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The Determination and Use of Condition Index of Oysters[1]

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ABSTRACT: Oyster condition measures should be standardized through use of Hopkins' formula: Condition Index = (dry meat weight in g) (100)/(internal cavity volume in cm^3). Cavity volumes, previously measured chiefly as capacity by a water displacement method, may be determined by subtracting the weight in air of the oyster's valves from the weight in air of the intact oyster (both in g). This method is valid because the effective density of cavity contents is close to 1 g per cm^3. The technique is simple and time-efficient and could promote more widespread use of oyster condition studies.

Introduction

The condition of the American oyster, *Crassostrea virginica* (Gmelin), is often routinely analyzed to provide estimates of factors such as meat quality and yield. In addition, studies (including Galtsoff et al. 1947; Galtsoff and Arcisz 1954; Lowe et al. 1972; Cunningham and Tripp 1975; Frazier 1975, 1976) have shown that this oyster is affected by a variety of waterborne pollutants and recent work (Scott and Middaugh 1978; Scott and Vernberg 1979; Scott and Lawrence, 1982) has suggested that the condition of these oysters might be used to monitor this pollution.

Yet problems remain before the condition of oysters can be routinely used in widespread comparisions of oyster physiology, environmental effects, or other factors. One involves the choice of a measure of condition; various indices of condition have been proposed (for example Grave 1912; Hopkins 1949; Korringa 1955; Ruddy et al. 1975; Mann 1977; and others). Of the proposed measures, the most widely used ones are variations of the Condition Index of A. E. Hopkins (Higgins 1938). This Index is a ratio of dry meat weight to the internal cavity volume of the shell, and is a prime indicator of how well an oyster has utilized the volume available for tissue growth (Haven 1961). Standardized usage of this measure is necessary, if oyster conditions are to be comparable and hence beneficial in physiological and environmental studies.

A second problem involves the analysis of Condition Index components. Both dry and wet meat weights have been used with Hopkins' ratio. Baird (1958) found a high correlation between the wet weight and dry weight of mussel meats, and believed that little accuracy was gained by the use of dry meat weights in any index of condition. Yet wet meat weight clearly depends upon draining time, and osmoregulation can be a problem in stressed organisms. Thus we believe dry weights are to be preferred, following the original arguments of Hopkins (1949).

In addition, internal cavity volume may be assessed by various methods. Most commonly, it is measured as capacity (ml) using a water displacement method (for example Grave 1912; Baird 1958; Galtsoff

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1964). This method may be subject to manipulative error and water density changes (Andrews 1961) and can be time-consuming. An alternative method involves two sets of weighings and uses an application of Archimedes' Principle (Quayle 1950; Westley 1961). The living and closed oyster is weighed both in air and in water; the difference in weight equals total oyster volume. The weighings are repeated with the two valves, and subtraction of the two obtained volumes does yield cavity volume. This method has the same limitations as the above water displacement method. Andrews (1961) pointed out the earlier findings of Havinga (1928), namely that over 98% of the weight of live oysters, suspended in seawater, is contributed by the valves. Thus the effective density of oyster meats (plus liquor) is very close to the density of seawater. Havinga's weighing technique has largely been used to study short-term shell growth. Yet his data suggested to us that cavity volume could be determined by subtracting the weight of the valves in air from the total weight of the oyster in air, since there is approximately a 1:1 ratio between cavity volume and the weight of materials removed from the cavity. We have found this method to be at least as accurate as the aforementioned techniques, simple, and also the most time-efficient of those available for internal cavity volume determination.

A third problem concerns the interpretation of Condition Index measures. Many factors can affect the condition or physiological state of oysters (Haven 1961; Galtsoff 1964) and, to use condition as an indicator of any one factor including pollution, the effects of the other factors must be identified. Widespread and relatively large samples (Baird 1958) of oysters will be necessary in this work; once again realistic, accurate, yet time-efficient measurements would be beneficial.

Thus in this paper we (1) propose that Hopkins' Condition Index, (dry meat weight in g) (100)/(internal cavity volume in cm^3) be used as a standard measure of oysters' condition, (2) show that an extension of Havinga's findings—that the density of oyster meats plus liquors is approximately 1 g per cm^3 and that a weighing in air technique can thus yield cavity volume—is applicable to *Crassostrea virginica* from at least the southeastern United States, (3) indicate that this is an accurate and efficient method in Condition Index analysis, and (4) suggest that utilization of this technique could help to make oyster condition studies more useful in water quality analyses.

Materials and Methods

Our adult oysters (5.0–16.7 cm height) came from three unpolluted sites in South Carolina: Leadenwah Creek, a tributary of the North Edisto River Estuary (32°36'N, 80°15'W) in Charleston County, and Crab Haul and Bread and Butter Creeks, tributaries of the North Inlet Estuary (33°20'N, 79°10'W) in Georgetown County. North Inlet Estuary oysters were collected specifically for this study; Leadenwah Creek oysters served as undosed controls in studies of the effects upon oysters of chronic exposure to chlorinated waters.

Samples of 25 to 50 oysters were collected from the North Inlet area creeks on 18 February, 25 March, and 6 May in 1977, cleaned on site with all fouling organisms removed, and transported to the lab where Condition Index analyses began immediately after each sampling.

Oysters from Leadenwah Creek were collected on 3 January, 7 April, and 30 June in 1977 and immediately transported to the lab where they were likewise cleaned. These oysters were placed in lab aquaria and kept in running estuarine waters, with condition measured after 15 to 90 days.

For each of these oysters, internal cavity volume was determined by both water displacement and weighing in air techniques. In the water displacement method, we took care to minimize the sources of error stated by Westley (1961) and Andrews (1961) and modified the apparatus described by Galtsoff (1964). Capacities were measured in a 2000 ml cylinder with 20 ml graduated increments. A reference level was chosen, the intact oyster or its valves introduced, and the water returned to the reference level by pipetting (10 ml pipette with 0.1 ml increments; estimation to closest 0.05 ml). Cavity capacities, in ml, were determined by subtracting the two sets of measures for each oyster.

TABLE 1. Mean values and standard errors of the means for cavity volumes and Condition Indices of the North Inlet and Leadenwah Creek collections of *Crassostrea virginica*, using both the water displacement and weighing in air techniques for input, with accompanying statistical tests and sample sizes. All correlations very significant ($p < 0.001$).

Collection Time	As Volume (cm³) by Weighing in Air		As Capacity (ml) Water Displacement		*t*-test Value	Correlation Coefficient	*n*
	Mean	SE	Mean	SE			
			OYSTER CAVITY				
North Inlet Estuary							
Feb. 1977	13.35	0.52	13.41	0.59	−0.06	0.93	96
Mar. 1977	14.94	0.60	14.45	0.61	+0.57	0.97	91
May 1977	13.54	0.69	13.87	0.70	−0.34	0.97	50
Leadenwah Creek							
Jan. 1977	15.04	0.44	14.39	0.43	+1.06	0.97	80
Apr. 1977	14.05	0.46	13.57	0.46	+0.74	0.97	75
Jun. 1977	16.05	0.67	15.48	0.62	+0.47	0.98	60
			CONDITION INDEX				
North Inlet Estuary							
Feb. 1977	5.11	0.22	5.21	0.28	−0.28	0.84	96
Mar. 1977	4.64	0.23	4.86	0.27	−0.62	0.96	91
May 1977	4.74	0.23	4.54	0.25	+0.30	0.95	50
Leadenwah Creek							
Jan. 1977	6.12	0.19	6.45	0.21	−1.15	0.96	80
Apr. 1977	5.68	0.21	5.89	0.23	−0.68	0.97	75
Jun. 1977	4.09	0.14	4.25	0.15	−0.78	0.97	60

In the weighing technique, intact oyster shells were air dried at room temperature for 45-60 minutes and only oysters remaining tightly closed were analyzed; valve weights were determined after 24-30 hours of similar air drying. Cavity volume was obtained by subtracting the two weights, each to the nearest 0.01 g.

Oyster meats were oven dried to constant weight (68 °C for 48 hours) and then weighed (to nearest 0.01 g) after a 5–10 minute cooling period.

To reaffirm Havinga's method and show a 1:1 ratio between cavity volume and weight of cavity contents, a special set of Leadenwah Creek oysters was collected on 3 August in 1978. Oysters were cleaned and defouled at the lab and kept in aquaria for 24 hours. Then 25 tightly closed oysters were weighed under estuarine water, the oysters shucked with meats sacrificed, the two valves reweighed under water (each weighing to nearest 0.01 g), and the ratio between valve weight and weight of the entire oyster determined.

For both North Inlet Estuary and Leadenwah Creek Condition Index studies, data were grouped by both the date the meats were sacrificed and by original collection date; the latter formed our primary groupings—six sets of 50–96 measures (Table 1). Data were variously subjected to mean, standard deviation, and standard error of the mean determinations; *t*-tests, and linear regressions with goodness of fit determination, were performed on the two sets of cavity measures and resulting Condition Indices.

Results and Discussion

The valves of Leadenwah Creek *C. virginica* did comprise over 98% (mean 98.39%; range 97.05–99.35%; standard deviation 0.70%; $n = 25$) of the weight of these oysters, when measured in estuarine waters, and the density of cavity contents must have been very close to that of the waters.

The concomitant nearly 1:1 ratio between cavity volume and weight of cavity contents was affirmed by the very significant ($p < 0.001$) correlation coefficients for the linear regressions of the cavity measures on each other (Table 1). Our lowest r value (0.93) occurred in the February 1977 North Inlet sample (Fig. 1) and we sus-

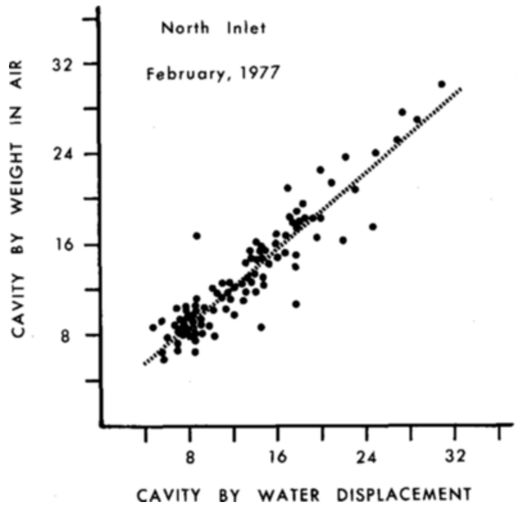

Fig. 1. Comparison of cavity capacity (in ml) by water displacement method with cavity volume (in cm^3) by weighing in air technique for North Inlet Estuary oysters collected in February of 1977. Correlation very significant ($r = 0.93$; $p < 0.001$). Additional discussion in text.

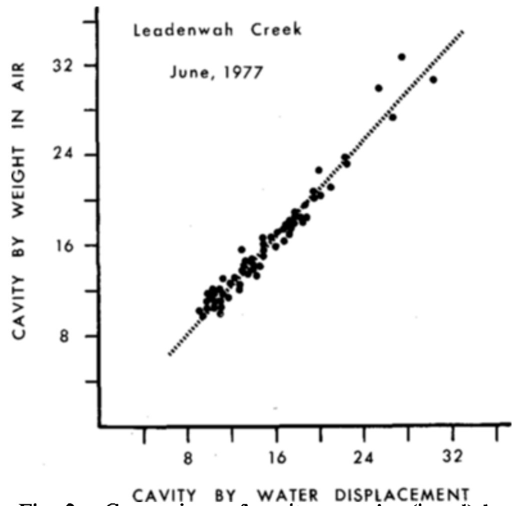

Fig. 2. Comparison of cavity capacity (in ml) by water displacement method with cavity volume (in cm^3) by weighing in air technique for Leadenwah Creek, North Edisto River Estuary oysters collected in June of 1977. Correlation very significant ($r = 0.98$; $p < 0.001$).

pected balance inaccuracies in this set of weighings. In subsequent determinations, we used the same standard 161.50 g mass to calibrate the several top-loading balances transported and used, and rechecked this calibration after each 25–50 weighings. Correlation was indeed higher ($r = 0.97$ to 0.98) in all of the later analyses (Fig. 2). There were no significant differences ($p < 0.001$) in mean Condition Indices calculated using the two sets of cavity measures as input (Table 1).

The two cavity measures did correspond in oysters showing a wide range of fatness (total Condition Index range 1.56 to 14.19). Our data, collected over the various seasons of the year, show that even physiological and seasonal factors such as gonadal tissue accumulation do not markedly affect the nearly 1:1 ratio between the volume of the cavity and the effective density of its contents. No seasonal adjustments in the method need to be made. The exact 1:1 ratio may be used in Condition Index studies, without adjustments for the density of seawater or other factors, so long as data compared have all been generated by the same technique. Potential errors introduced by this simplification are comparable to those of even elaborate water displacement equipment (see Baird 1958).

One distinct advantage of the weighing technique is its simplicity, since it uses but two stock pieces of lab equipment—a top-loading balance and a drying oven. Chances for manipulative error are still present but are, in our experience, less in the weighing method than in comparable techniques. The method avoids the air bubble problems mentioned by Westley (1961) and thus will be advantageous in the study of perforated oysters.

The reality of any oyster condition measure depends greatly upon the oysters used in the analysis; tightly closed shells must be chosen for drying since mass losses from the cavity must be avoided before the weighing of the entire oyster. We customarily select for drying at least 10% more than our desired number of individuals, to accommodate gaping and fluid losses during the drying process.

The variability in condition of an area's oysters is well-known and the use of large samples will produce average and comparable measures of condition. We expect any errors in the weighing technique to be adequately offset by samples of 50 individuals, which can be efficiently handled. Indeed, although we analyzed our oysters singly to establish the validity of the weighing technique, this latter technique is also compatible with batch lot determination of condition of oysters. As data accumulate and the condition differences between stressed and nonstressed oysters become clearer, smaller samples may be sufficient to detect any real differences caused by environmental factors. Smaller samples would increase the utility of oyster condition studies, which already show potential in environmental monitoring.

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