A Statistical Method for Evaluating the Reproducibility of Age Determination

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The coefficients of variation and the index of precision provide a statistical test of reproducibility of aging between readers. Because the coefficients of variation and the index of precision incorporate the averaged year-class of a fish species, they are free from the shortcoming of the percent agreement method. Because variance is a better estimator than absolute difference, the coefficient of variation is a stronger estimator than the index of average percent error in providing a test statistic.

Key words: age determination, coefficients of variation, index of precision, average percent error, percent agreement

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Les coefficients de variation et l'indice de précision permettent de vérifier statistiquement la reproductibilité des déterminations d'âge par des chercheurs différents. Comme ces deux paramètres incorporent la moyenne des classes d'âge d'une espèce de poissons, ils sont exempts des imperfections que l'on rencontre dans la méthode du pourcentage de lectures identiques. La variance étant un meilleur estimateur que la différence absolue, le coefficient de variation est supérieur à l'indice d'erreurs moyennes de pourcentage comme méthode de vérification statistique.

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METHODS to test the reproducibility of the results from scale reading to determine fish age are many. One of the common techniques to assess the precision of fish age estimated from scale readings is to compare the percentages of determination of age which are agreed upon by several readers (Kennedy 1970). However, this technique has a disadvantage because it fails to take into consideration the range of fish year-class as available to the fishery. Beamish and Fournier (1981) pointed out this problem and showed that if 95% of age determinations between two readers agree within ±1 yr for Pacific cod (*Gadus macrocephalus*), this can be very poor precision as most commercial samples are made up of fish within a narrow age range. On the other hand, if 95% of spiny dogfish (*Squalus acanthias*) age determinations agree within ±5 yr, this can represent good precision as dogfish may be as old as 60 yr with ~30 age-groups in a fishery. Nonetheless, this example involves a tacit assumption that the range of fish year-class available to the fishery increases in proportion to the average age of fish in the fishery, or, in other words, that the standard deviation is proportional to the mean. Beamish and Fournier (1981) proposed a method based on this assumption and incorporating the range of year-class into the computation of their index, which uses the average absolute deviation from the arithmetic mean age per fish expressed as a function of the arithmetic mean. This paper more explicitly suggests an alternative index which provides a statistical test of reproducibility of aging between readers.

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Methods — An average percent error (APE) in aging the jth fish is shown in Beamish and Fournier (1981) as

$$(1)\quad \frac{1}{R}\sum_{i=1}^{R}\frac{|X_{ij}-X_j|}{X_j}$$

where X_{ij} is the ith age determination of the jth fish, X_j is the average age calculated for the jth fish, and R is the number of times each is aged.

This paper suggests the use of a coefficient of variation (V) for testing the reproducibility of aging between readers. The coefficient of variation is the standard deviation as a fraction of the mean expressed as a percentage and may be obtained by replacing the average absolute deviation from the arithmetic mean age in equation (1) with the standard deviation. Because V is greater than APE by $\left(\frac{(\Sigma X_{ij}-X_j)^2}{R(R-1)}\right)^{1/2}\Big/X_j$, the estimates from V are always greater than those from APE by the same quantity. The percent error contributed by each observation to the average age-class may be estimated by an index of precision (D), which is V divided by $\sqrt{R}$ (Elliott 1977; Sokal and Rohlf 1969).

Standard methods for testing the variability of two readers in this situation include the use of the coefficient of variation, or the log transformation approach to the standard error of the mean (Zar 1974; Sokal and Rohlf 1969).

Results and Discussion — The advantages of the index of average percent error (APE) in determining the reproducibil-

TABLE 1. Example of a set of walleye pollock (*Theragra chalcogramma*) ages using the fin-ray method (Beamish and Fournier 1981).[a]

Fish No.	Reader 1						Reader 2					
	1st	2nd	3rd	APE	*V*	*D*	1st	2nd	3rd	APE	*V*	*D*
1	7	6	7	0.0667	0.0866	0.0501	6	5	6	0.0784	0.1019	0.0589
2	7	6	6	0.0717	0.0912	0.0527	6	5	6	0.0784	0.1019	0.0589
3	6	6	5	0.0784	0.1019	0.0589	5	4	6	0.1333	0.2000	0.1156
4	4	4	4	0.0	0.0	0.0	4	4	3	0.1212	0.1575	0.0910
5	4	5	6	0.1333	0.20	0.1156	6	5	5	0.0833	0.1083	0.0626
6	3	3	3	0.0	0.0	0.0	3	3	2	0.1667	0.2165	0.1251
7	5	5	5	0.0	0.0	0.0	5	4	5	0.0952	0.1237	0.0715
8	4	4	4	0.0	0.0	0.0	5	4	4	0.1026	0.1332	0.0770
9	4	4	4	0.0	0.0	0.0	4	3	3	0.1333	0.1732	0.1001
10	7	8	7	0.0606	0.0787	0.0455	6	5	7	0.1111	0.1667	0.0963
11	7	7	7	0.0	0.0	0.0	7	5	6	0.1111	0.1667	0.0963
12	3	2	3	0.1667	0.2165	0.1251	3	2	3	0.1667	0.2165	0.1251
13	5	5	5	0.0	0.0	0.0	5	4	4	0.1026	0.1332	0.0770
14	4	4	4	0.0	0.0	0.0	5	2	4	0.3030	0.4166	0.2408
15	6	6	4	0.1667	0.2165	0.1251	6	4	5	0.1333	0.2000	0.1156
16	7	7	7	0.0	0.0	0.0	5	6	5	0.0833	0.1083	0.0626
17	6	6	5	0.0784	0.1019	0.0589	5	5	5	0.0	0.0	0.0
18	7	7	7	0.0	0.0	0.0	7	6	6	0.0702	0.0912	0.0527
19	8	7	7	0.0606	0.0787	0.0455	7	5	5	0.1569	0.2038	0.1178
20	5	5	5	0.0	0.0	0.0	5	4	5	0.0952	0.1237	0.0715
$\bar{x}$				0.0441	0.0586	0.0339				0.1163	0.1571	0.0983

[a]Where APE is the average percent error using the index of Beamish and Fournier; *V* is the coefficient of variation; and *D* is an index of precision.

TABLE 2. The frequencies with which the age assigned by the first reader differed from that assigned by the second reader using the set of data presented in Table 1.

Age difference	No.
−3	0
−2	1
−1	4
0	23
+1	23
+2	8
+3	1
Percent agreement in the age assigned within ±1 yr	83.3
Percent agreement in the age assigned within ±2 yr	98.3

ity of age determination is shared by the coefficients of variation (*V*) and the index of precision (*D*). These indices agree closely, particularly between APE and *D* (Table 1). Reader 1 has a greater precision in APE than Reader 2; the same relationship is shown in the averaged values of the coefficients of variation and in the index of precision between these readers. Because the coefficients of variation and the index of precision are indices which incorporate the averaged year-class of fish, they are free from the disadvantage of a percent agreement technique. In Table 2, for example, one can see that using the same set of data presented in Table 1, the percent agreement technique shows considerable precision between two readers in the age determination; 83% agreed within 1 yr and 98% within 2 yr. However, if one uses the coefficient of variation, an index of precision, and the index of average percent error (Table 1), the difference between two readers is remarkable.

There are additional benefits in using the coefficients of variation and the index of precision in the examination of reproducibility of age determination. First, variance is a better estimator than absolute difference as it is an unbiased and consistent estimator, the mean and variance of which converge as sample size increases; the coefficient of variation for all practical purposes shares this property (Simpson et al. 1960). Second, the index of precision (D_j) can be used to show the percent error contributed by each observation to the averaged age determination for the *j*th fish; if one multiplies the index of precision (D_j) by the averaged age for the *j*th fish, the result is the error in age determination made for each observation.

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Nutrient Distributions and Their Relationships to Water Masses in Baffin Bay

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We report measurements of phosphate, nitrate, and silicate concentrations in Baffin Bay and relate them to water masses identified by salinity and temperature. Our results illustrate the remarkable homogeneity of the water structure throughout Baffin Bay and show that nutrient concentrations can be used to label water masses in the Baffin Bay deep layer with similar resolution to that provided by salinity and temperature.

Key words: phosphates, nitrates, silicates, Baffin Bay, water masses, nutrient concentrations

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On présente ici le résultat de dosages de phosphates, nitrates et silicates dans la baie Baffin et on établit la relation entre ces derniers et les masses d'eau telles qu'identifiées par la salinité et la température. Nos resultats démontrent bien la remarquable homogénéité de la structure de l'eau dans toute la baie. Ils indiquent également que les concentrations de nutriments peuvent servir à identifier les masses d'eau de la couche profonde avec une résolution semblable à celle que fournissent la salinité et la température.

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PHOSPHATE, nitrate, and silicate concentrations have been measured throughout Baffin Bay. Previously reported results from the Canadian Archipelago showed that these nutrients were able to distinguish between water masses flowing into Baffin Bay that would not otherwise have been easy to identify from salinity and temperature measurements alone (Jones and Coote 1980; Codispoti 1979; Codispoti and Owens 1975). Our aim in this paper is to describe the distribution of nutrients in Baffin Bay and to relate nutrient concentrations to the water masses found there.

Some previous nutrient measurements have been reported for Baffin Bay. These were made at several stations in the Northwater region, south of Smith Sound, and at a few stations in the south central region (McGill and Corwin 1964; Corwin and McGill 1963). These earlier measurements, however, are not complete enough or, for phosphate and nitrate concentrations, precise enough for a reasonable characterization of the water in Baffin Bay.

Methods — Samples for nutrient measurements were collected during the summer season (August and September, 1977) at several locations in Baffin Bay (Fig. 1). They were analyzed within a few hours of collection using standard methods (Strickland and Parsons 1968) with an AutoAnalyzer II. Sampling error was monitored by analyzing duplicate samples for about 1-in-10 samples. Analytical precision was ±0.4 μg-at./L for nitrate and silicate concentrations and ±0.02 μg-at./L for phosphate concentrations. Accuracy was monitored with CSK standards and is believed to be within twice this range. Salinity and temperature values were measured using a Guildline Mk. III analogue CTD system (salinity precision ≈0.01‰, temperature precision ≈0.01°C). Temperatures were also measured at selected depths using both protected and unprotected reversing thermometers. Salinity values were determined for all samples using a Guildline Autosal model 8400 salinometer (salinity precision ≈0.002‰).

Results and discussion — Our results are illustrated by three section plots: northern Baffin Bay, central Baffin Bay, and Davis Strait (Fig. 2). Near-surface features, above about 25 m, are omitted in these figures. Where they can be compared, our silicate concentrations are within about 2% of the earlier results (Corwin and McGill 1963; McGill and Corwin 1964). Our nitrate concentrations tend to be slightly lower and both our nitrate and phosphate concentrations show less scatter when plotted against salinity. The reduced scatter is probably due to using more modern analytical techniques and to analyzing the samples soon after collection instead of preserving them for much later analysis in the laboratory.

To consider the relationship of nutrient concentrations to the water masses in Baffin Bay, we first summarize the physical oceanography of Baffin Bay (Coachman and Aagaard 1974; Muench 1971). Water flows into Baffin Bay from the Arctic Ocean through Lancaster and Jones Sounds over sills of about 150 m and through Nares Strait (at Smith Sound)

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