat : dry shell) indices. Walne (1970) and Gabbott and Stevenson (1974) both report a good correlation in *Ostrea edulis* between the dry weight : shell cavity ratio (Ci-vol-p of this study, Ci-vol of Crosby and Gale, 1990) and a glycogen condition index calculated as [glycogen (g) / internal shell volume (ml)] (P < 0.01 and P < 0.001, respectively). Mann (1978, Table 1) compared dry meat : dry shell condition indices (Ci-shell of Crosby and Gale, 1990) with percentage carbohydrate, carbohydrate : N ratios and percentage organic content values for field populations of *Crassostrea gigas* (data of Matsumoto et al. 1934), *Ostrea edulis* (data of Walne and Mann 1975) and *Mytilus edulis* (data of Dare and Edwards 1975). In all but two instances highly significant (P < 0.001) positive relationships were observed, and significance values for the remaining plots were P < 0.01 and P < 0.02. Further, Table 2 of the same study compares four biochemical indices; percentage carbohydrate, carbohydrate : N ratio, C : N ratio, and percentage organic content to the same shell condition index for laboratory maintained populations of *Crassostrea gigas* and *Ostrea edulis* (data subsequently published in Mann 1979a) and *Tapes philippinarum* (Adams and Reeve) = *Tapes japonica* (data subsequently published in Mann 1979b) and in all instances found highly significant (P < 0.001) positive relationships. Lucas and Beninger (1985) expand this offering to include net growth efficiency, scope for growth, O:N ratio (oxygen consumption relative to nitrogen excretion) and relative maintenance cost).

Both Ci-vol and Ci-shell condition indices reflect biochemical or nutritive status, and generate a quantitative measure by comparing a sensitive numerator, dry meat weight, against a relatively stable demoninator, shell weight or volume measured in absolute units. Efforts to generate intercalibration factors between indices, especially cavity volume and shell weight based indices, within a single group of animals have been limited. The relationships illustrated in Figure 2 suggest that simple linear algorithms cannot be generated to intercalibrate shell and volume condition indices, although this may be a function of possible volumetric measuring error as mentioned earlier. Further, the aforementioned comments of Galtsoff (1964) underscore the problem of attempting to compare data collected by different investigators at different times and locations and strongly suggests possible age (and presumably size) dependency. Size, measured as length or volume, dependency was not observed in the present study for any of the three indices measured; however, size dependency in condition (Ci-vol-p of this study, Ci-vol of Crosby and Gale) was observed in oysters collected from Virginia estuaries by Austin, Haven and Mustafa (in review). Condition indices clearly have value for comparisons within data sets that have been consistently collected; however, comparisons with quantitative data of other authors and/or historical data sets collected by other investigators or methods may be limited to discussion of temporal trends rather than absolute values.

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