A Comparison of Two Stratification Schemes Used in Sampling Canadian Atlantic Cod, *Gadus morhua*

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ABSTRACT—Sampling is a key element in the assessment of any fish stock. It is often one of the most expensive activities of the management process; thus, improved efficiency can result in significant cost savings. In most cases a two-phase sampling strategy is employed. Two commonly used versions of such stratified random schemes were simulated using a test population based on Atlantic cod, Gadus morhua. *A 1 otolith per 1 cm length frequency currently used for many flatfish and some smaller gadoids and a 3 otolith per 3 cm length frequency currently used for many of the larger gadoids. No difference was detected in the age composition or mean length at age for either scheme; however, 10 percent fewer otoliths were collected in 1 for 1 sampling than 3 for 3. There was an improvement of between 30 and 60 percent in the coefficient of variation of the estimated catch numbers at age using the 1 for 1 compared with the 3 for 3 stratified sampling. For these reasons and other operational considerations, the 1 for 1 stratified random design of sampling appears to be superior.*

Introduction

Management of commercial fisheries depends upon accurate catch statistics and representative sampling—preferably of the "catch" by sea sampling but often confined to "landings" by port sampling. Beckett (1983), in his review of sampling standards in the Canadian northwest Atlantic, indicated the importance placed on this subject by the International Commission for the Northwest Atlantic Fisheries (ICNAF). ICNAF set minimum sampling guidelines as "one sample per 1,000 tonnes of fish caught for each division, quarter of year, and gear. As an approximate guideline, such samples should consist of 200 fish from the entire length range for length composition and one fish per centimeter length group for age composition" (Anonymous, 1974:70–71). The interpretation of the expression ". . .per centimeter length group. . ." is considered to be 1, 2, or 3 cm length groups depending on species (Hodder[1]).

Commercial sampling by Canada's Department of Fisheries and Oceans (DFO) along Canada's Atlantic coast has traditionally been conducted as a two-phase stratified process for the estimation of age composition. The first sample is a random length frequency and the second sample is a stratified sub-sample of otoliths taken from this length frequency. This sampling scheme was meant to collect otoliths, for age determination, from all length ranges of fish. At the same time the expense involved in determining ages from these sampled fish was to be minimized. As age and length are correlated, the most efficient method of sampling the unknown variable age is by stratifying by the known variable length. In addition, as other biological data were also being collected, it was felt that stratified schemes were more appropriate than random sub-sampling, despite the fact that random sub-sampling may provide greater precision in age at length keys (Kimura, 1977).

Three groupings have been used for various demersal fish species. These are 1 for 1 (1 otolith randomly collected for each centimeter interval observed in the length frequency of the sample) applied to the American plaice, *Hippoglossoides platessoides*; redfish, *Sebastes* sp.; silver hake, *Merluccius* sp., and other small fishes; 2 for 2 applied to haddock, *Melanogrammus aeglefinus*, only; and 3 for 3 applied to Atlantic cod, *Gadus morhua*, white hake, *Urophycis tenuis*, and other long fishes (Anonymous, 1974:128). The length frequency is recorded in 1 cm intervals by the port sampler who then transcribes the frequency into appropriate intervals for each species. Part of the logic in determining length grouping was the total number of intervals that could be keypunched on an 80-column data card. This was considered acceptable as the larger fish are generally thought to grow faster and thus show less variation in age within a 3 cm interval than smaller fish.

Powles (1983) outlined the sampling programs proposed for the Gulf (of St. Lawrence) Region of the DFO. In his plan he tried to optimize the human and financial resources required to obtain the best coverage of the diverse fisheries of this region. He did not carry his proposals down to the detail of stratification schemes for the collection of aging materials from the length-frequency samples. The Gulf region has since attempted to standardize the sampling for all species of demersal and pelagic finfish. One means of doing this is to sample otoliths and record length frequency data with a 1 for 1 stratification scheme on research cruises and in commercial sampling. An immediate

[1]Hodder, V. 1986. Assistant Executive Secretary, North Atlantic Fisheries Organization, Bedford Institute of Oceanography, Dartmouth, Nova Scotia, Canada. Personal commun.

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advantage of this is the reduction in errors due to transcribing the length frequency data obtained from the port sampler and the research survey. The data can be keypunched as recorded (1 for 1) rather than being pooled into larger groupings and transcribed, with the accompanying loss of precision, before keypunching.

This study attempts to identify what differences, if any, may arise from the different sampling stratification schemes. If there is no difference, then standardization of the length groupings for various demersal species could be considered.

Methods

During a survey on the research vessel *E. E. Prince* in September 1978, a total of 1,497 otolith pairs were collected from Atlantic cod. These observations of length and age were taken as the starting population from which simulated samples were drawn. The otoliths from this cruise were collected using a 3 for 3 stratification scheme and so are not to be taken as representing the "true" cod population in the southern Gulf of St. Lawrence in 1978. They are only a convenient sample starting "population" of lengths and ages upon which to simulate the effects of the two stratification schemes. To test the effect of sampling from small vs. large "populations" and to remove the necessity of applying the finite population correction (Cochran, 1977), a second data set comprising 10,186 observations was also used. These data were collected using the same sampling protocols from six research surveys conducted in September of each year between 1975 and 1981. Some confounding may occur in such a comparison as the larger multiyear data set will have additional variation caused by year-to-year population and growth differences.

From these samples of Atlantic cod ages and lengths, arranged in order of capture, random sub-samples of 200 fish were taken (with replacement for the small data set; without replacement for the large data set). In all simulated samples some data were lost as either no length was recorded or the otoliths were unreadable. Thus only 95–99 percent of possible fish were actually included in the sample.

The sample length frequency was made up of all fish with valid length data. The observations with valid ages were selected for catch at age calculations in two ways: 1) A 1 for 1 and 2) a 3 for 3 stratification scheme.

Data were randomly selected from the starting population and used to construct the length frequency. Two tests were then applied to the data to determine in which age-at-length key(s), if any, the data would be used. If no other fish of that cm length had been sampled, the corresponding age of the sampled fish was entered into the age length key for 1 for 1 sampling. If 2 or fewer fish had been sampled in the particular 3 cm length span in which the fish occurred, the age was entered into the age length key for 3 for 3 sampling. After 3 entries were made in a particular 3 cm length interval, no further age data were recorded in that interval. Thus a fish with valid data would end up recorded in the length frequency and in one, two, or none of the age length keys.

Two estimates of catch at age were calculated by individually applying the 1 cm age-at-length key and the 3 cm key to the length frequency, in the latter case, to a length frequency aggregated to 3 cm intervals.

The two-tailed Kolmogorov-Smirnov (K-S) test (Meddis, 1975) was used to test the null hypothesis that the sub-samples came from the same overall population and have the same distribution characteristics. The percentage age composition and the mean length at age were the parameters tested for the above hypothesis. This was based on the assumption that mean lengths represent the cumulative growth by length over the first 10 years of life and that there should be no differences in the age composition from the two sampling schemes. The above test was run using a microcomputer statistical package[2] (NWA, 1984).

[2]North West Analytical STATPAK, Portland, Oreg. Mention of trade names or commercial products does not imply endorsement by DFO, Canada, or the National Marine Fisheries Service, NOAA.

Table 1.—Sampling statistics for 1, 5, and 20 samples collected using a 1 for 1 (1:1) and a 3 for 3 (3:3) stratification scheme. Each sample consisted of 200 randomly selected Atlantic cod from a test population consisting of 1,497.

Item	Trials					Mean
No. of samples	1	1	1	1	1	1
No. of fish sampled	196	195	197	198	195	196
No. of otoliths (1:1)	55	54	51	51	53	53
No. of otoliths (3:3)	59	57	58	56	59	58
No. of samples	5	5				5
No. of fish sampled	993	994				994
No. of otoliths (1:1)	271	263				267
No. of otoliths (3:3)	292	301				297
No. of samples	20	20				20
No. of fish sampled	3,926	3,946				3,936
No. of otoliths (1:1)	1,108	1,062				1,085
No. of otoliths (3:3)	1,224	1,198				1,211

A comparison of the variance in mean length at age (Snedecor and Cochran, 1978) and in the variance in catch at age (Gavaris and Gavaris, 1983) was made between the two sampling schemes.

Several different simulations were conducted on both sample data sets using different random seeds for selecting (sampling) the fish. Generally only one of each of these simulations has been presented in this paper. However, despite slight differences observed from each of these runs, no change in conclusions would result.

Results

Age-length keys were developed from otoliths collected from individual samples (about 200 fish), 5 samples combined (about 1,000 fish), and 20 samples combined (about 4,000 fish). For 5, 2, and 2 trials respectively (Table 1), the number of otoliths collected by 1 for 1 sampling was from 9.5 to 11.5 percent less than with 3 for 3 sampling. During additional simulations one extreme observation of only a 5 percent difference was observed.

The mean length at age (Table 2a) estimated from two keys constructed from 20 samples of about 200 fish each show little difference between the stratification schemes (Fig. 1). Freidman's method (Sokal and Rohlf, 1981) gives chi squared values for this data in the range of 0.9–3.6 ($X_{(0.025,1)} = 5.02$); this indicates the CV for the mean length at age was not signifi-

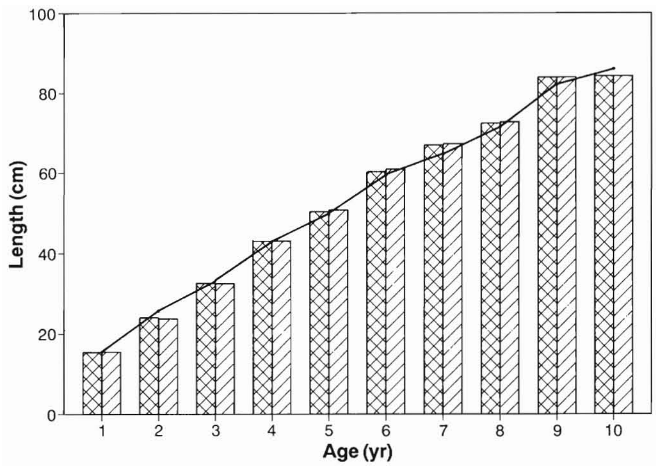

Figure 1.—Mean length at age estimated from the two sampling schemes based on 20 samples for each age at length key. Cross hatching is 1 for 1 sampling and single hatching is 3 for 3 sampling; the solid line represents the test population of Atlantic cod (1,497) from which the samples were taken.

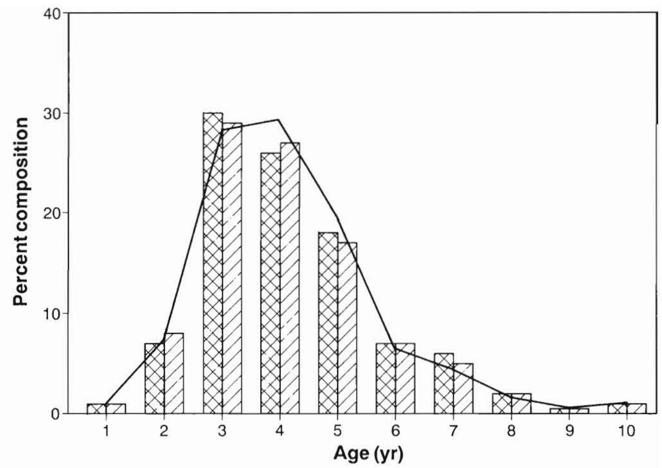

Figure 2.—Age composition estimated from the two sampling schemes based on 20 samples for each age at length key. Cross hatching is 1 for 1 sampling and single hatching is 3 for 3 sampling. The solid line represents the test population of Atlantic cod (1,497) from which the samples were taken.

Table 2a.—Mean length (cm) at age from a test population (1,497) as estimated from 1 for 1 (1:1) and 3 for 3 (3:3) sampling stratification schemes; 1, 5, or 20 samples were taken for the variuos trials.

		Ages									
		1	2	3	4	5	6	7	8	9	10
	Pop. mean length	16.0	27.0	33.4	42.3	50.2	59.6	63.1	69.6	80.2	87.0
No. sam.	Strat. scheme										
1	1:1	16.0	22.9	33.2	44.7	52.0	63.0	68.0	77.7	79.5	87.5
1	3:3	16.0	24.4	34.0	45.0	53.1	62.8	72.3	76.0	79.5	87.5
1	1:1	15.0	21.9	32.5	45.7	49.1	57.6	73.3	73.5	79.0	90.5
1	3:3	15.2	22.2	33.4	44.9	55.5	58.0	72.5	68.0	79.0	90.5
1	1:1	16.0	24.0	34.1	43.6	50.1	58.3	70.8	76.7		87.5
1	3:3	16.0	23.3	33.8	42.4	51.9	58.8	67.4	77.5		87.5
5	1:1	16.1	23.6	33.0	42.6	52.9	61.8	65.4	68.5	71.6	78.2
5	3:3	16.3	24.3	32.8	43.3	53.4	61.4	65.8	72.8	72.0	78.2
5	1:1	16.7	23.2	33.3	44.1	51.7	60.5	65.9	70.9		90.3
5	3:3	16.3	23.7	32.8	42.5	52.3	61.4	65.9	72.2		90.3
20	1:1	15.5	24.1	32.7	43.1	50.4	60.3	67.1	72.6	84.0	84.3
20	3:3	15.6	23.8	32.6	43.1	50.8	61.0	67.4	72.9	84.0	84.3
20	1:1	17.5	24.2	33.0	42.9	53.1	61.3	68.6	72.0		91.3
20	3:3	17.5	24.7	33.0	42.7	52.0	61.3	67.9	72.5		91.3

Table 2b.—Coefficients of variation of the mean length (cm) at age in the trials in Table 2a.

		Ages									
		1	2	3	4	5	6	7	8	9	10
	Pop. mean length	16.0	27.0	33.4	42.3	50.2	59.6	63.1	69.6	80.2	87.0
No. sam.	Strat. scheme										
1	1:1	12	13	13	8	8	7	7	7	9	8
1	3:3	12	13	14	8	8	8	8	7	9	8
1	1:1	7	13	12	9	14	5	4	14	8	7
1	3:3	7	14	12	9	12	5	4	16	8	7
1	1:1	10	14	13	9	10	8	8	10		8
1	3:3	10	13	13	9	11	8	7	10		8
5	1:1	13	13	13	9	10	8	9	8	7	7
5	3:3	13	13	12	10	11	9	10	9	8	7
5	1:1	10	14	13	11	10	8	10	10		10
5	3:3	10	14	13	11	10	9	12	10		9
20	1:1	16	16	12	10	10	10	10	10	10	8
20	3:3	16	16	12	10	10	10	9	10	10	8
20	1:1	11	14	12	11	10	9	10	9		9
20	3:3	10	14	12	10	11	9	11	9		9

cantly different between sampling schemes (Table 2b). They ranged from 7–18 percent over the sampled ages; the lowest values of 7–10 percent occurred in the ages contributing most to the population (4–8 years), and the remaining ages had CV's of their mean lengths between 10 and 18 percent.

The percentage age composition (Table 3) from these same two age length keys also shows little variation from the starting population (Fig. 2). There is no significant difference (K-S test) at the 5 percent level for any of the various levels of sampling intensity (i.e., 1–20 samples per key) for the percentage age composition or the mean length at age collected by the two sampling strategies (Table 4).

At the same time this study was underway, the sampling unit of our

Table 3.—Percent age composition of a test population (1,497) of Atlantic cod as estimated from 1 for 1 and 3 for 3 sampling stratification schemes; 1, 5, or 20 samples were taken for the various trials.

		Ages									
		1	2	3	4	5	6	7	8	9	10
	Population	.014	.075	.277	.292	192	.068	.042	.016	.005	.008
No. sam.	Strat. scheme										
1	1:1	.01	.08	.36	.28	18	.03	.03	.02	.01	.01
1	3:3	.01	.17	.29	.26	17	.03	.02	.02	.01	.01
1	1:1	.04	.07	.38	.28	.15	.03	.02	.02	.01	.02
1	3:3	.03	.07	.38	.33	.09	.03	.02	.02	.01	.01
1	1:1	.01	11	.37	.23	16	.03	.05	.02	.00	.01
1	3:3	.01	.09	.32	.30	.13	.04	.08	.01	.00	.01
5	1:1	.02	.09	.29	.29	.19	.06	.04	.02	.01	.01
5	3:3	.03	.09	.31	.26	18	.07	.03	.01	.00	.01
5	1:1	.02	.09	.34	.23	.18	.09	.02	.02	.00	.00
5	3:3	.02	.10	.30	.24	.20	.08	.02	.02	.00	.00
20	1:1	.01	.07	.30	.26	18	.07	.06	.02	.00	.01
20	3:3	.01	.08	.29	.27	17	.07	.05	.02	.00	.01
20	1:1	.01	.07	.28	.29	.20	.04	.06	.03	.00	.02
20	3:3	.01	.09	.24	.30	.20	.05	.06	.02	.00	.02

Table 5a.—Catch at age (total) and variance estimated using the two stratification schemes; 1 for 1 (1:1) and 3 for 3 (3:3) sampling of two populations of Atlantic cod. Three independent runs are given for each of the two data sets.

			No. of samples				
Run no.	Strat. scheme	Variable	1	3	5	10	20
Small data set[1]							
1		Catch	194	590	983	1,968	3,925
	1:1	Variance	—[2]	410	2,286	3,327	8,015
	3:3	Variance	1,716	836	3,923	7,566	17,600
2		Catch	195	585	983	1,949	3,897
	1:1	Variance	—[2]	865	1,798	3,983	6,399
	3:3	Variance	2,182	1,114	4,409	7,494	12,029
3		Catch	195	589	998	1,970	3,900
	1:1	Variance	—[2]	1,230	1,609	3,763	7,670
	3:3	Variance	1,628	2,337	4,524	8,497	12,779
Large data set[3]							
1		Catch	196	591	975	1,963	3,890
	1:1	Variance	—[2]	933	2,105	3,536	7,157
		Catch	196	570	975	1,951	3,887
	1:1	Variance	—[2]	1,621	2,034	3,477	6,970
	3:3	Variance	1,434	2,380	3,743	7,090	13,992
3		Catch	197	591	973	1,965	3,887
	1:1	Variance	—[2]	1,395	1,546	3,477	7,102
	3:3	Variance	664	2,656	2,593	6,623	13,387

[1]Sampled world = 1,497 fish.
[2]Unestimable value as only one individual is sampled in each length stratum.
[3]Sampled would = 10,186 fish.

Table 4.—The K statistic for the Kolmogorov-Smirnov two-sample test. (n1 = n2 = 10, for the two samples; the 1 for 1 and 3 for 3 sampling schemes on a test population of 1,497 Atlantic cod.) This test compares percentage age composition and mean length at age as estimated from samples collected by the two statification schemes.

Percentage age composition		
Number of samples	K	Significance levels
1	0.201	Not significant at 5%
1	0.134	Not significant at 5%
1	0.157	Not significant at 5%
5	0.067	Not significant at 5%
5	0.089	Not significant at 5%
20	0.022	Not significant at 5%
20	0.089	Not significant at 5%
Mean length at age		
Number of samples	K	Significance levels
1	0.170	Not significant at 5%
1	0.331	Not significant at 5%
1	0.119	Not significant at 5%
5	0.078	Not significant at 5%
5	0.048	Not significant at 5%
20	0.014	Not significant at 5%
20	0.045	Not significant at 5%

region conducted an empirical study to investigate this subject. Lambert[3] used the two sampling schemes during part of the 1984 sampling season to double-sample the NAFO Division 4T Atlantic cod stock. He observed no significant differences in either the mean age composition or the mean size at age estimated by the two schemes.

[3]Lambert, J. D. 1986. Sampling biologist, Maurice Lamontagne Institute, Department of Fisheries and Oceans, Mont-Joli, Quebec, Can. Personal commun.

The estimates of the catch in numbers at age (Table 5a) calculated according to the method of Gavaris and Gavaris (1983) indicates decreasing coefficients of variation (CV) with increasing numbers of samples (Table 5b). The CV's ranged from 5–8 percent with the two stratification levels and three samples to 2.17–3.38 percent with 20 samples (Fig. 3). The two-tailed F-test indicates a significant difference in the variance in every case; with the shift from the 1 for 1 stratification to the 3 for 3, this resulted in an increase in the CV of between 30 and 60 percent.

Table 5b.—Summary of table giving the coefficient of variation for each estimated catch at age.

		No. of samples				
Run no.	Strat. scheme	1	3	5	10	20
Small data set[1]						
1	1:1	—[2]	3.43	4.86	2.93	2.28
2	1:1	—[2]	5.03	4.31	3.24	2.05
3	1:1	—[2]	5.95	4.02	3.11	2.25
1	3:3	21.36	4.90	6.37	4.42	3.38
2	3:3	23.96	5.71	6.76	4.44	2.81
3	3:3	20.69	8.21	6.74	4.68	2.90
Large data set[3]						
1	1:1	—[2]	5.15	4.68	3.00	2.17
2	1:1	—[2]	6.99	4.58	3.01	2.15
3	1:1	—[2]	6.32	3.99	3.18	2.17
1	3:3	24.86	8.81	6.17	4.17	2.99
2	3:3	19.33	8.80	6.40	4.34	3.04
3	3:3	13.08	8.72	5.31	4.10	2.98

[1]Sampled world = 1,497 fish.
[2]Unestimable value as only one individual is sampled in each length stratum.
[3]Sampled world = 10,186 fish.

Conclusions

It was proposed by the FAO Working Party on Tuna Length Measurements and Tabulation (Anonymous, 1981) that the length groupings for sampling stratification follow the geometric progression of 0.5, 1, 2, 4, 8 cm, etc., to allow data to be compared after being aggregated (i.e., sharing the same midpoints). The main reason for stratifying is the reduction of the number of relatively expensive

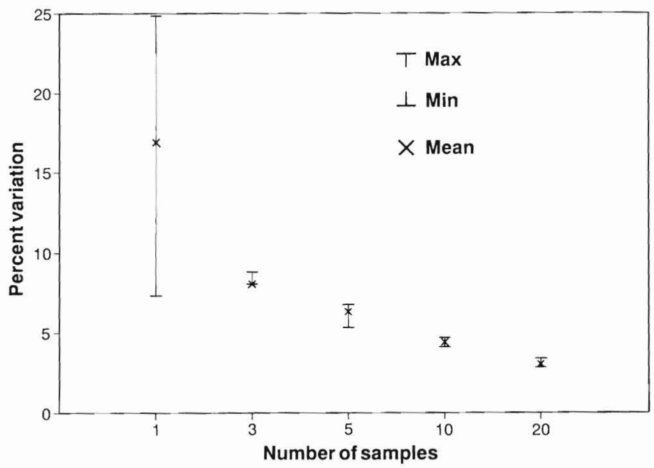

Figure 3.—Coefficient of variation (%) for the estimated catch in numbers at age for different numbers of samples. The range and mean CV's are shown for six independent simulations of the 3 for 3 sampling of a test population of Atlantic cod (10,186).

hard parts collected for aging while maintaining the representative nature of the sampling for the entire length range. Gulland (1955) suggested such sampling should aim to produce similar CV's for estimated numbers at age for all ages, and ICNAF (Anonymous, 1974:134) suggested a level of 10 percent would be satisfactory. Species should be selected for the stratified length groupings by their maximum range of length and the consideration of cost and the number of age determinations required. FAO (Anonymous, 1981) has suggested all fish with a maximum length less than 30 cm use the 0.5 cm grouping while fish over this use 1 cm.

In the test populations of Atlantic cod, there was no significant difference in the mean values of the data collected by the two sampling techniques. Although there was no advantage of one sampling scheme over the other with regard to the variance about the mean length, there is a distinct advantage in the 1 for 1 sampling scheme regarding the variance in the estimated catch numbers at age. The 1 for 1 stratification scheme would appear the superior one, as about 10 percent fewer otoliths are collected to provide the same or better information (depending on the parameter being estimated), thus reducing the costs of sampling and aging fish collected during both commercial sampling and research surveys. Further, the 1 for 1 stratification does not require transcribing of the data, resulting in fewer errors and less work.

The data presented here are for a simulated population of Atlantic cod collected from research surveys of the southern Gulf of St. Lawrence. The conclusions of this study cannot be categorically accepted for all species in both commercial and research situations; however, there is no reason to doubt that the conclusions would hold for the majority of gadoid species along the Atlantic coast. Commercial data tend to be similar to that collected from the same populations by research surveys except for varying degrees of truncation of the younger age groups.

One instance where this might not be considered a superior technique would occur if large numbers of otoliths were considered necessary for each age length key, such as in long-lived slow growing fish. If the fishery was considered adequately represented by the existing length frequencies, then excess length frequencies would be required so additional otoliths could be collected.

If statistical differences do not dictate a choice between the two stratification schemes, then other operational considerations will probably determine which of the schemes will be put in use. Four such considerations might be:

1 for 1	*>1 for >1*
1) Greater detail for biological analysis.	1) Not as sensitive to small changes in population parameters.
2) Fish with large length ranges will require forms that may be long and cumbersome.	2) Forms can be shorter and simpler although data requires summarizing and transcription.
3) If all species are sampled 1 for 1, then instructions can be simpler; samplers have one set of data forms for all species.	3) Variety of forms are required with different protocols for each sampling scheme.
4) Large volume of recorded data.	4) Data can be reduced to between 50 and 66 percent of the volume of the 1 for 1 scheme.

Jinn et al. (1987), in a study of optimal two-phase sampling, used examples that indicate the optimal sample size (for length measurements) could range from 150 to 250 fish for small (flatfish) and large (cod) fish, respectively. Baird (1983) developed a method to select the optimal number of otoliths to be collected at length for aging. In his study to achieve an overall CV of about 10 percent he had to vary the number of otoliths for different length strata. Thus it is probable that optimal efficiency in sampling may dictate a relatively complex scheme involving different numbers of fish:

1) Sampled for length (depending on the number of length strata involved for the species),
2) Stratified for otoliths (depending on growth rate of the stock), and
3) Possibly varying aggregations of lengths comprising the length strata.

Data can always be aggregated into larger groupings if it is collected in the smallest feasible intervals. Although financial constraints may force stratification of detailed sampling, there is no justification for length frequency aggregation beyond 1 cm.

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