NOTES

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

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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

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Great Lakes Research Division, The University Chang, W. Y. B. 1982. A statistical met determination. Can. J. Fish. Aquat The coefficients of variation and the interproducibility of aging between readers. Becof precision incorporate the averaged year-case shortcoming of the percent agreement method absolute difference, the coefficient of variat average percent error in providing a test station of the coefficient of variat average percent error in providing a test station of the coefficients of the coef tion 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

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of reproducibility of aging between readers.

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

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

where X_{ij} is the *i*th age determination of the *j*th fish, X_i is the average age calculated for the *i*th 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 $\left(\frac{(\sum X_{ij} - X_j)^2}{R(R - 1)}\right)^{1/2} X_j$, 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 reproducibilNOTES 1209

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

Fish	Reader 1						Reader 2					
No.	1st	2nd	3rd	APE	V	D	lst	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
\overline{X}				0.0441	0.0586	0.0339				0.1163	0.1571	0.098
	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.						percent agreement technique shows considerable probetween two readers in the age determination; 83% within 1 yr and 98% within 2 yr. However, if one accoefficient of variation, an index of precision, and the of average percent error (Table 1), the difference between					
	reader usi		ssigned l	by the secon	ıd	wit coe of a	ween two nin 1 yr fficient o verage po	reade and 98 f varia ercent e	rs in t % with tion, a error (T	he age de nin 2 yr. I n index of	terminatio However, precision	n; 83% if one u , and the
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Age difference	No.
-3	0
-2	1
-1	4
0	23
+ 1	23
+2	8
+3	I
Percent agreement in the age	
assigned within ±1 yr	83.3
Percent agreement in the age	
assigned within ±2 yr	98.3

 \rightarrow ation (V) and the index of precision (D). These indices agree Sclosely, particularly between APE and D (Table 1). Reader Of 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 yearclass 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_i) can be used to show the percent error contributed by each observation to the averaged age determination for the jth fish; if one multiplies the index of precision (D_i) by the averaged age for the *i*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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±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 sys-

tem (salinity precision ≈0.01%, temperature precision

≈0.01°C). Temperatures were also measured at selected

depths using both protected and unprotected reversing ther-

mometers. Salinity values were determined for all samples

using a Guildline Autosal model 8400 salinometer (salinity

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 com-

pared, 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 scat-

ter when plotted against salinity. The reduced scatter is proba-

bly due to using more modern analytical techniques and to

analyzing the samples soon after collection instead of pre-

serving them for much later analysis in the laboratory.

precision $\approx 0.002\%$).

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.

lected 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

Methods — Samples for nutrient measurements were col-±0.4 μg-at./L for nitrate and silicate concentrations and

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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