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Maturity at Age from Length Stratified Sampling

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Much of the research sampling of age composition in commercial fish species is stratified on the basis of length, with a fixed number of samples taken from each a priori length class. For most fish species, a given age can straddle several length classes. Further, the probability of being mature at a given age is influenced by length at that age. This can result in biases in the estimation of proportion mature at age if catch at length is not taken into account. We present a method to correct for the bias in maturity at age from a length stratified sampling scheme and apply it to cod and American plaice in the Northwest Atlantic. In general, the differences between the corrected and uncorrected estimates were small, but some comparisons showed substantial differences.

INTRODUCTION

The ability to accurately determine age at maturity is important to the study and management of commercially exploited fish species. While spawning stock biomass can be estimated using a knife edge estimate of maturity (eg. assuming all 7+ fish are mature), and biomass at age estimates, use of the estimated proportion mature at each age will produce a more accurate estimate of the biomass of spawning fish. The ability to track changes in spawning stock biomass can be crucial to monitoring the health of stocks. Also, there are often changes in the age at maturity with changing population size (eg. Beacham, 1983; Pitt, 1975; Templeman et al. 1978; Shelton and Armstrong, 1983). These changes will be more reliably detected if one has an unbiased estimate of the proportion mature at each age.

Many sampling programs for collecting an age sample from fish populations are designed on the basis of length stratification, with a fixed number of samples being taken from each a priori length group. The age of the sampled fish is then determined later. Maturity at age estimates determined from samples collected in this way are subject to errors if the number of fish in each length group is not taken into account. When an age straddles several length classes the probability of being mature can increase with length and therefore, one must account for the catch at length and the distribution of age across length.

In this paper we show that maturity at age is affected by length at age in two important commercial species in the Northwest

Atlantic, the American plaice (*Hippoglossoides platessoides*) and the Atlantic cod (*Gadus morhua*). Maturity at age in both these species is sampled using a length stratified scheme. We present a method to estimate the proportion mature at age from this sampling regime by weighting the observations from each length group by the abundance of the length category. We then compare the results to those obtained without accounting for length composition in these species.

MATERIALS AND METHODS

The data examined were collected during spring multispecies groundfish surveys conducted by the Canadian Department of Fisheries and Oceans. The surveys are conducted annually from April to June in NAFO Division 3L on the northern Grand Bank off Newfoundland, using an otter trawl with a fine mesh liner in the cod end. In the surveys, a depth stratified design was used where sets in the depth strata were chosen at random, with the number of sets being approximately proportional to the stratum area (Doubleday, 1981). For American plaice, data from the spring surveys from 1971-1992 were used and for cod the data came from the spring surveys in the years 1978-1992. For both species, otoliths were collected for ageing using a length stratified scheme. For cod, 25 samples are collected from each 3 cm length class. For American plaice, a fixed number of fish are sampled for each 2 cm length class. The fixed number varies with the size of fish, with fewer fish sampled at the smallest and largest lengths. In all surveys an attempt was made to spread the sampling throughout the entire NAFO Division. Maturity stages were determined at sea according to the scheme of Templeman et al. (1978). In this scheme there are 7 main maturity stages for males and 9 for females. The first stage for each sex refers to immature fish and all other stages show some evidence of maturing to spawn in the present year or of having spawned and are classed as mature. During these surveys, length frequency data were collected from every successful fishing set to provide an estimate of the length distribution of the populations.

Currently the proportion mature at age is calculated using only data from the aged sample, dividing the number of mature fish at an age by the number of fish at that age.

$$Proportion\ mature\ at\ age_a = \frac{\sum_{j=1}^{n} P(a|j)\ P(m|a,j)}{\sum_{j=1}^{n} P(a|j)} \qquad (1)$$

where: $P(a|j)$ = probability of age a given length j
$P(m|a,j)$ = probability of being mature given age a and length j
n = number of length classes

For each species, the proportion of mature fish at each age and sex in each year was calculated using the fish from the aged sample as shown above. Also, the proportion mature at each length class for each age was also calculated for each sex in each year (ie. no summation across length class). The effect of length class on the proportion mature at age was examined using a Kruskal-Wallis test.

The data from the aged sample and from the length frequency sample were combined to correct for the effect of the length stratification scheme. This estimator weights the observations from each length category by the abundance of the length category.

$$\textit{Proportion mature at age}_a = \frac{\sum_{j=1}^{n} C_j \, P(a|j) \, P(m|a,j)}{\sum_{j=1}^{n} C_j \, P(a|j)} \tag{2}$$

where: C_j = number caught at length j
$P(a|j)$ = probability of age a given length j
$P(m|a,j)$ = probability of being mature given age a and length j
n = number of length classes

The denominator is simply the number of fish at age a while the numerator is the number of mature fish at age a.

The number at length (C_j) was produced from research vessel survey length frequencies using Stratified Analysis Programs (STRAP) (Smith and Somerton, 1981) which weight the catch in a stratum by the size of the stratum.

The difference between the estimates obtained from weighting by the abundance of each length category (weighted estimates, equation 2) and the estimates of percentage mature at age from the unweighted method (equation 1) was calculated by subtracting the weighted from the unweighted estimate for each age in each year. Age at 50% maturity was produced for each species, for each sex and year, using probit analysis assuming a normal distribution. This was done for both the weighted and unweighted estimates.

RESULTS

For both cod and American plaice there was an effect of length on the proportion mature at age, with the probability of a fish being mature at a given age increasing with increasing length. As an example, results for age 9 American plaice are presented in Figure 1 and for age 6 cod in Figure 2. The effect of length on proportion mature was statistically significant (age 9 plaice male: ^{2}=43.14, df=15, p<0.0001; age 9 plaice female: ^{2}=84.08, df=13, p<0.0001; age 6 cod male: ^{2}=33.67, df=15, p<0.005; age 6 cod female: ^{2}=45.93, df=12, p<0.0001).

When the weighted percent mature at age calculated using equation 2 was compared to the unweighted percent mature at age where length was not taken into account (equation 1), all ages for which the fish were neither all mature nor all immature showed a difference between the two estimates. This was true in all years. The differences were sometimes negative and sometimes positive and for a given age they varied from year to year both in magnitude and direction of the difference. However, for both sexes of both species approximately one-third of the differences were less than 1%.

For male American plaice (Figure 3, top), 26.2% of the comparisons had a difference of less than 1%. There was a difference of greater than 5% in 28.9% of the comparisons and the largest difference was 49.3%. For American plaice females (Figure 3, bottom), 32.7% of the comparisons differed by less than 1%. 15.7% of the comparisons differed by more than 5% and the largest difference between unweighted and weighted estimates was 25.7%.

For male cod (Figure 4, top), 27.6% of the comparisons differed by less than 1%, 16.2% differed by more than 5% and the largest difference was 16.2%. For female cod (Figure 4, bottom), 29.5% of the comparisons differed by less than 1% with 22.8% differing by more than 5% and the largest difference being 15.0%.

For both species, there were only small differences (less than one year) in the estimates of age at 50% maturity from the two methods (Table 1 & 2). The magnitude of the differences between the two estimates was not consistent over years nor was the direction of the difference consistent.

DISCUSSION

For both cod and American plaice the probability of being mature at a given age increased with size. This means that estimates of maturity at age based on a length stratified sampling scheme will be biased if the distribution of size at age is not accounted for properly. This potential bias can be easily weighted for as presented here, accounting for the effect of length on the probability of being mature at a given age, the distribution of a given age across length classes, and the length frequency of the population.

The differences between the weighted and unweighted estimates of the percent mature at age were generally small. However, there was a difference for all ages where the fish were neither all mature nor all immature. Also, some large differences did occur, up to 49% for male American plaice. The differences were not consistent in magnitude or direction across ages, or for a given age across years. Therefore, a constant empirical correction factor can not be applied.

There was also little difference in the estimate of age at 50% maturity between the two methods. However, even a small difference in the age at maturity can be have a significant impact on the estimation of expected yield of a fishery (Welch and Foucher, 1988). Again the magnitude and direction of the differences were not consistent, precluding the application of a constant empirical correction factor.

Although differences in the weighted and unweighted estimates were generally small, the method presented is simple to apply. It will result in a more accurate estimate of proportion mature at age.

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Table 1. Estimates of age at 50% maturity in American plaice using weighted and unweighted estimates of proportion mature at age.

Year	Males		Females	
	Weighted	Unweighted	Weighted	Unweighted
1971	6.15	6.41	10.61	10.52
1972	5.90	6.14	10.93	10.83
1973	5.53	5.47	9.81	9.78
1974	5.67	6.29	11.09	10.82
1975	6.88	7.23	11.61	10.79
1976	6.46	6.78	10.99	10.68
1977	6.35	6.69	11.17	10.93
1978	5.51	5.72	10.15	9.79
1979	6.10	6.25	10.00	9.68
1980	6.54	6.78	10.73	10.56
1981	6.25	6.62	9.85	9.68
1982	6.70	7.34	10.42	10.29
1984	5.06	5.38	8.50	8.59
1985	4.86	5.44	8.40	8.47
1986	5.01	5.63	8.43	8.53
1987	5.62	5.95	7.99	8.03
1988	3.76	4.52	7.78	7.89
1989	3.98	4.96	7.92	7.90
1990	4.47	4.78	7.74	7.75
1991	4.73	5.46	8.71	8.64
1992	4.03	4.73	7.95	7.92

Table 2. Estimates of age at 50% maturity for cod using weighted and unweighted estimates of proportion mature at age.

Year	Males		Females	
	Weighted	Unweighted	Weighted	Unweighted
1978	5.10	5.04	6.07	6.05
1979	4.82	4.85	5.91	5.59
1980	5.00	4.96	5.63	5.58
1981	5.02	5.08	5.64	5.61
1982	4.74	4.63	5.42	5.35
1985	5.18	5.10	6.21	6.11
1986	5.04	5.01	6.04	5.88
1987	5.22	5.29	5.98	6.00
1988	4.78	4.96	5.93	5.93
1989	5.74	5.70	6.00	6.00
1990	5.03	4.98	5.27	5.25
1991	5.48	5.35	6.07	5.89
1992	4.06	4.24	5.08	4.93

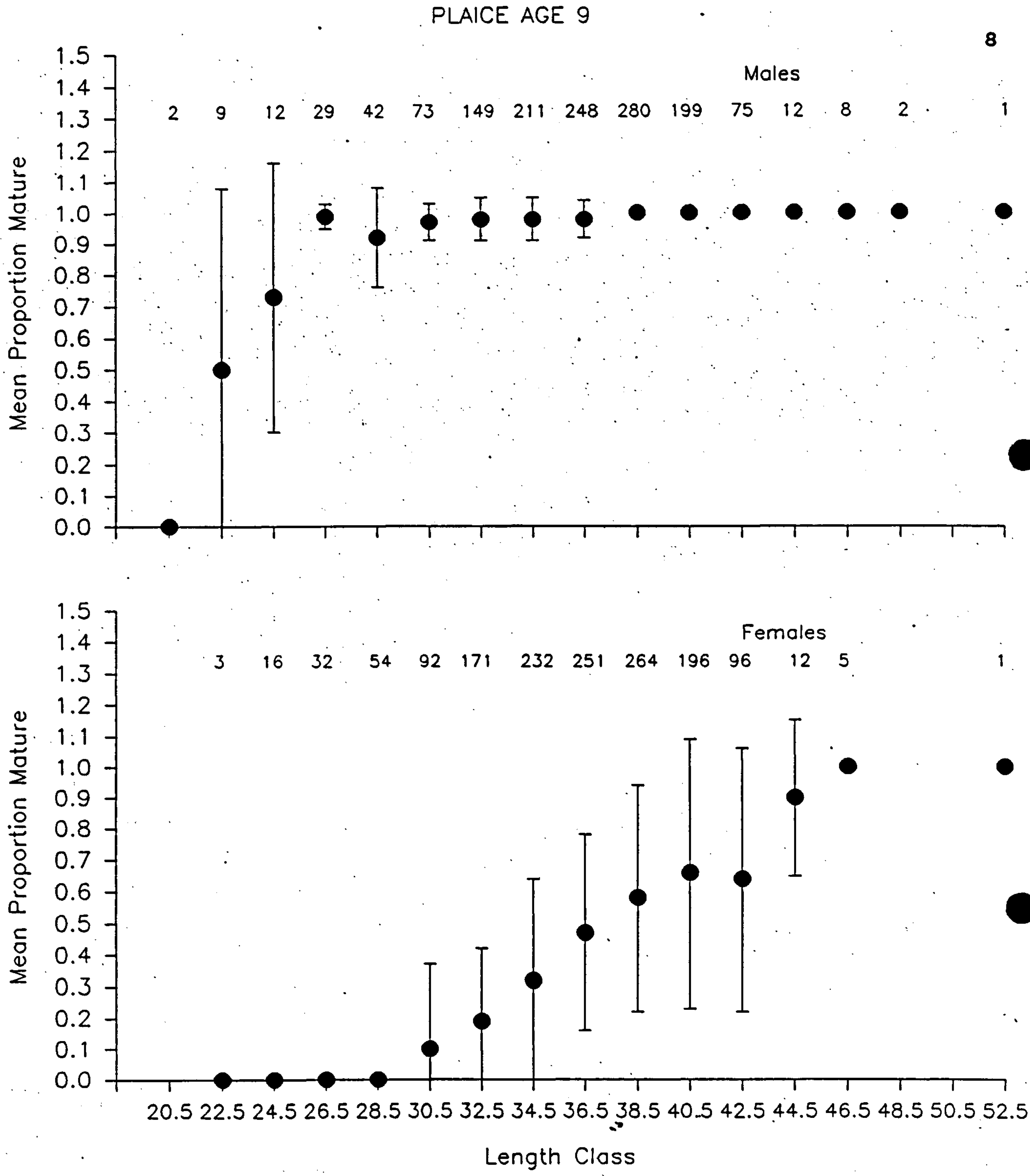

Figure 1. Mean (+ 1 Std. dev.) proportion mature for age 9 American plaice males and females at each length class. The means are over the years 1971 to 1992. The numbers above the points are the number of fish examined.

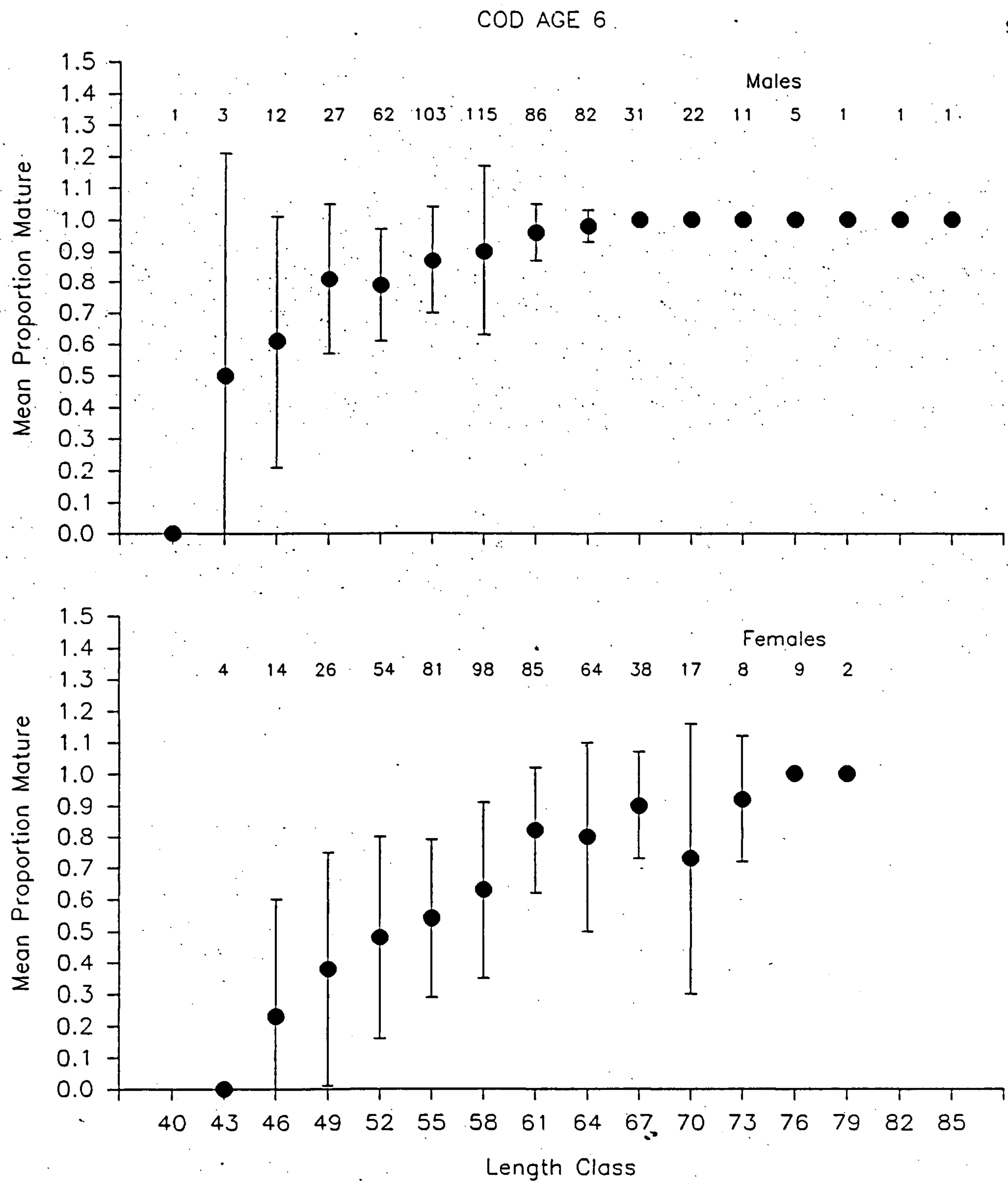

Figure 2. Mean (+ 1 Std. dev.) proportion mature for age 6 cod males and females at each length class. The means are over the years 1978 to 1992. The numbers above the points are the number of fish examined.

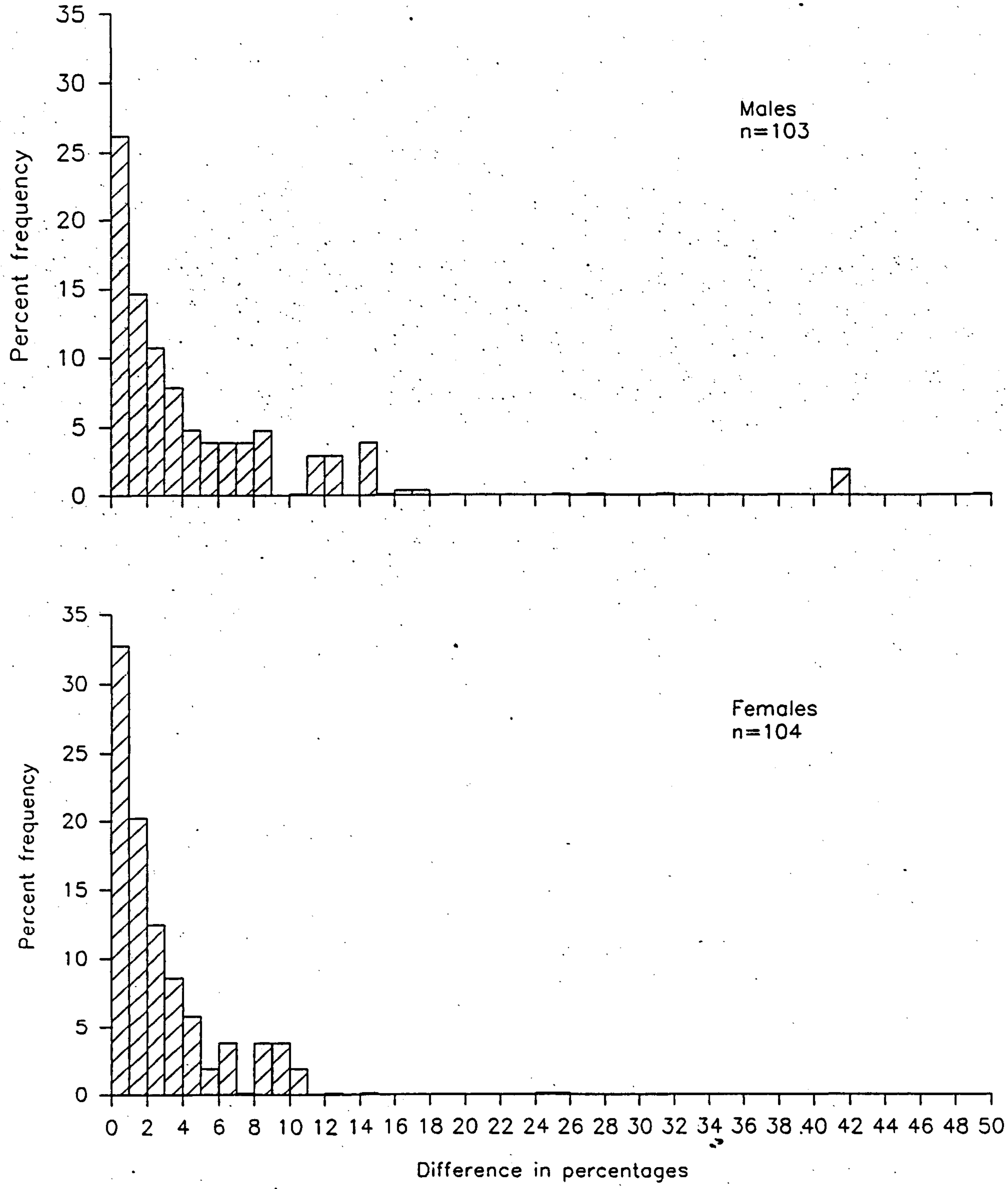

Figure 3. Percent frequency of occurrence of difference between weighted and unweighted percentage mature at each age in each year for male and female American plaice. n = total number of age X year combinations compared.

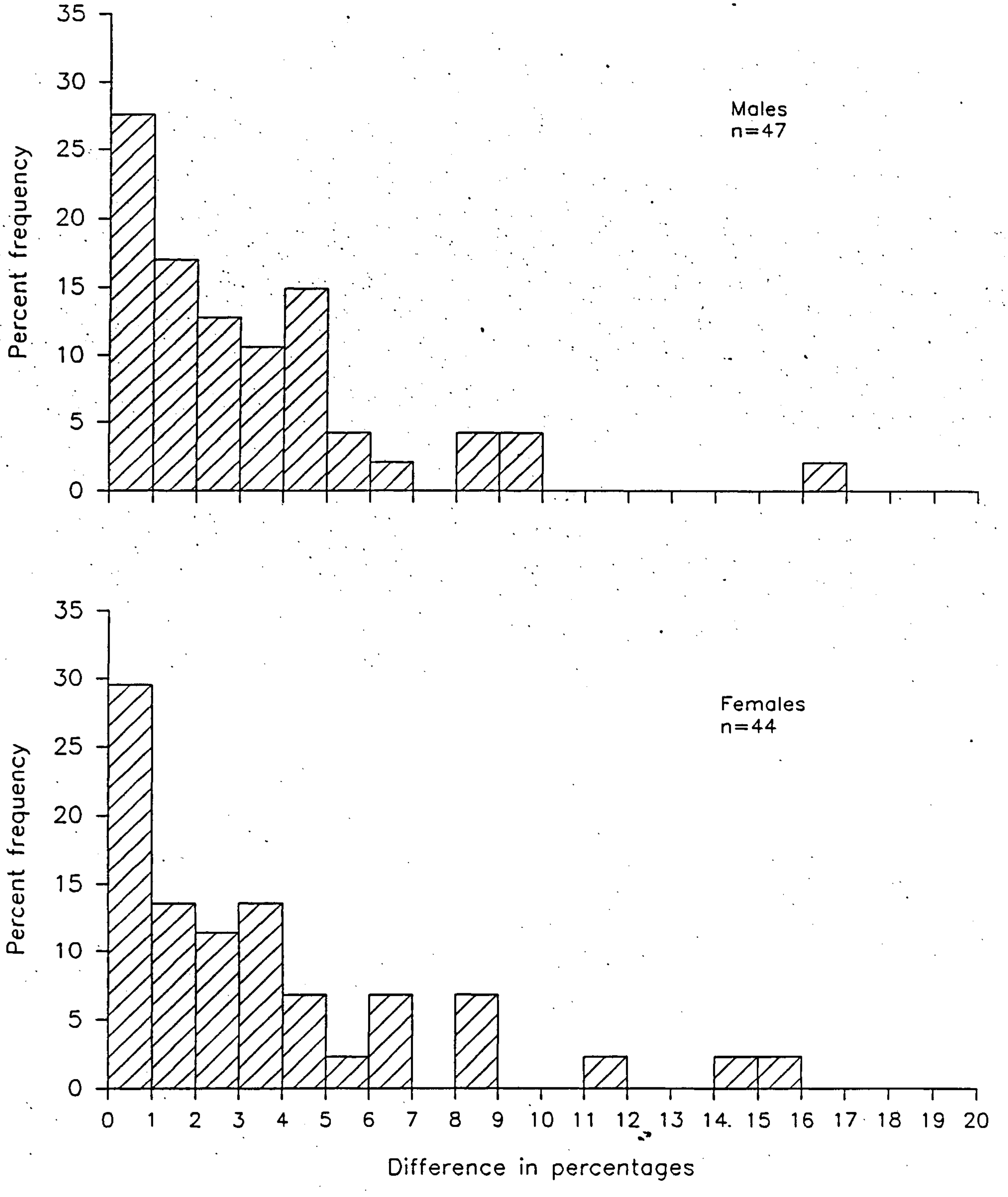

Figure 4. Percent frequency of occurrence of difference between weighted and unweighted percentage mature at each age in each year for male and female cod. n = total number of age X year combinations compared.