

FRI-UW-8402
Rev. March 1984

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FEASIBILITY OF USING SCALE ANALYSIS METHODS TO
IDENTIFY BERING SEA HERRING STOCKS

by

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Annual Report

to

National Marine Fisheries Service
Contract No. 83-ABC-00165

Rev. March 1984

Approved



Robert L. Burgner, Director

Submitted March 23, 1984

TABLE OF CONTENTS

	Page
LIST OF FIGURES	iii
LIST OF TABLES	v
INTRODUCTION	1
METHODS	3
Construction of Standards	3
Construction of Unknowns	4
Character Selection	4
Classification Procedures	5
Linear Discriminant Function Analysis	6
RESULTS	7
Body Location of Scales	7
Incidental Trawl Catches	7
Variability in Scale Measurements	7
Classification of Standards	9
Classification of Unknowns	9
DISCUSSION	11
REFERENCES	13
ACKNOWLEDGMENTS	15

LIST OF FIGURES

Fig.	Page
1. Bering Sea statistical fishing areas and the locations from which most herring scale samples were collected from foreign trawl fisheries	16
2. Catches of Pacific herring in the eastern Bering Sea, 1960-1983. Winter catches are for the year ending, e.g., 1960 for 1959-60	17
3. Annual biomass estimates and catches for Togiak (T), Security Cove-Goodnews Bay (S), Cape Romanzoff (C) and Norton Sound (N) from 1978 through 1983	18
4. Eastern Bering Sea Study area	19
5. Mean length by age (growth curves) for Togiak and Cape Romanzof herring stocks as calculated from scale samples of age 5 herring 1982-1983 and age 6 herring in 1983	20
6. Means, ± 2 S.E. and ± 2 S.D. of the distances between annuli (inches at $50\times$) for samples from Norton Sound, Cape Romanzof, Nelson Island, Security Cove, Togiak, and Port Moller collected in 1982 and 1983	21
7. Relative growth (number of standard deviations from the mean distance between annuli for each age group) and the means of the monthly air temperature deviations (May-August) for Bristol Bay	22
8. Monthly air temperature deviations (from 62-year means) in Bristol Bay (Dillingham and King Salmon) for summer months, April-October (top) and winter months, November-March (bottom), Nov. 1966 to Oct. 1983	23
9. Frequency distributions of standard length (mm) at age 5 for the age 5 standards from 1982	24
10. Frequency distributions of scale size at age 5 for the age 5 standards from 1982	25
11. Frequency distributions of standard length (mm) at age 5 for age 5 standards and unknown from 1983	26
12. Frequency distributions of scale size at age 5 for the age 5 standards and unknown from 1983	27

Fig.	Page
13. Frequency distributions of standard length (mm) at age 6 for the age 6 northern standards from 1983	28
14. Frequency distributions of standard length (mm) at age 6 for the age 6 southern standards and unknown from 1983	29
15. Frequency distributions of scale size at age 6 for the age 6 northern standards from 1983	30
16. Frequency distributions of scale size at age 6 for the age 6 southern standards and unknown from 1983	31
17. Frequency distributions of scale size at age 5 for the 1983 age 5 Security Cove, Goodnews Bay, and combined Security Cove/Goodnews Bay standards	32
18. Frequency distributions of scale size at age 6 for 1983 age 6 Security Cove, Goodnews Bay and combined Security Cove/Goodnews Bay standards	33
19. Frequency distributions of standard length (mm) at age 6 for the 1983 age 6 Security Cove, Goodnews Bay, and combined Security Cove/Goodnews Bay standards	34
20. Frequency distributions of scale size at age 5 for the 1982 age 5 Norton Sound standard and standards derived through isolation of subdistricts	35
21. Plots of the mean scale length on the mean body length for age 5 herring from 1982 and 1983 (solid points) and age 6 herring from 1983 (circles)	36

LIST OF TABLES

Table	Page
1. Age composition of the incidental catch of Pacific herring in 1982 and 1983 (one year was added to the number of annuli counted for samples collected in the winter months of January-March)	36
2. Scale characters examined for the discriminant function analyses of age 5 Pacific herring	37
3. Scale characters examined for the discriminant function analyses of age 6 Pacific herring	38
4. Sample sizes (n), means and standard deviations for 1982 age 5 scale characters	39
5. Sample sizes (n), means and standard deviations for 1983 age 5 scale characters	41
6. Sample sizes (n), means and standard deviations for 1983 age 6 scale characters	43
7. Final decision arrays for the a) 1982 age 5 PDF analysis, b) 1983 age 5 PDF analysis, c) 1983 age 6 PDF analysis, and d) 1983 age 6 LDF analysis	46
8a. Mixing proportion estimates of age 6 herring in the 1983 Dutch Harbor fishery (percentages with 90% confidence intervals)	47
8b. Mixing proportion estimates of age 6 herring in the 1983 Dutch Harbor fishery, as determined by linear discriminant analysis (percentages with 90% confidence intervals)	47

ABSTRACT

Scale pattern analysis was applied to eight spawning stocks of eastern Bering Sea herring to determine their identity and separation in a mixed stock fishery. The stocks could be separated by geographical area - northern stocks (Norton Sound and Cape Romanzof) from central stocks (e.g., Togiak) from southern stocks (e.g., Port Moller) - largely on the basis of body length, scale length and growth increments (distances between annuli). Northern stocks generally exhibited less growth than central or southern Bering Sea stocks. There was significant annual variation in growth which corresponded to variation in summer air temperatures, but the differences among areas were generally maintained between years.

An attempt to classify the origins of herring caught incidentally in foreign trawl fisheries was unsuccessful because the quality of the scale samples was poor. The origins of herring caught in the summer fishery at Dutch Harbor were analyzed. Northern stocks and one local stock were practically absent in the fishery samples. About 88% of the herring in the fishery samples were classified to the largest spawning stock in the eastern Bering Sea, i.e., the Togiak stock.

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INTRODUCTION

Although minor subsistence and commercial food fisheries for Pacific herring (Clupea harengus pallasii) had existed along the eastern Bering Sea coast since the early 1900s, it was not until 1928 that a sizable U.S. commercial fishery began. This was a late-summer to early-fall fishery off Unimak Island which reached a peak harvest of 2,277 m.t. in 1932. The fishery terminated after 1945 because price and demand were low (Wespestad and Barton 1981). A fishery was re-established in the Aleutian Islands near Dutch Harbor in 1981 and the catches by this late-summer fishery were about 3,600 m.t. in 1982 and 3,200 m.t. in 1983.

Herring in the eastern Bering Sea were first extensively exploited by a U.S.S.R. winter-trawl fishery in the late 1950s. A Japanese fleet joined this winter fishery in the mid 1960s and the combined catches reached a peak harvest of about 126,000 m.t. in 1968-69. The catches by this offshore fishery, centered northwest of the Pribilof Islands (area 2 in Fig. 1), declined during the early 1970s (NPFMC 1982).

Domestic spring fisheries for herring roe developed in Bristol Bay (Togiak) and Norton Sound during the 1960s with the first large catch in 1977 (2,500 m.t.). The U.S. coastal catches of roe herring increased to 30,750 m.t. in 1983, whereas offshore herring fisheries were practically eliminated after 1980 (Fig. 2). However, herring continue to be caught incidentally by offshore trawl fisheries which target on other species.

The incidental herring catches in the eastern Bering Sea (areas 1 and 2, Fig. 1) declined from 19,000 m.t. in 1977 (the first year of estimates) to only about 300 m.t. in 1981, but then increased to 1,900 m.t. in 1982 and 1,400 m.t. in 1983. Most of the incidental catches were made in area 2 except in 1982, when 1,300 m.t. were caught in area 1. The largest incidental catches were usually made during fall and winter (Nelson et al. 1978, 1979, 1980, 1983; French et al. 1981, 1982).

The coastal spawning stocks may make extensive migrations after the spring spawning season. The eastern Bering Sea spawning stocks probably overwinter near the Pribilof Islands and some may pass through the Aleutian Islands during the summer (Wespestad and Barton 1981). The exact spawning stocks involved and their relative abundances in specific offshore wintering grounds or summer migration areas has not been determined. Stock identification is important to determine stock composition in the summer fishery, on wintering grounds, and in the

incidental catches by trawl fisheries. It is also important to determine if several stocks mingle in eastern Bering Sea coastal areas before migrating to individual spawning grounds.

Scale pattern analysis was first used on Pacific herring in 1982 to determine the stock composition of fish caught in the Dutch Harbor summer fishery (Walker and Schnepf 1982). The results indicated that Togiak, Nelson Island and Port Moller stocks were present in the fishery. The Togiak stock provides for the largest roe fishery in western Alaska (Figs. 3 and 4).

The primary objectives of this study were to 1) determine the separability of major spawning stocks of herring in eastern Bering Sea, north Alaska Peninsula and Aleutian areas by scale pattern characters from two or more age classes of herring, and if spawning stocks are separable 2) examine stock composition of herring collected from the domestic summer food and bait fishery at Dutch Harbor and from offshore overwintering grounds. Secondary objectives were to 1) determine the effects of the body location (where the scale is collected) on scale measurements, 2) mount and age scales collected by NMFS observers from incidental trawl catches and determine how suitable the scales are for scale pattern analysis, and 3) examine the variability in scale measurement parameters between years and among ages for known origin spawning stocks.

METHODS

The main assumption in the use of scale measurements to separate stocks of herring is that fish from different areas experience different growth patterns (genetic and/or environmental) that are reflected on their scales. Scale characters, e.g., radius measurements to annuli (length at age) or measurements between annuli (growth increments), from known spawning populations can then be used to classify herring from mixed stock areas or fisheries to their stock of origin.

Methods of scale measurement and statistical analysis follow our 1982 scale pattern analysis and the methods of Cook (1982). The Alaska Department of Fish and Game (ADF&G) provided 1982 and 1983 mounted and aged scale samples from the major eastern Bering Sea spawning stocks: Norton Sound, Cape Romanzof, Nelson Island, Security Cove, Goodnews Bay, Togiak, Port Moller, Canoe Bay and Dutch Harbor (Fig. 4). Scales of unknown origins were also provided from the Dutch Harbor food and bait fishery. The Fisheries Research Institute assisted in Togiak and Dutch Harbor scale collections. The National Marine Fisheries Service (NMFS) provided 1982 and 1983 herring scales from foreign incidental catches which were collected by NMFS observers. We mounted and aged most of the scale samples but made scale measurements only on 373 scales from age 5 herring collected in 1982.

Construction of Standards

Standards (subsamples from known spawning stocks) were constructed for both age 5 and age 6 herring collected in 1983. Scale measurements were not made on the Canoe Bay samples because the herring were significantly younger than those from the other stocks. A Norton Sound standard was constructed of samples from three subdistricts weighted according to ADF&G biomass estimates and the Togiak standard was likewise constructed from four subdistricts.

Frequency distributions of scale size (length) and standard lengths of the fish were constructed for the standards, some subdistricts or locations within the standards, and for the unknowns from the Dutch Harbor fishery. The 1983 age 6 Port Moller standard exhibited strong bimodality in scale measurements and fish lengths (some bimodality was also evident in the age 5 samples from 1982 and 1983). Sampling was conducted from three sites at Port Moller in 1983 and at one site the fish and scales were obviously smaller than at the other two sites. We thus decided to treat the Port Moller area as containing two stocks. The longer fish were labelled Port Moller 1 and the shorter Port Moller 2.

Measurements from subdistricts within Norton Sound and Togiak were generally very similar compared to the differences in measurements between districts; however, bimodal distributions were evident for the

combined standards of 1983 age 5 and 6 herring from Security Cove/ Goodnews Bay. These stocks were originally combined to form a single standard because the spawning areas were near each other. Because these stocks had relatively small biomasses compared to the nearby Togiak stock they were regarded lightly in our analysis. When our original standard of 200 scales was split into two standards of 100 scales each we obtained a clear definition of the Security Cove stock but not the Goodnews Bay stock.

The 1982 Norton Sound and Cape Romanzof standards exhibited bimodal distributions for scale size. These standards misclassified with each other in the analysis and were combined to form one standard. Afterward, it was found that one subdistrict within Norton Sound (St. Michael) accounted for the larger scales while the other two subdistricts produced smaller scales. For our purposes, the St. Michael subsample was labeled Norton Sound 1 and the other Norton Sound 2. The bimodality of Cape Romanzof was not isolated. For the 1983 age 5 and 6 samples the Cape Romanzof standards displayed a relatively wide, slightly bimodal distribution. We could not isolate the bimodality and there was little misclassification with the Norton Sound standard to justify any rearrangement.

Construction of Unknowns

The unknown origin samples from the Dutch Harbor fishery could be stratified by location and time, however variability in location was inconsequential for 1982 and 1983. The time periods averaged 5 days each in 1983 but the periods in 1982 were more complicated because fishing was irregular. In both years scales were collected over a period of about one month and this spanned most of the fishing season.

Samples were collected from purse seiners as they returned to port for processing and preferred scales were often not available. Preferred scales are essential for scale pattern analysis to avoid misclassification of unknowns, therefore we used only the preferred scales from the Dutch Harbor fishery.

Unknown samples were also derived from the incidental catches of foreign trawlers. Samples from eight cruises in 1982 were aged and samples from six cruises were digitized for analysis. However, within cruises there were several fishing locations and dates. Moreover, scales were often not from the preferred body location. These limitations reduced the effective samples to one and this was from a location too far west to be considered to contain only eastern Bering Sea coastal stocks.

Character Selection

A non-parametric selection method, the Kruskal-Wallis test, was used to determine the characters to be utilized in the polynomial

discriminant function (PDF) analysis. Overall, the best characters from the 30 examined were, in order, back-calculated length, scale size, and annual scale growth (Tables 2 and 3). Proportionate scale growth was generally a poor character. Since similar characters (e.g., back-calculated length at age 5 and back-calculated length at age 4) are usually correlated, only one character from any major type was selected for developing functions.

The final characters selected for the 1982 analysis were: 1) back-calculated length at age 5 (back-calculation was not required for most standard scales), 2) scale size at age 5, 3) scale growth in the third year, and 4) proportion of scale growth in the second year. The final characters chosen for the 1983 age 5 analysis were: 1) back-calculated length at age 5, 2) scale size at age 5, 3) scale growth in the second year; whereas those used in the age 6 analysis were: 1) back-calculated length at age 5, 2) scale size at age 4, 3) scale growth in the second year, and 4) proportion of scale growth in the sixth year.

Classification Procedures

After dividing the age 6 Port Moller stock into two stocks, a 6-class analysis was performed which included standards from Norton Sound, Nelson Island, Togiak, Port Moller 1, Port Moller 2, and Dutch Harbor. Preliminary analyses had demonstrated Cape Romanzof to be absent throughout the food and bait fishery, so it was omitted. With Security Cove separated from Goodnews Bay, Security Cove was shown to misclassify heavily with Togiak, and therefore it was omitted. Generally, the procedure following this type of misclassification would be to combine the two stocks in weighted proportions with respect to their estimated biomass, but since the estimated biomass of Security Cove is much smaller than that of Togiak, its effect would likely be inconsequential. The Goodnews Bay stock was not included because it had a wide frequency distribution and small estimated biomass. Although estimates for the Dutch Harbor stock were negative in earlier analyses, it was retained so misclassification with the adjacent Port Moller 2 standard could be noted.

The age 6 analysis was reduced to a 4-class analysis, without the undetected Port Moller 2 and Dutch Harbor standards. This was done to improve confidence in assigning mixing proportion estimates. The procedures for classifying 1982 and 1983 age 5 standards have been reported previously (Rogers et al. 1983). The absence of a Nelson Island standard in 1983 due to weak sampling left this analysis incomplete.

Nearly unbiased estimates of mixing proportions and corresponding 90% confidence intervals were calculated for 1982 age 5 and 1983 age 6 unknown samples. Positive point estimates were those greater than zero, and significant point estimates were those with 90% confidence intervals above zero.

Linear Discriminant Function Analysis

We desired to obtain higher classificatory accuracies, and therefore attempted a linear discriminant function (LDF) analysis. Program BMDP7M was used to develop functions, determine classificatory accuracies, and to classify the unknowns. Only the final four standards of the age 6 PDF analysis were used, with the main purpose of obtaining classificatory accuracies.

While certain assumptions regarding normality should be met, the analysis is very robust against non-normal distributions. Those characters with the highest F-to-enter at each step of the selection procedure were chosen, until a minimum F-to-enter of 4.000 was reached. In this manner, five characters were selected: 1) back-calculated length at age 5, 2) back-calculated length at age 2, 3) scale size at age 6, 4) ratio of scale growth in the sixth year to scale growth in the fifth year, and 5) scale growth in the second year. The unknown origin samples were stratified by time as before, and nearly unbiased estimates and 90% confidence intervals were obtained.

RESULTS

Body Location of Scales

Scale measurements were made on two scales from each of five areas on 25 herring to determine the effect of body location on scale characters. Also, a preferred area scale was taken from each side of the body (Rogers et al. 1983). Four scale characters were used in the statistical analysis: 1) total scale size through age 7; 2) growth ratio of years 3 + 4/years 1 + 2; 3) proportional growth of year 2/all years; and 4) back-calculated length at year 2. By using these characters, the four major types of scale characters used in the analysis were represented.

The body location of the scale had a statistically significant effect only on total scale size; however, this is usually an important character in scale pattern analysis. There were no significant differences in scale measurements on scales taken from either side of the body; therefore, it was recommended that when preferred scales on the left side of the body cannot be found, the right side should be examined for a preferred scale before collecting from the next body area (usually behind the pectoral fin).

Incidental Trawl Catches

Age compositions of herring in the 1982 and 1983 incidental catches in foreign trawl fisheries were calculated by location and dates (Table 1). Herring caught in the late-winter to spring (Feb.-May) were primarily ages 3-5 in 1982 and ages 4-6 in 1983. Herring caught during the summer were predominantly age 5 in 1982 and age 6 in 1983. The change in age composition between years corresponded to the shift from predominantly age 5 herring in the 1982 coastal spawning stocks to age 6 herring in the 1983 coastal spawning stocks.

A sample of 373 age 5 scales from the 1982 incidental catch samples was digitized. These unknowns were analyzed with the standards constructed for the 1982 scale pattern analysis but the unknowns could not be accurately classified. We believe that this was caused by the fact that lengths were recorded to the nearest centimeter rather than millimeter and scales were not consistently available from a single body area. These factors probably caused a considerable amount of imprecision in the unknown scale measurements.

Variability in Scale Measurements

The success of the stock separation depends on the extent of the differences between stocks in the frequency distributions of the scale (or length) parameters and the consistency of the differences among

samples from a stock and among years. If annual variation is relatively small, the sample standards from one year could be used to classify unknown origin samples from another year. It is also desirable that the observed differences in scale parameters among stocks or years have some biological or environmental validity, e.g., smaller measurements (poorer growth) at northern locations compared to southern or less growth during cold years than during warm years.

The means and standard deviations of the 25 scale characters for age 5 herring and the 30 characters for age 6 herring are presented in Table 4-6. The mean lengths at capture and the back-calculated lengths at age for the herring from the northern stocks (Norton Sound and Cape Romanzof) were the smallest, whereas those from Togiak and Port Moller were the largest. The Nelson Island and Security Cove/Goodnews Bay stocks were of intermediate size as were those collected from the Dutch Harbor spawning stock. The variation in lengths among years and ages relative to the differences between two extreme stocks (Togiak and Cape Romanzof) is illustrated in Figure 5.

The annual variation in growth was best demonstrated by the growth increments (distances between annuli) according to the years when the growth occurred. Herring growth appeared to be better in 1977, 1979 and 1981 than in 1978 and 1980, when growth increments for the three age classes were compared (Fig. 6). The means of the distances between annuli were standardized¹ by age for the Togiak, Norton Sound, Security/Goodnews and Cape Romanzof samples and compared to the annual summer (May-August) air temperatures in Bristol Bay (Fig. 7). The summers of 1979 and 1981 were the warmest during the years available, whereas 1980 and 1982 summers were the coolest and growth varied correspondingly. Since herring growth in the eastern Bering Sea appears to be related to summer air temperatures, it is likely that growth was generally poor from 1970 to 1976 with the exception of 1974 (Fig. 8).

The differences in growth between stocks was generally maintained between years and ages sampled (Fig. 9-19); however, the annual variation in growth precludes the use of scale standards from different years in classifying samples of unknown origin. It was primarily the relationship between scale size and body length that separated the eastern Bering Sea herring stocks. The Norton Sound stock had small fish with relatively large scales, whereas the small fish from the Cape Romanzof stock also had small scales. Togiak herring were large with large scales and Port Moller herring were generally large but with

$$^1 \left(\frac{X - \bar{X}}{S.D.} \right)$$

where: n = 12
 \bar{X} = mean distance for a given stock at a given age.
 \bar{X} = grand mean for a given age.
 S.D. = standard deviation of X.

relatively small scales (Fig. 20). The other spawning stocks (Nelson Island, Security Cove/Goodnews Bay, and Dutch Harbor) were intermediate in their scale length to body length relationship and the unknown origin samples from the Dutch Harbor fishery more closely resembled the Togiak stock than any other stock for which we had scale samples.

Classification of Standards

The final classification decision arrays, including the one for 1982 by Walker and Schnepf (1982), are presented in Table 7. The overall classificatory accuracy for the age 6, 6-class PDF analysis, which included two standards from Port Moller was barely acceptable at 58.6%. The confidence intervals for mixing proportion estimates from the 6-class analysis were very wide. However, there were negative estimates for the Port Moller 2 and Dutch Harbor standards, so the age 6 analysis was redone as a 4-class analysis without these standards to improve the confidence limits on mixing proportion estimates. There are two ways that the number of standards used for classification may be reduced. One is if misclassification is heavy between two (or more) standards and the other is if negative mixing proportion estimates are always obtained for a standard, i.e., for each date or subsample of unknowns.

The decision array for the 4-class PDF analysis had an overall accuracy of 63% (Table 7c). This was acceptable, however, in consideration of reduced number of classes, not much improved over the 6-class analysis. The Togiak stock had the lowest accuracy (48.2%) while the Port Moller 1 stock had the highest accuracy (74.2%). Misclassification was fairly heavy between Togiak and Port Moller 1.

The LDF analysis of the 4 standards used in the age 6 PDF analysis resulted in a slightly higher overall classificatory accuracy of 64.3% (Table 7d). The leaving-one-out approach was used as in the PDF analysis. The individual classificatory accuracies in the LDF analysis were less variable than in the PDF analysis but the Togiak stock still had a substantially lower accuracy than the other three stocks.

Classification of Unknowns

The 1982 classification of Dutch Harbor unknowns reported by Walker and Schnepf (1982) was summarized by an overall mixing proportion estimate of 43.3% for Togiak, 35.4% for Nelson Island and 21.3% for Port Moller. However, this analysis included the classification of non-preferred scales and the use of a bimodal Port Moller standard. Thus, the 1982 classification of the Dutch Harbor unknowns is somewhat suspect.

For 1983, the age 5, 4-class matrix was used to classify 78 unknown scales, but small sample sizes hampered this analysis. Nelson Island was not represented and the unknown sample was too small to be stratified by time periods. Point estimates and confidence intervals were not determined, however cross tabulation of the classification results indicated the presence of Togiak and Port Moller stocks in the fishery.

For the age 6 analysis, five time periods resulted from stratifying the unknown samples by 5-day intervals. The first time period had only 25 scales because preferred scales were scarce. This is the minimum acceptable sample size and a larger sample size is preferred. We classified 443 specimens according to the PDF analysis. The mixing proportion estimates and 90% confidence intervals are presented in Table 8a. The confidence intervals were wide and overlapped because the accuracy of the standards was marginal. The results for the first time period are questionable because the sample size was small. The Norton Sound stock was estimated to have been a slight contributor to the fishery in the second period, but negative estimates were obtained for the later periods. The Nelson Island estimates were higher in the early periods and the Port Moller 1 estimates were higher in the late periods, but only the Togiak stock had consistently significant estimates. The overall mixing proportion was 87.5% for Togiak and 12.5% for Nelson Island. This matched almost exactly the result of our 2-class analysis (Rogers et al. 1983).

The mixing proportion estimates determined by the LDF analysis were, on the whole, roughly similar to those determined by the PDF analysis. Results are given in Table 8b. The same trends may be noted as in the PDF analysis. Estimates were consistently higher for Norton Sound and Togiak while consistently lower for Nelson Island and Port Moller. For both analyses, however, significant estimates were obtained only for the Togiak standard. The overall mixing proportion estimate by the LDF analysis was 93.8% for Togiak, 3.1% for Norton Sound and 3.0% for Nelson Island.

DISCUSSION

The major spawning stocks of eastern Bering Sea herring were identifiable from their scale patterns and lengths. The northern stocks (Norton Sound and Cape Romanzof), central stocks (Nelson Island, Security Cove, Goodnews Bay and Togiak), and southern stocks (Port Moller, Dutch Harbor) were separated by scale pattern analysis. It was evident that the Togiak stock was the primary contributor to the Dutch Harbor fishery.

Scale pattern analysis was shown to be a valid method of identifying and thus potentially separating Bering Sea herring from a mixed stock fishery. The main problems with the method are primarily associated with the collection of the scale samples, and if these sampling problems are solved the method is quite useful.

Classification estimates derived through scale pattern analysis strongly depend on consistently good sampling techniques, among locations and within locations, with regard to each fish sampled. If a location is sampled incorrectly (e.g., if non-preferred scales are always collected), the stock from that location will be misrepresented. A stock may, for instance, be regarded as consisting of small-scaled fish when scale size is actually larger. If a location is incorrectly sampled, a bimodal distribution may occur. Speculation arose regarding sampling technique when the 1982 and 1983 herring standards were analyzed, in particular, Norton Sound in 1982 and Cape Romanzoff in both years.

A bimodal distribution with regard to fish length is less likely to be attributed to improper sampling, and when there is also a corresponding bimodal distribution in scale size, then two stocks or substocks were probably sampled. This was most notably the case for Port Moller. Of significance is the fact that the Dutch Harbor spawning stock consisted of relatively small fish. It was noted in the preliminary report that body length was longer for the more southerly located stocks, down through Port Moller. From the little information available, it appears that a change occurs here and smaller fish can again be found among spawning stocks. While the majority of herring in the eastern Bering Sea are believed to winter near the Pribilof Islands (Wespestad and Barton 1981), there are reports of herring along the Aleutian Islands in the winter. It may be that the smaller fish are part of these native stocks.

Marginal classification accuracies may reflect somewhat random migrational patterns by herring. Random mixing between stocks could be determined through tagging, but tagging has thus far proved unrealistic for herring. Random mixing likely occurs to some degree, and could be responsible for the misclassification between Togiak and Port Moller 1, for example.

Age 6 mixing proportion estimates for the Dutch Harbor fishery highly favored the Togiak stock. This was anticipated before the analysis was begun because the biomass of the Togiak stock was so much greater than the other stocks. The more northern stocks of Nelson Island and Norton Sound were not expected to be found in the food and bait fishery because it seemed unlikely that they would migrate so far south. All possible contributors to an unknown sample should be included in a discriminant analysis, otherwise unknown observations will be misclassified to the most similar standard available. This may be the explanation for the Norton Sound and Nelson Island estimates. However, the estimated biomass of these stocks is relatively substantial.

The LDF analysis was interesting in that classification accuracy was slightly improved over the PDF analysis, while easier and less expensive to perform. The mixing proportion estimates obtained by the two analyses were roughly similar and thus support the methods employed throughout the entire research. It is our belief that scale pattern analysis as employed toward herring in the eastern Bering Sea is quite feasible.

The following are recommendations for future work:

- 1) Use of the LDF analysis for herring scale analyses.
- 2) Increase surveys and establish new sampling locations along the Aleutian Islands.
- 3) Increase sampling at Nelson Island.
- 4) Continue to ensure consistent sampling of preferred scales.
- 5) Collection and analysis of unknown origin scales from wintering grounds or other migration areas.

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ACKNOWLEDGMENTS

We especially thank those who provided scale samples and biological information on Bering Sea herring: Steve Fried and Larry Malloy of ADF&G, and Russ Nelson, Janet Wall and Vidar Wespestad of NMFS. This research was done at the request of the North Pacific Fishery Management Council and funded through NOAA (NMFS). We also thank Marcus Duke (Fisheries Publications Center) for preparation of the report.

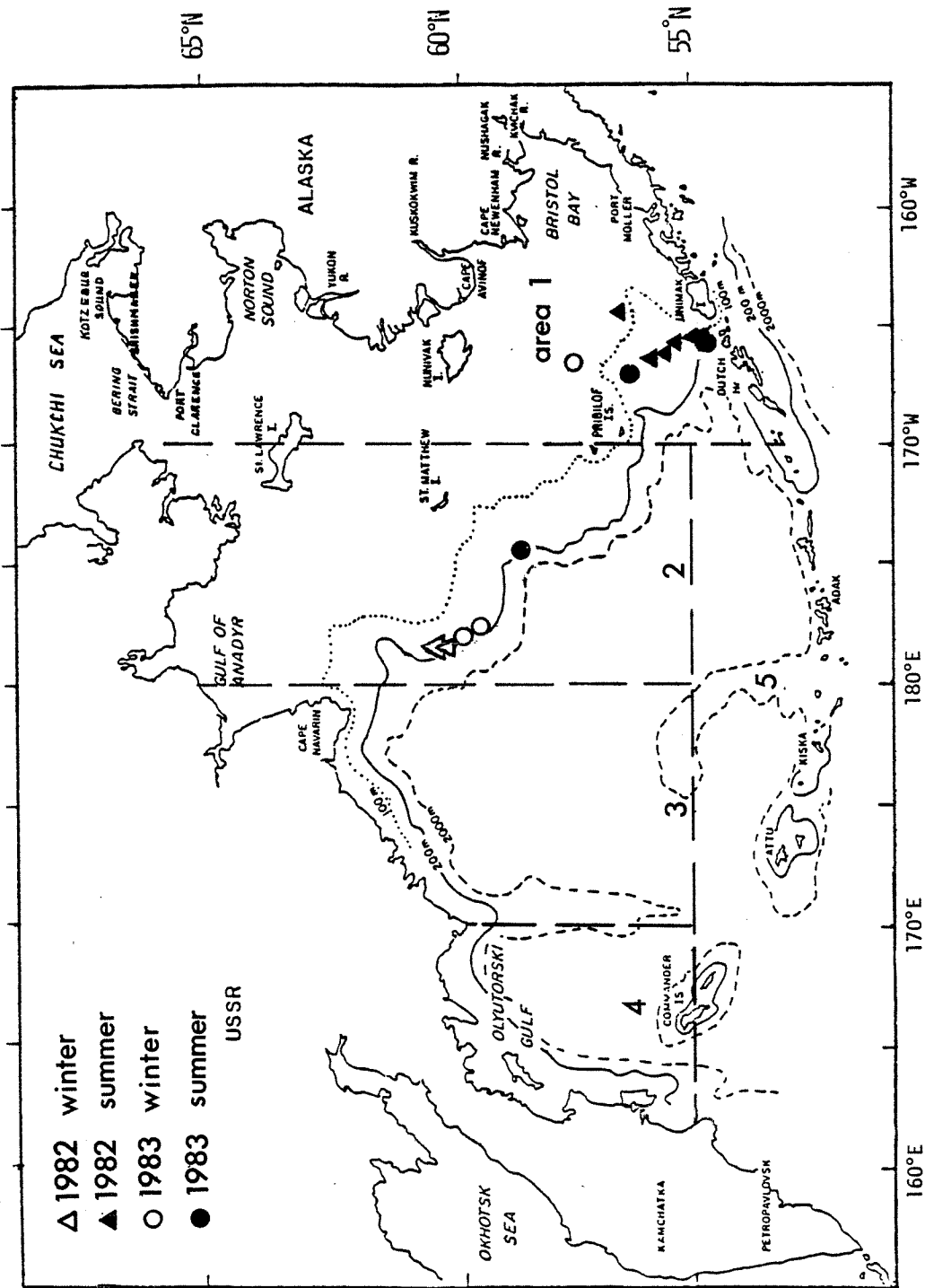


Fig. 1. Bering Sea statistical fishing areas and the locations from which most herring scale samples were collected from foreign trawl fisheries.

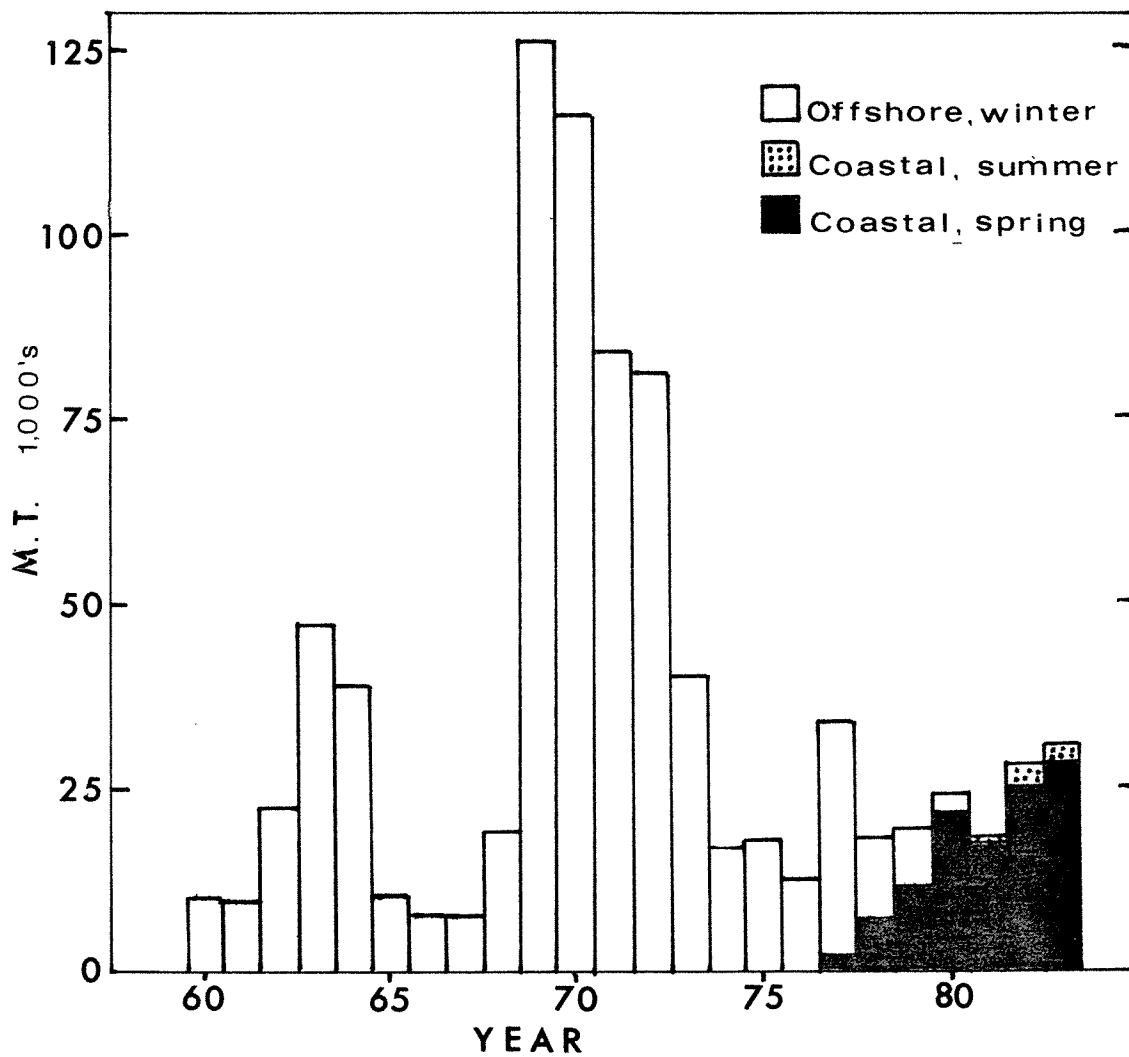


Fig. 2. Catches of Pacific herring in the eastern Bering Sea, 1960-1983. Winter catches are for the year ending, e.g., 1960 for 1959-60.

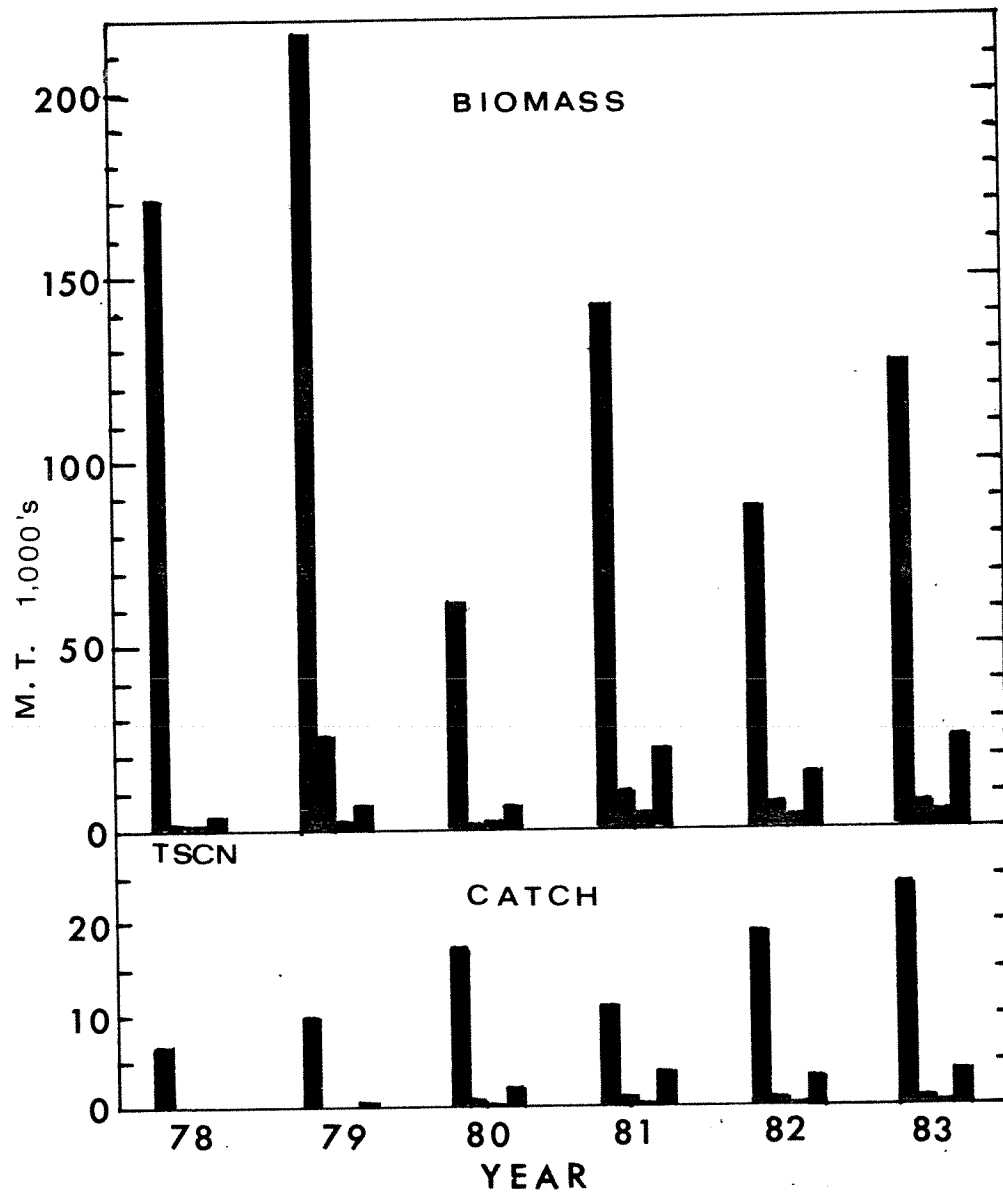


Fig. 3. Annual biomass estimates and catches for Togiak (T), Security Cove-Goodness Bay (S), Cape Romanzof (C), and Norton Sound (N) from 1978 through 1983. (Source: Fried and Whitmore, 1983).

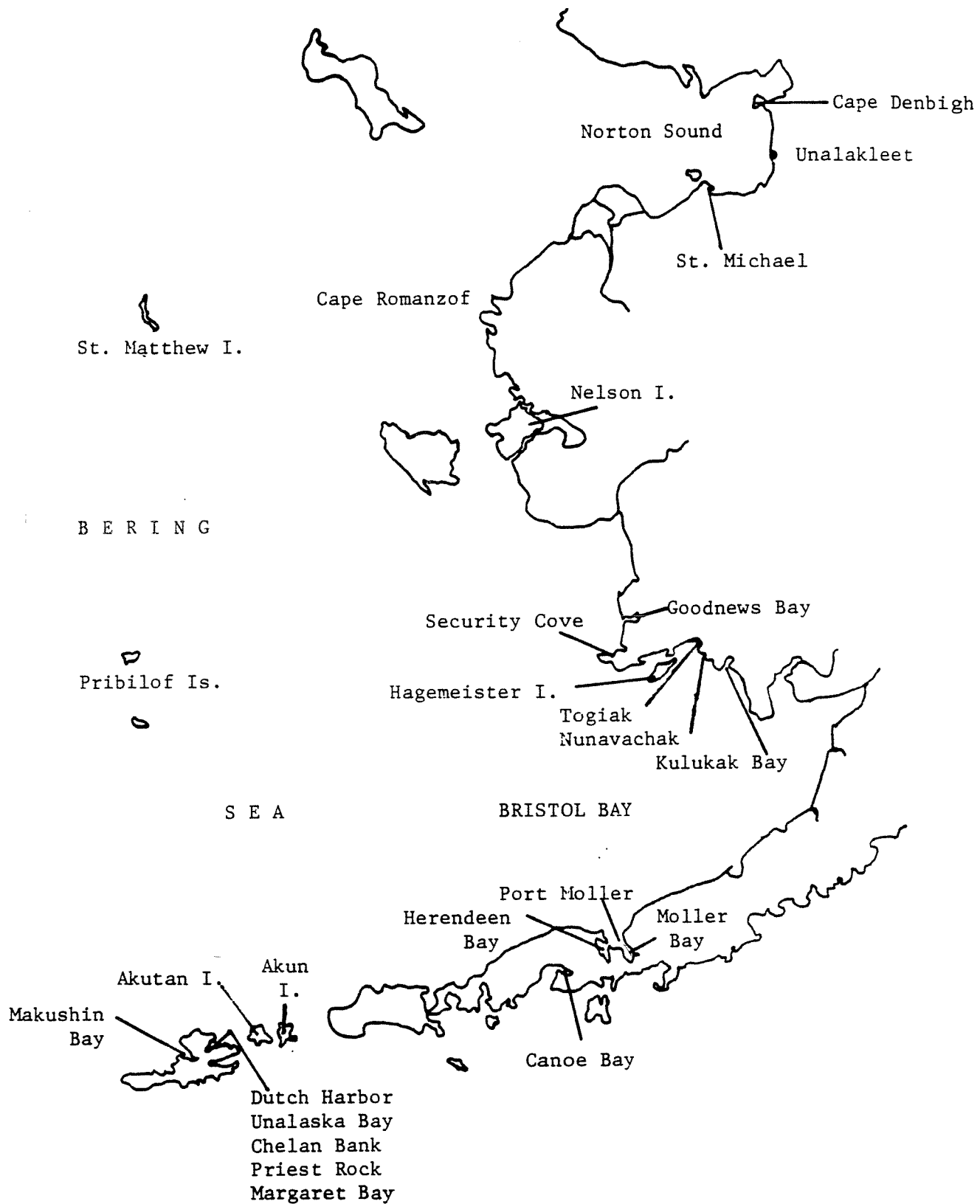


Fig. 4. Eastern Bering Sea study area.

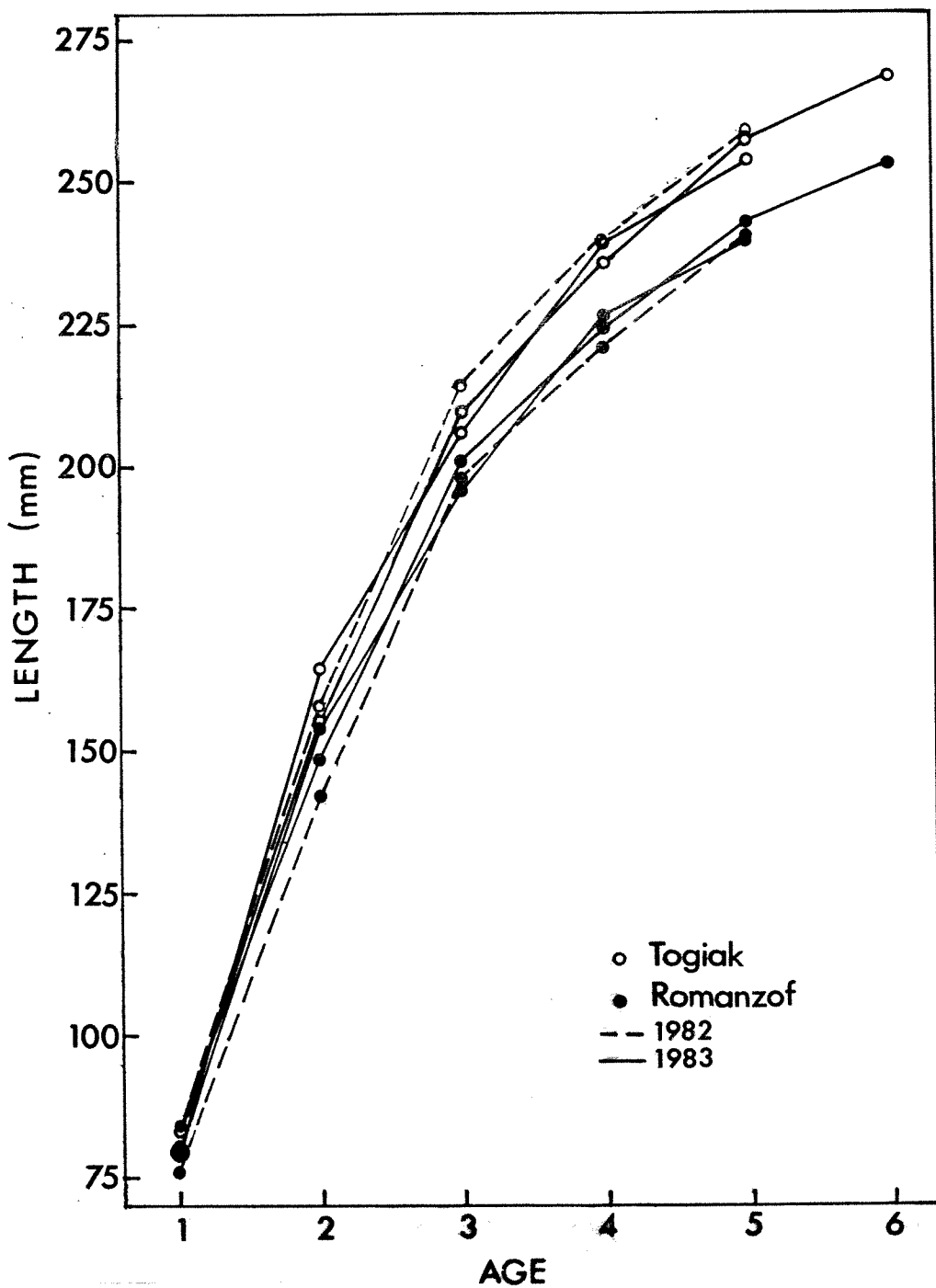


Fig. 5. Mean lengths by age (growth curves) for Togiak and Cape Romanzof herring stocks as calculated from scale samples of age 5 herring in 1982-1983 and age 6 herring in 1983.

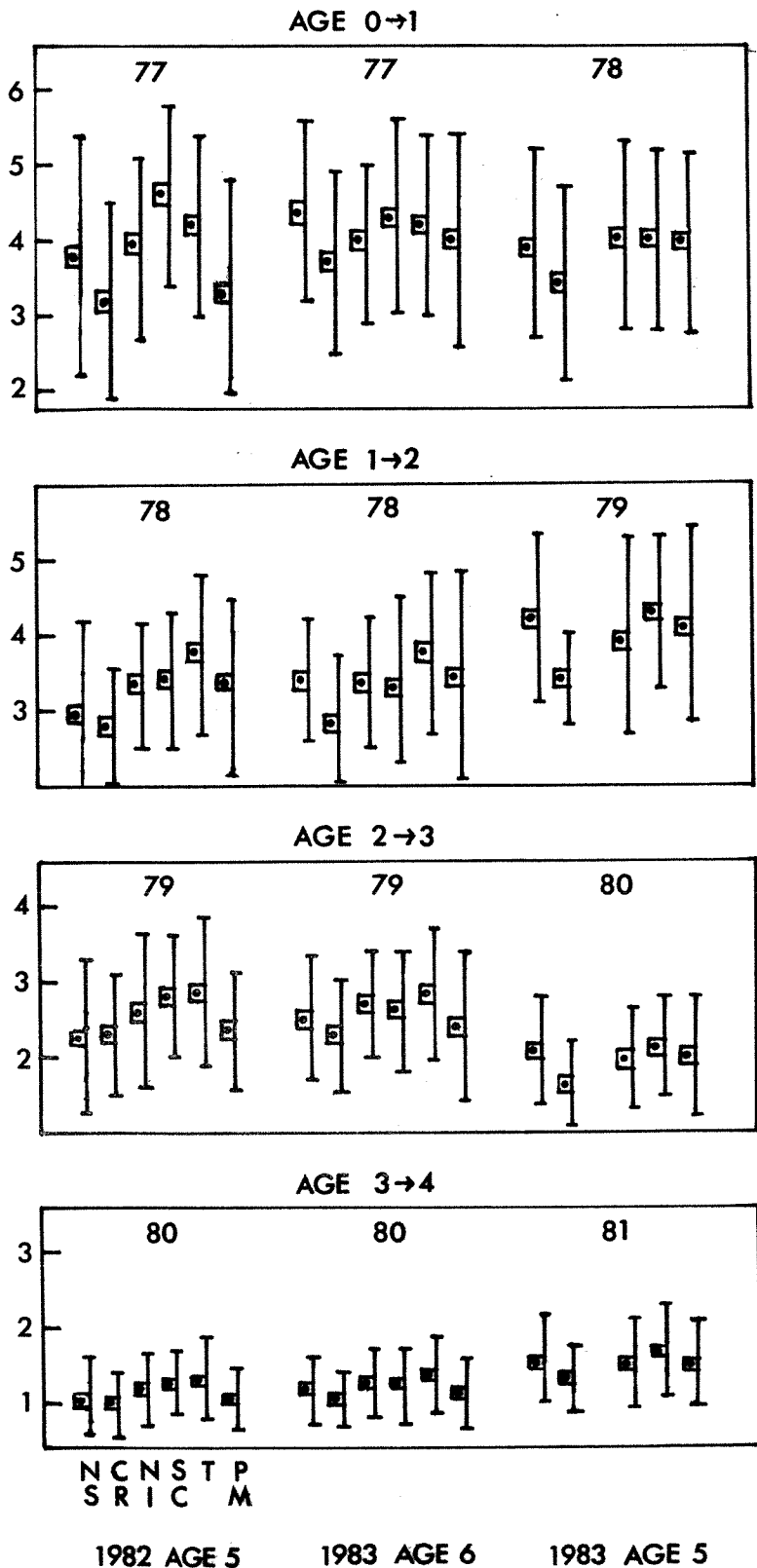


Fig. 6. Means, ± 2 S.E. and ± 2 S.D. of the distances between annuli (inches at 50x) for samples from Norton Sound, Cape Romanzof, Nelson Island, Security Cove, Togiak, and Port Moller collected in 1982 and 1983. Numbers in the boxes indicate the years in which the growth occurred.

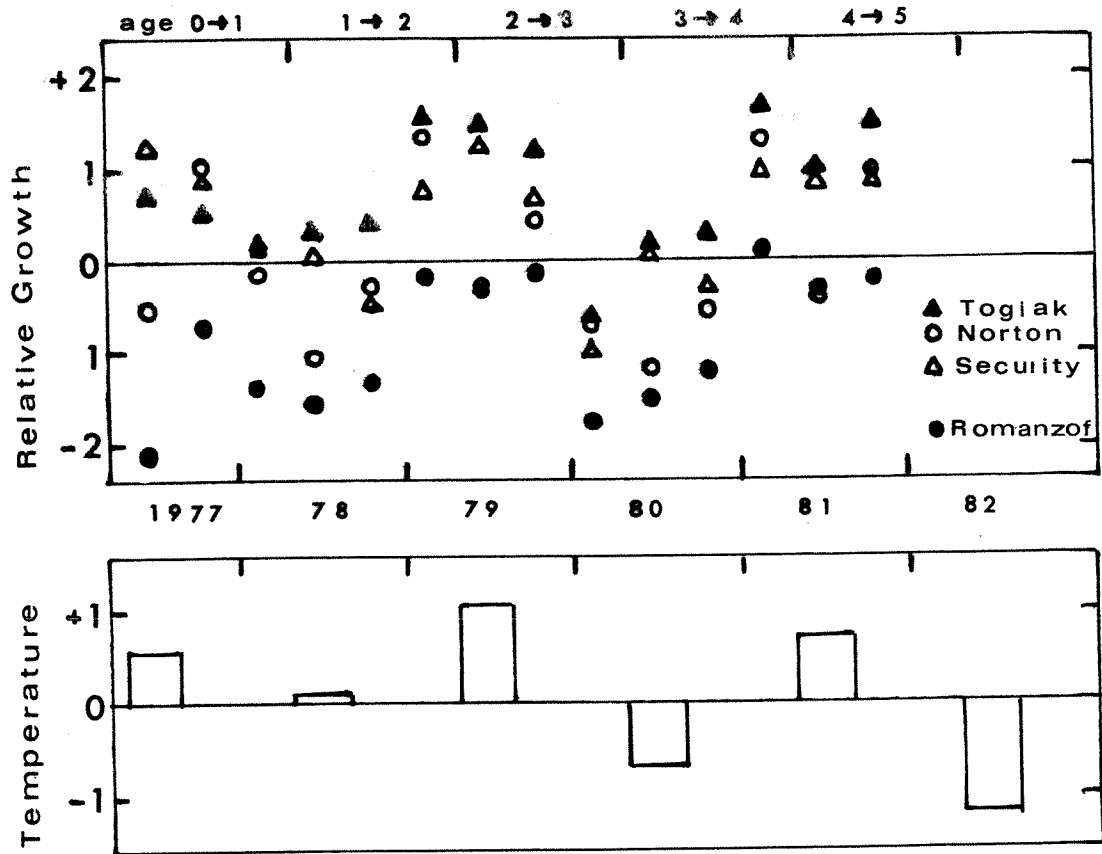


Fig. 7. Relative growth (number of standard deviations from the mean distance between annuli for each age group) and the means of the monthly air temperature deviations (May-August) for Bristol Bay.

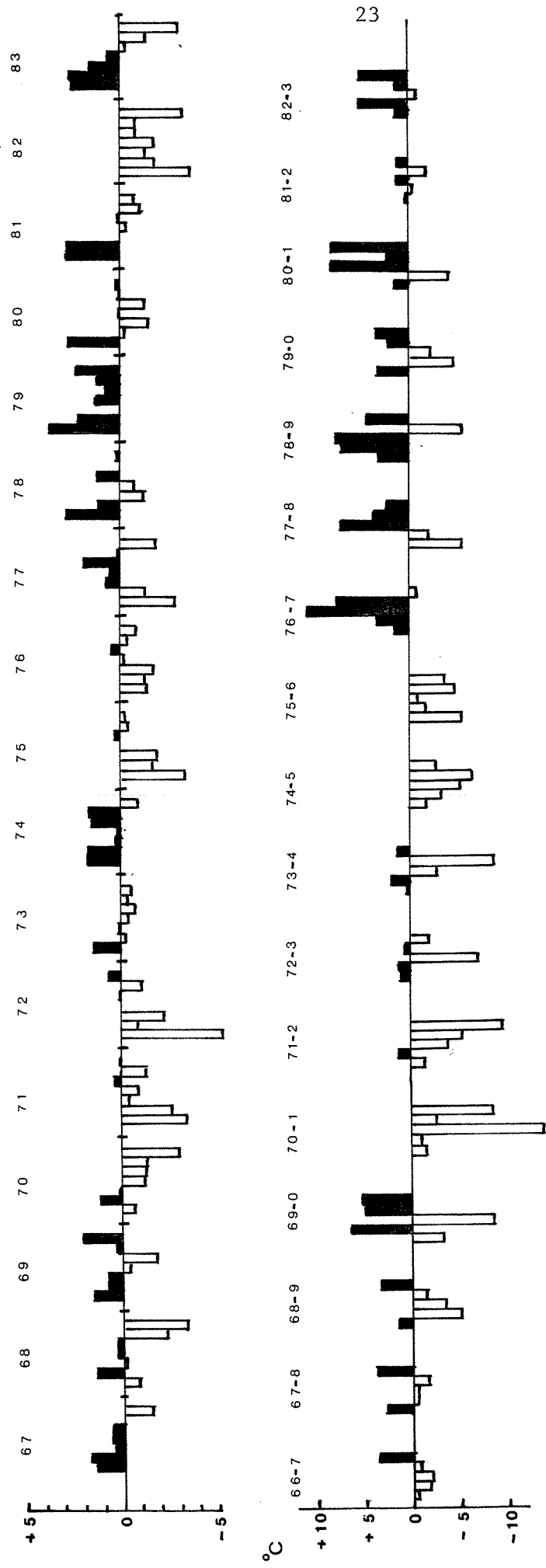


Fig. 8. Monthly air temperature deviations (from 62-year means) in Bristol Bay (Dillingham and King Salmon) for summer months, April-October (top) and winter months, November-March (bottom), Nov. 1966 to Oct. 1983.

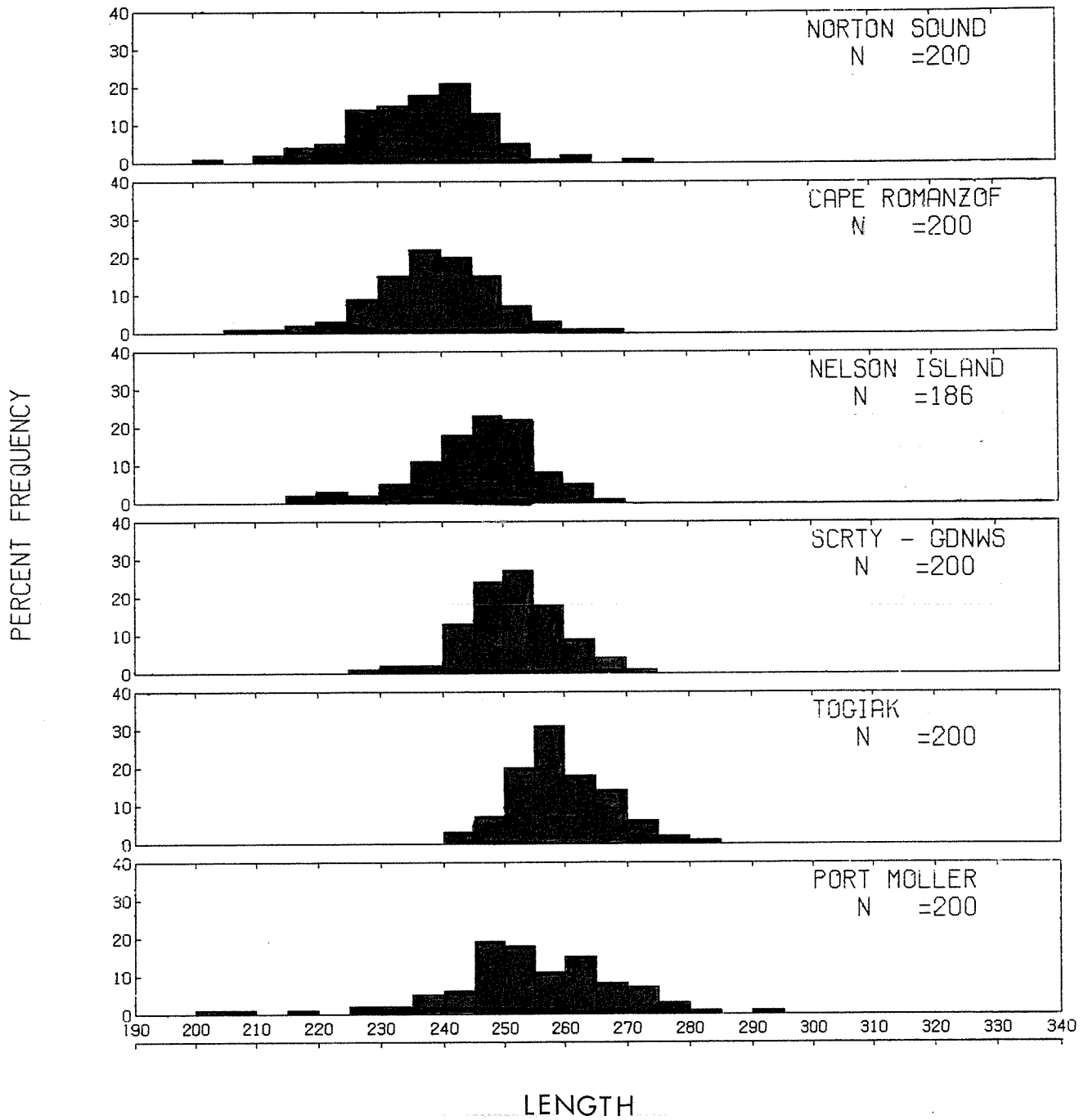


Fig. 9. Frequency distributions of standard length (mm) at age 5 for the age 5 standards from 1982.

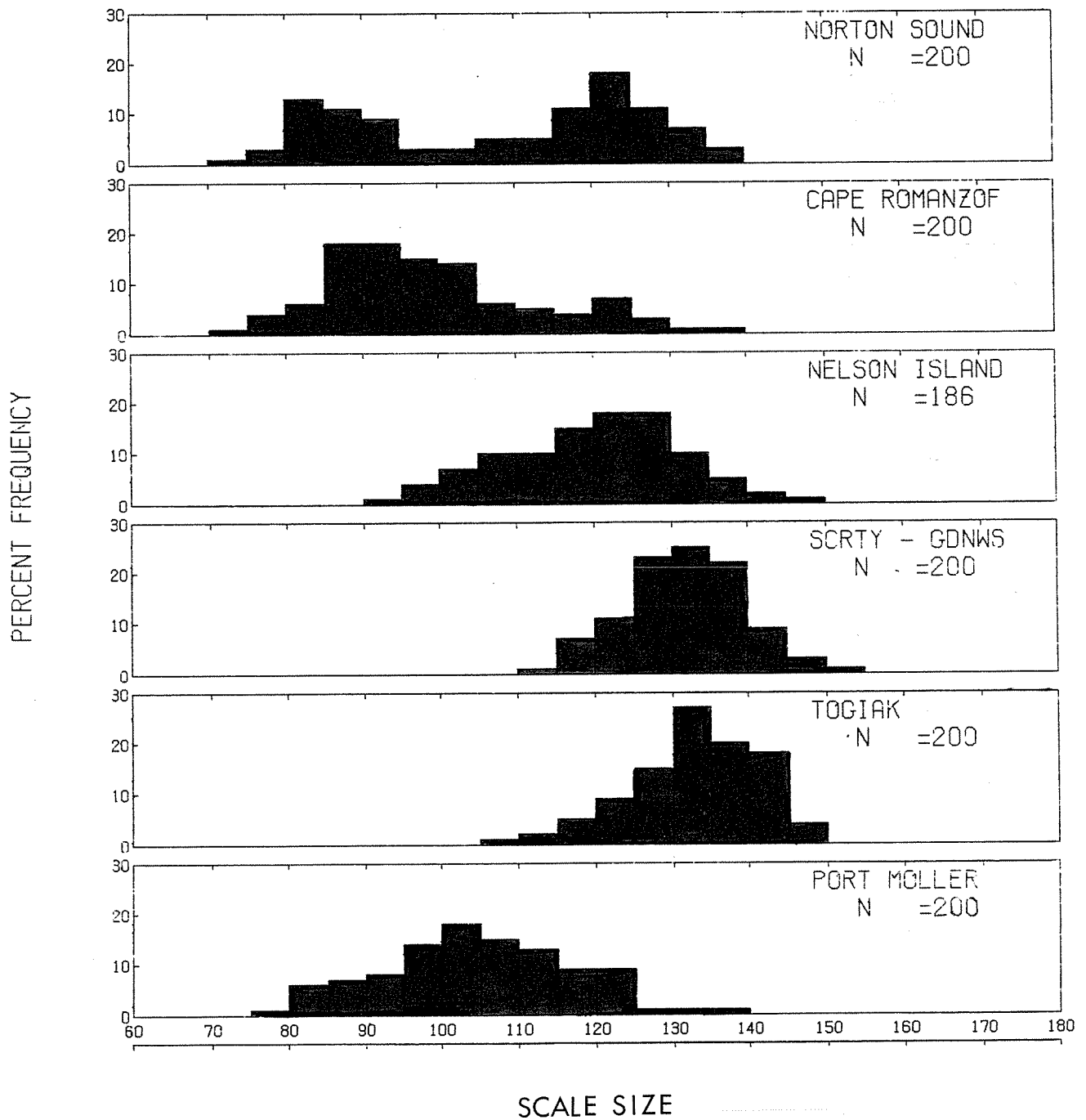


Fig. 10. Frequency distributions of scale size at age 5 for the age 5 standards from 1982. Measurements in .1 inches when magnified 50x.

82 Age 5

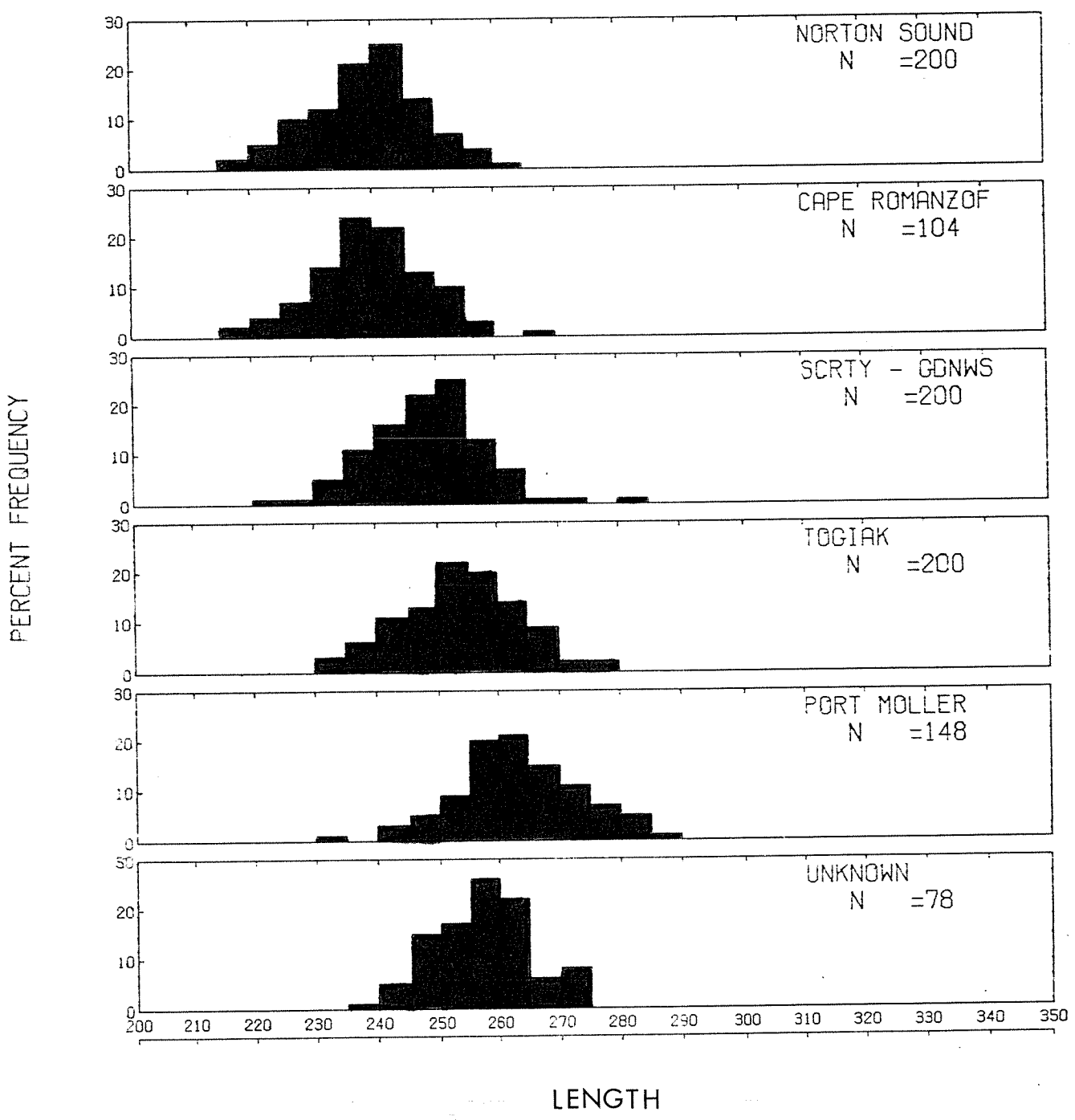


Fig. 11. Frequency distributions of standard length (mm) at age 5 for the age 5 standards and unknown from 1983.

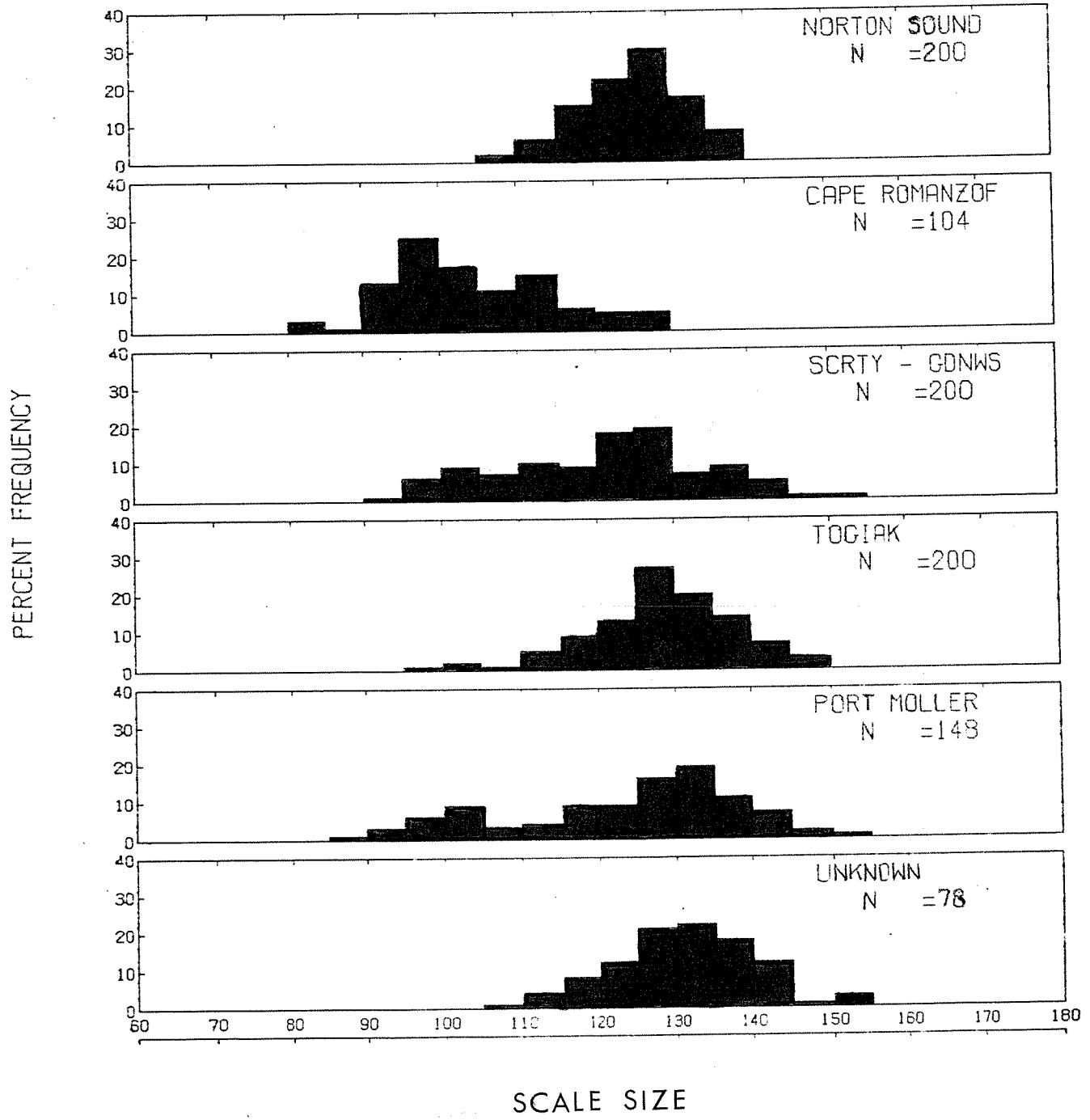


Fig. 12. Frequency distributions of scale size at age 5 for the age 5 standards and unknown from 1983. Measurements in .1 inches when magnified 50x.

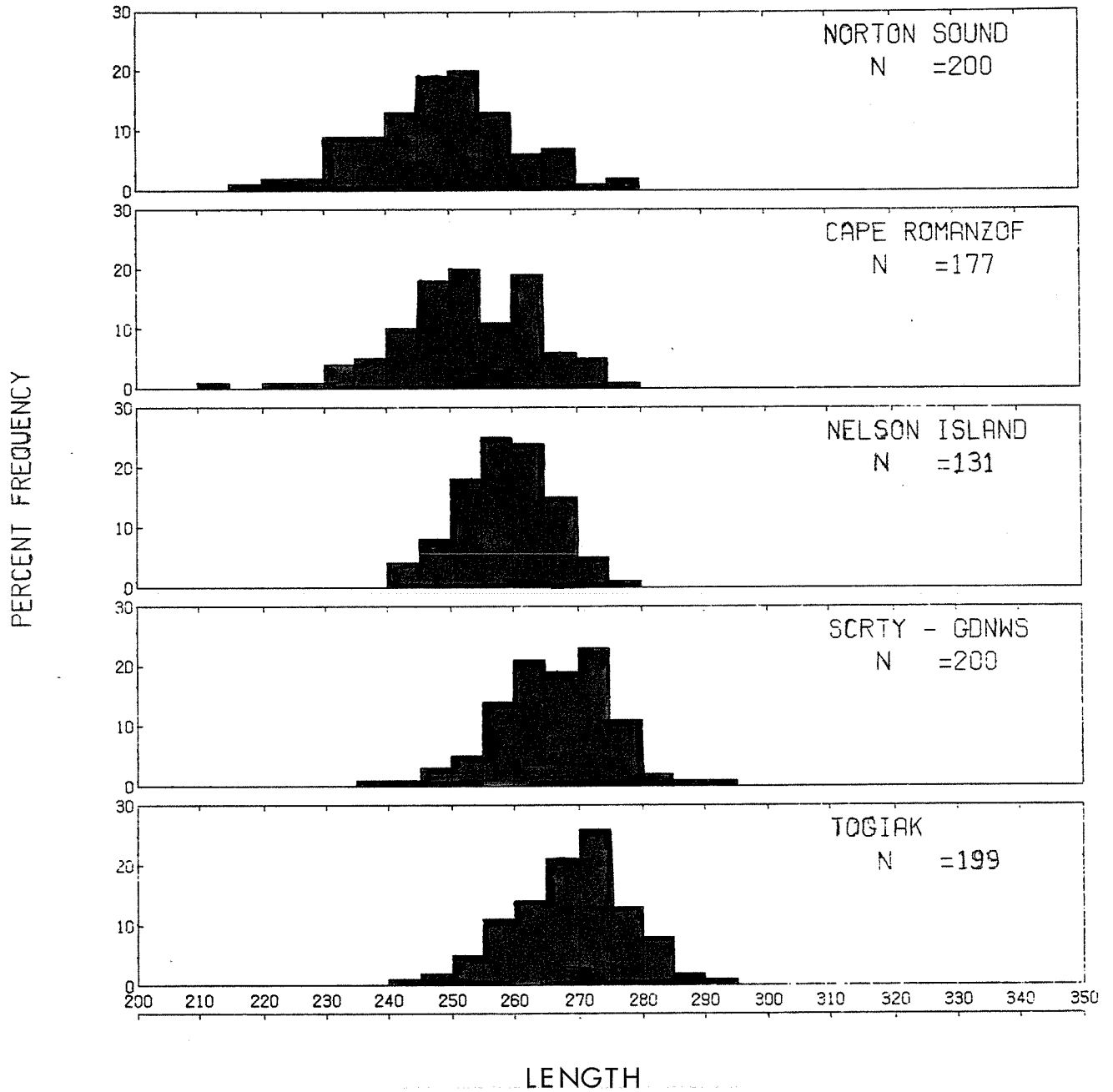


Fig. 13. Frequency distributions of standard length (mm) at age 6 for the age 6 northern standards from 1983.

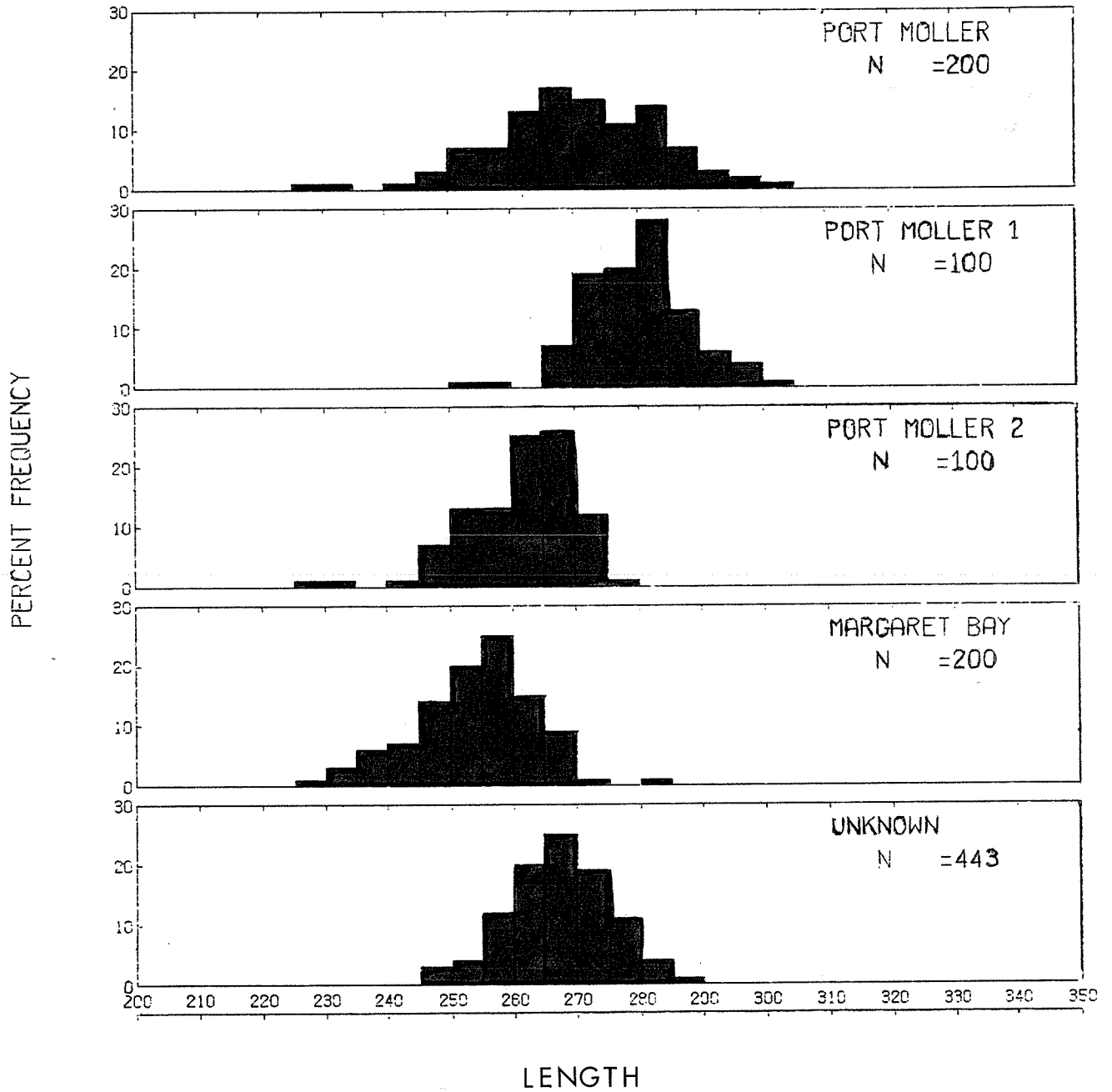


Fig. 14. Frequency distributions of standard length (mm) at age 6 for the age 6 southern standards and unknown from 1983.

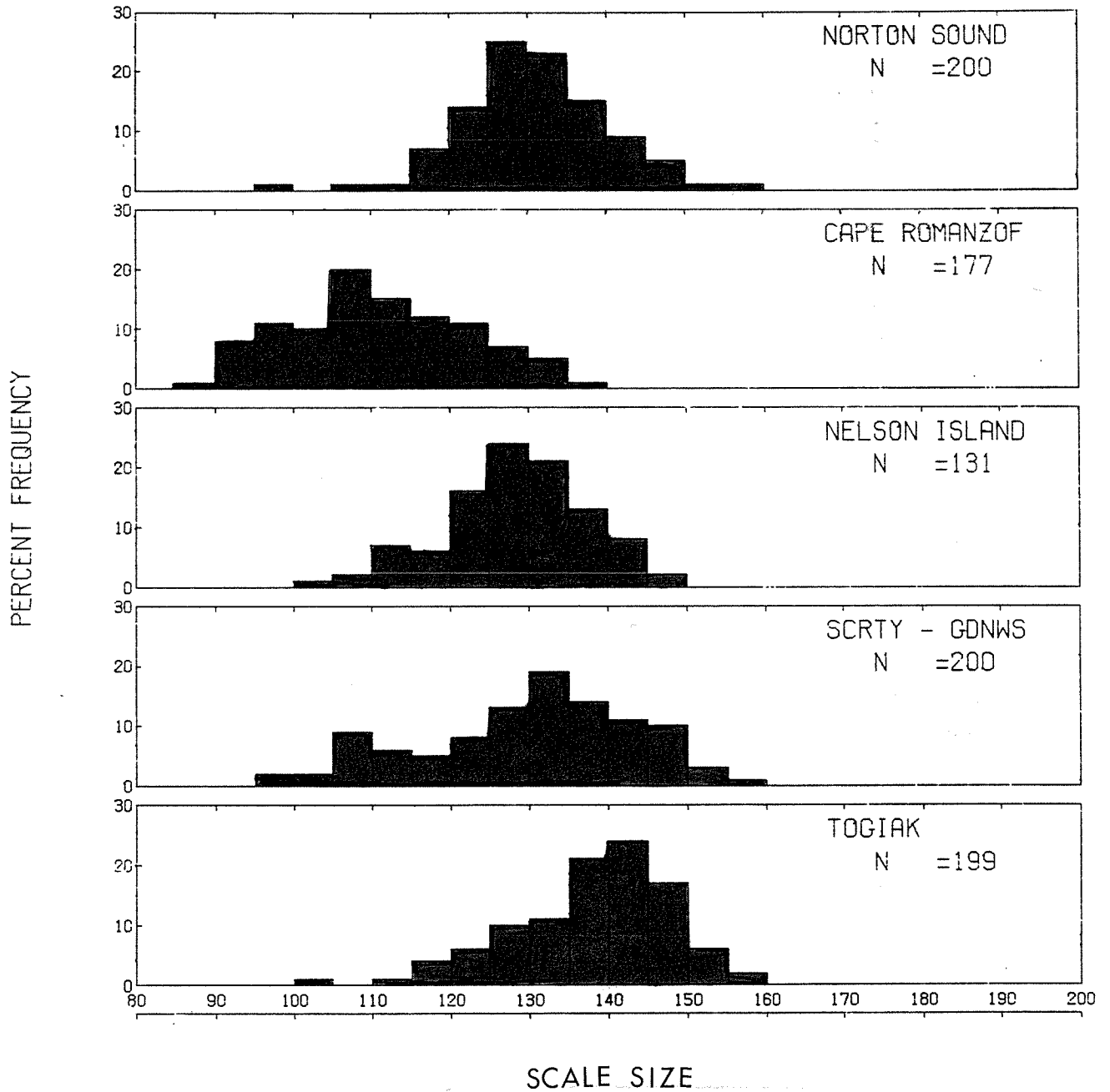


Fig. 15. Frequency distributions of scale size at age 6 for the age 6 northern standards from 1983. Measurements in .1 inches when magnified 50x.

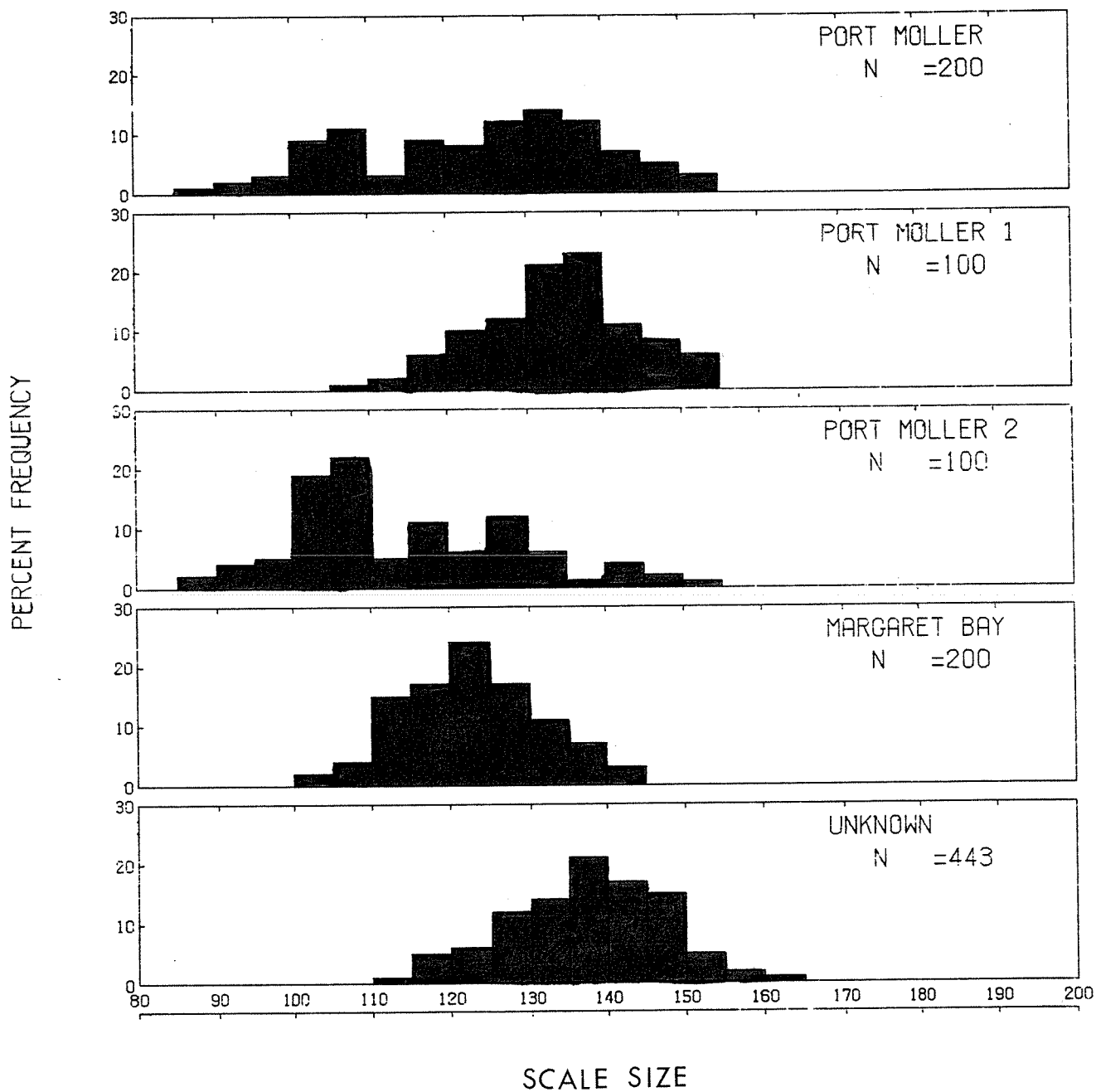


Fig. 16. Frequency distributions of scale size at age 6 for the age 6 southern standards and unknown from 1983. Measurements in .1 inches when magnified 50x.

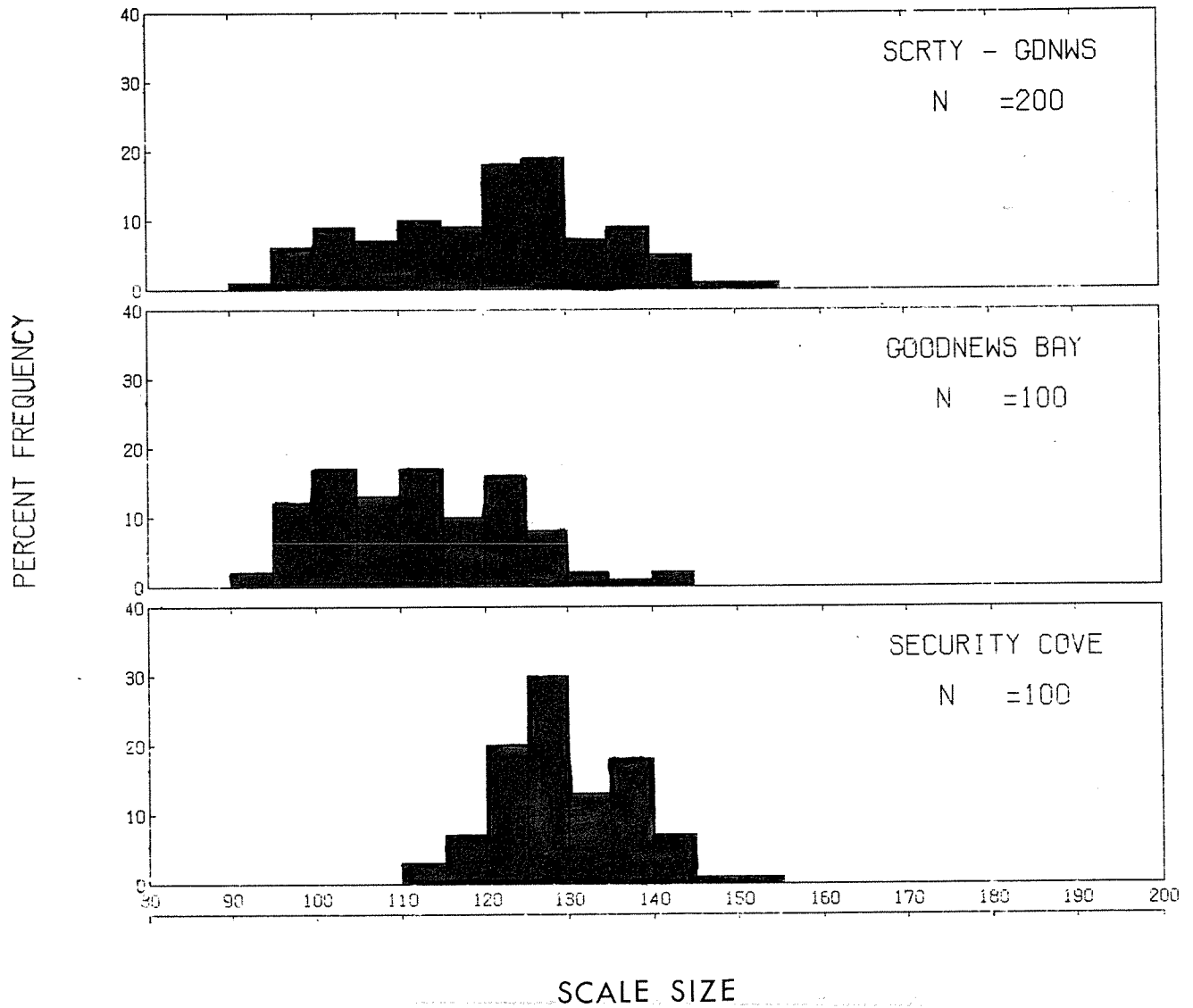


Fig. 17. Frequency distributions of scale size at age 5 for the 1983 age 5 Security Cove, Goodnews Bay, and combined Security Cove/Goodnews Bay standards. Measurements in .1 inches when magnified 50x.

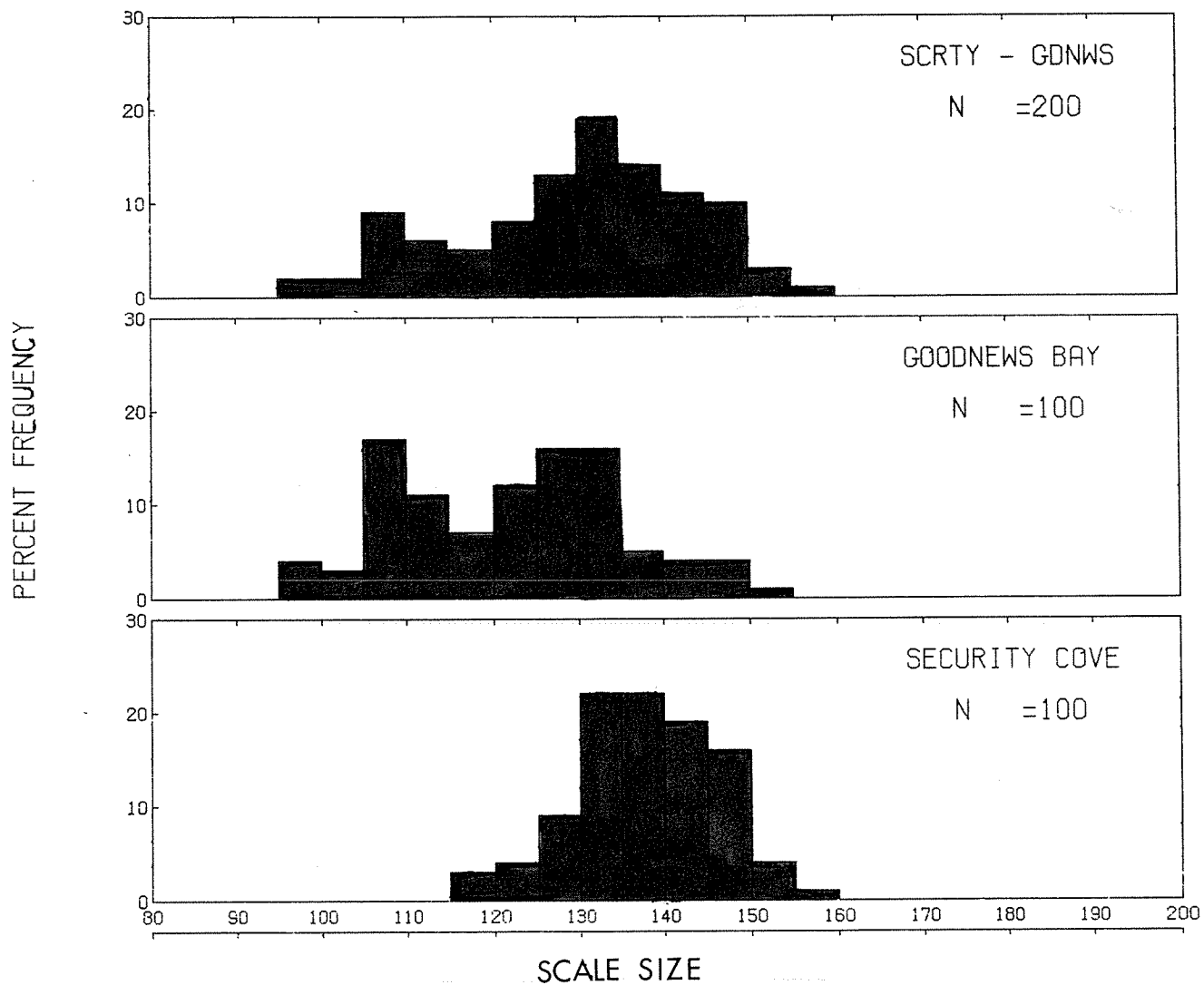


Fig. 18. Frequency distributions of scale size at age 6 for the 1983 age 6 Security Cove, Goodnews Bay, and combined Security Cove/Goodnews Bay standards. Measurements in .1 inches when magnified 50x.

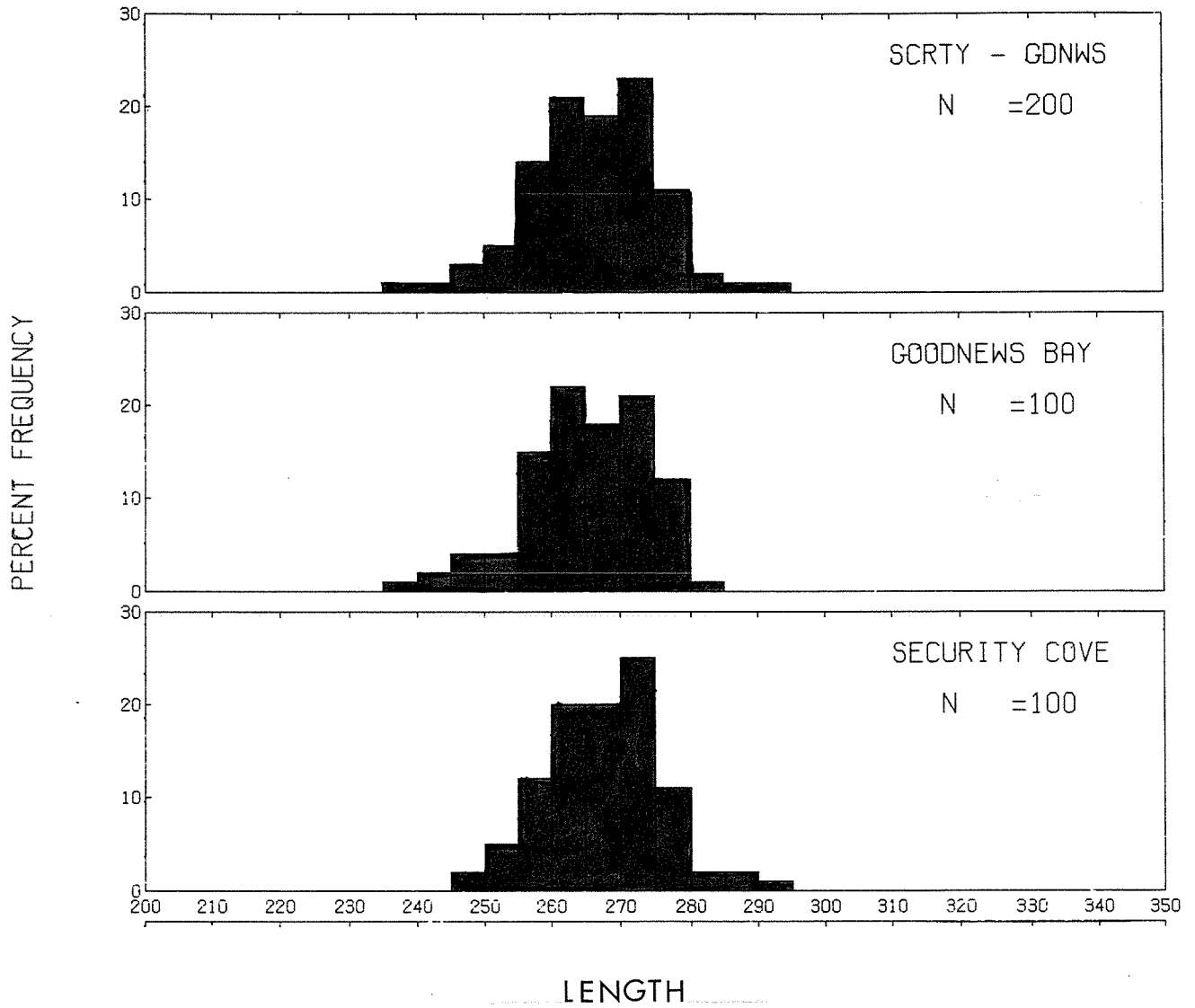


Fig. 19. Frequency distributions of standard length (mm) at age 6 for the 1983 age 6 Security Cove, Goodnews Bay, and combined Security Cove/Goodnews Bay standards.

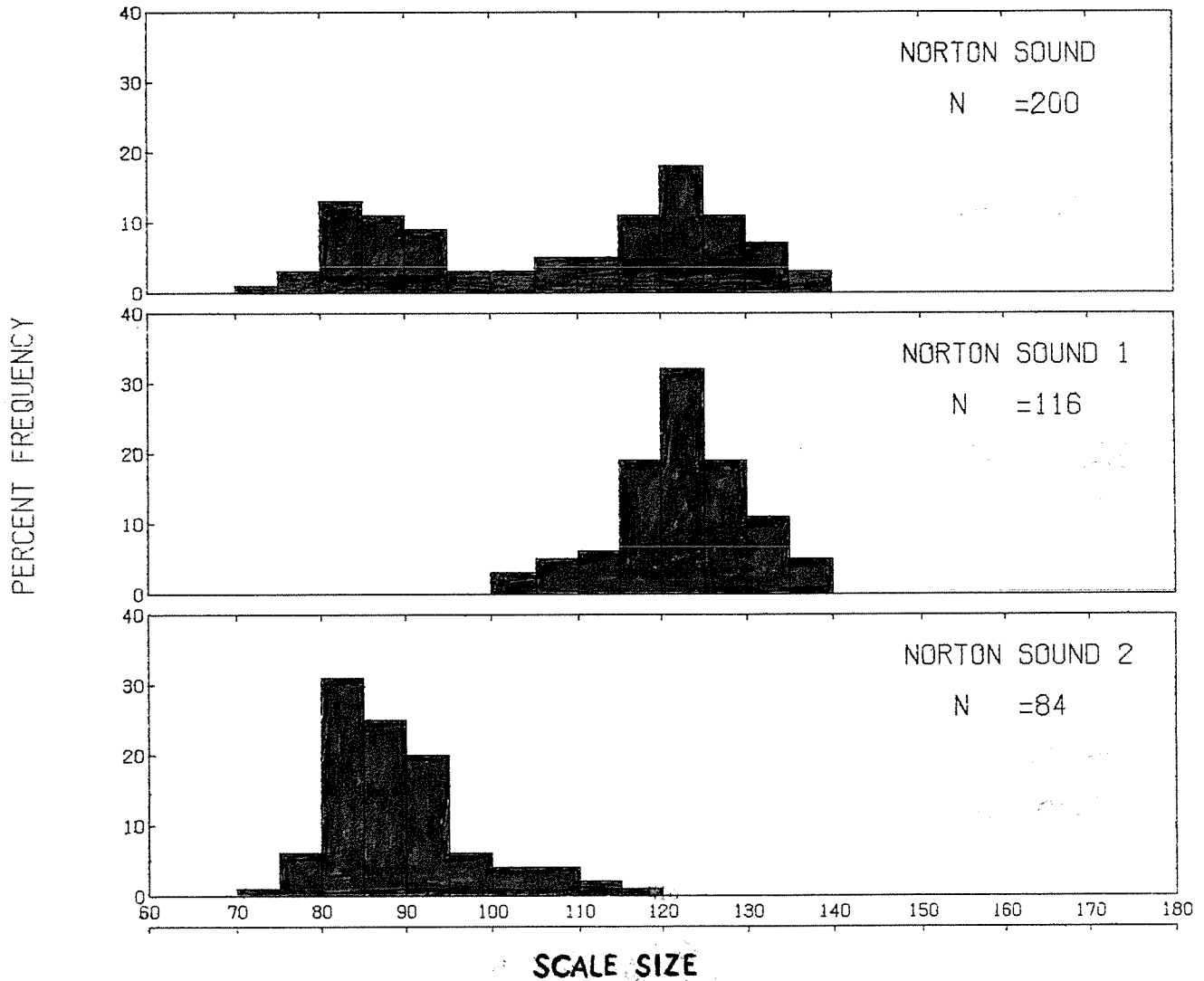


Fig. 20. Frequency distributions of scale size at age 5 for the 1982 age 5 Norton Sound standard and standards derived through isolation of subdistricts. Measurements in .1 inches when magnified 50 X.

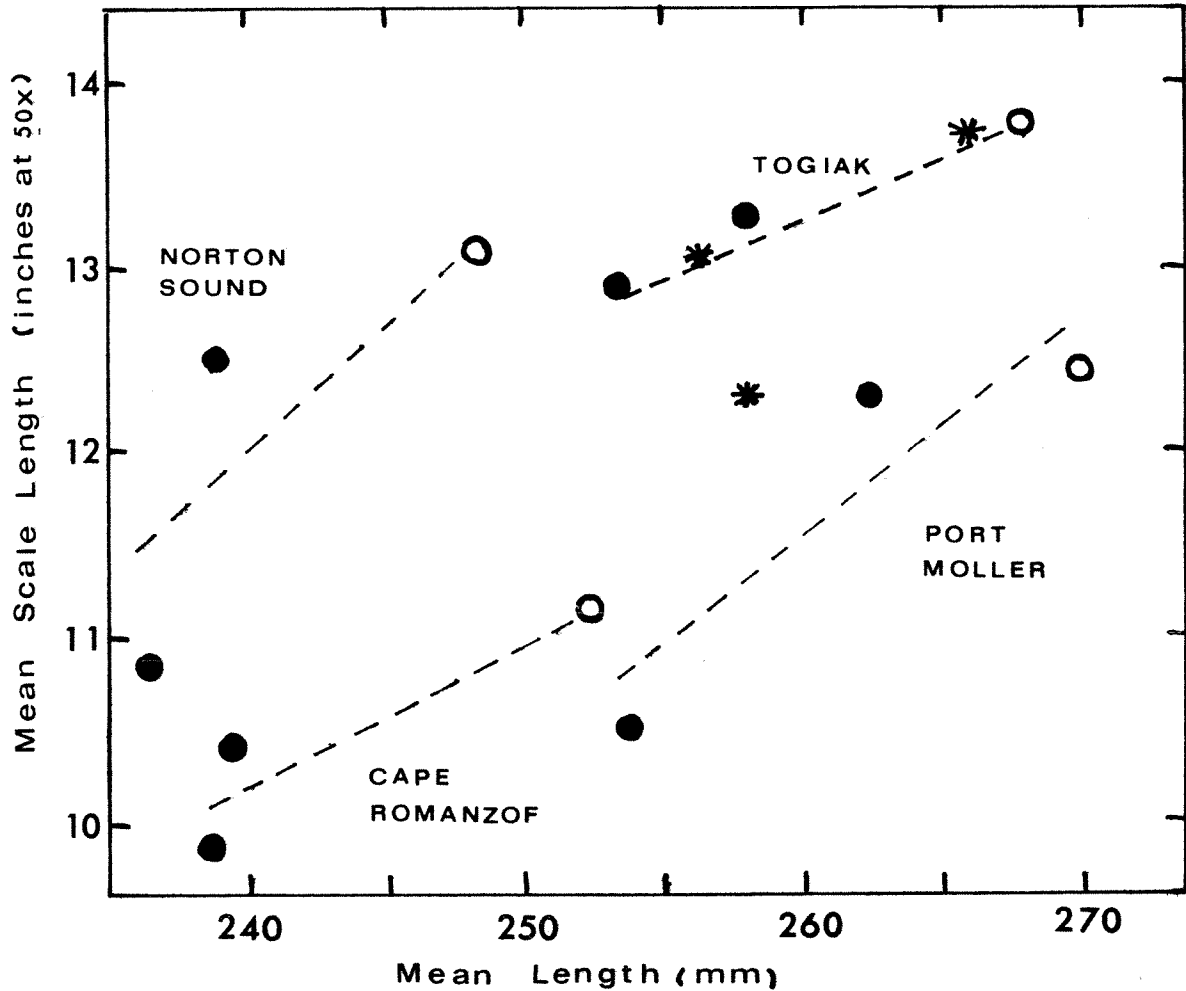


Fig. 21. Plots of the mean scale length on the mean body length for age 5 herring from 1982 and 1983 (solid points) and age 6 herring from 1983 (circles). The means from Dutch Harbor fishery samples are indicated by asterisks. (Observations from Nelson Island, Security Cove and Dutch Harbor spawning stocks (not shown) were intermediate between Norton Sound and Togiak.)

Table 1. Age composition of the incidental catch of Pacific herring in 1982 and 1983. (One year was added to the number of annuli counted for samples collected in the winter months of January-March.)

Fishing area	1982 Dates	Age composition (percent)										n
		2	3	4	5	6	7	8	9	10+		
2	3/7-3/15	0	32.6	38.1	26.6	1.4	0.9	0.4	0	0	0	218
1	7/6-7/16	0	0	0	8.0	10.7	7.2	38.4	21.4	14.3	0	112
1	8/5-8/9	0	0	6.4	41.0	12.8	3.2	18.0	7.7	10.9	0	156
1	8/1-8/19	0	0.8	24.8	44.8	9.6	2.4	8.0	3.2	6.4	0	125
1	8/8-8/24	0	0	7.8	46.1	8.7	2.5	18.1	9.8	7.0	0	358
1	9/9-9/28	0	0	15.6	64.4	6.2	1.2	10.0	1.3	1.3	0	160
1	9/14-9/26	0	3.5	9.2	56.3	5.7	2.3	11.5	8.0	3.5	0	87
2	11/29	0	0	11.0	67.7	14.2	0.8	5.5	0.8	0	0	127

Fishing area	1983 Dates	Age composition (percent)										n
		2	3	4	5	6	7	8	9	10+		
2	2/15-3/7	0	0	10.5	26.3	55.3	5.3	2.6	0	0	0	38
2	2/18-3/15	0	0	38.2	22.5	27.0	6.7	1.1	1.1	3.4	0	89
1	5/8-25	0.9	0	60.2	25.0	13.0	0.9	0	0	0	0	108
1	6/25-7/14	0	0	0	7.6	57.7	6.0	5.3	13.9	9.5	0	381
1	7/18-26	0	0	7.6	17.7	39.2	8.9	5.1	11.4	10.1	0	79
2	7/27-8/13	0	0	3.4	15.2	47.4	8.5	6.8	11.9	6.8	0	59

Table 2. Scale characters examined for the discriminant function analyses of age 5 Pacific herring.

Character number*	Description
1	Distance between focus and first annulus.
2	Distance between first and second annuli.
3	Distance between second and third annuli.
4	Distance between third and fourth annuli.
5	Distance between fourth and fifth annuli.
6	Distance from focus to second annulus.
7	Distance from focus to third annulus.
8	Distance from focus to fourth annulus.
9	Distance from focus to fifth annulus.
10	Proportion of scale growth in first year.
11	Proportion of scale growth in second year.
12	Proportion of scale growth in third year.
13	Proportion of scale growth in fourth year.
14	Proportion of scale growth in fifth year.
15	Back-calculated length at age 1.
16	Back-calculated length at age 2.
17	Back-calculated length at age 3.
18	Back-calculated length at age 4.
19	Length at age 5 (back-calculated for unknown summer samples).
20	Proportion of scale growth in first two years.
21	Proportion of scale growth in first three years.
22	Proportion of scale growth in first four years.
23	Proportion of growth in third, fourth, and fifth years.
24	Ratio of growth in third year to growth in second year.
25	Ratio of growth in fifth year to growth in fourth year.

*Scale characters 1-9 are in inches and characters 15-19 are in millimeters.

Table 3. Scale characters examined for the discriminant function analyses of age 6 Pacific herring.

Character number*	Description
1	Distance between focus and first annulus.
2	Distance between first and second annuli.
3	Distance between second and third annuli.
4	Distance between third and fourth annuli.
5	Distance between fourth and fifth annuli.
6	Distance between fifth and sixth annuli.
7	Distance from focus to second annulus.
8	Distance from focus to third annulus.
9	Distance from focus to fourth annulus.
10	Distance from focus to fifth annulus.
11*	Distance from focus to sixth annulus.
12	Proportion of scale growth in first year.
13	Proportion of scale growth in second year.
14	Proportion of scale growth in third year.
15	Proportion of scale growth in fourth year.
16	Proportion of scale growth in fifth year.
17	Proportion of scale growth in sixth year.
18	Back-calculated length at age 1.
19	Back-calculated length at age 2.
20	Back-calculated length at age 3.
21	Back-calculated length at age 4.
22	Back-calculated length at age 5.
23	Length at age 6 (back-calculated for unknown summer samples).
24	Proportion of scale growth in first two years.
25	Proportion of scale growth in first three years.
26	Proportion of scale growth in first four years.
27	Proportion of growth in fourth, fifth and sixth years.
28	Ratio of growth in third year to growth in second year.
29	Ratio of growth in sixth year to growth in fifth year.
30	Ratio of growth in fourth and fifth years to growth in sixth year.

*Scale characters 1-11 are in inches and characters 18-23 are in millimeters. Character number 11 is total scale size for all spawning samples.

Table 4. Sample sizes (n), means and standard deviations for 1982 age 5 scale characters.

Scale char- acter number	Location						
	Norton Sound (200)	Cape Romanzof (200)	Nelson Island (200)	Security Cove Goodnews Bay (200)	Togiak (200)	Port Moller (200)	
1	\bar{X}	3.78	3.13	3.93	4.47	4.26	3.26
	S.D.	0.81	.64	.62	.60	.62	.73
2		2.98	2.73	3.36	3.55	3.72	3.26
		0.61	.42	.48	.47	.51	.60
3		2.23	2.23	2.63	2.86	2.95	2.27
		0.50	.40	.51	.38	.44	.42
4		1.04	0.97	1.19	1.30	1.33	.94
		.27	.22	.25	.24	.26	.24
5		0.81	0.80	0.89	1.00	1.03	.76
		.22	.18	.23	.21	.20	.22
6		6.77	5.86	7.29	8.02	7.98	6.52
		1.22	.88	.70	.56	.62	.87
7		9.00	8.09	9.92	10.88	10.93	8.79
		1.55	1.11	.93	.64	.72	1.00
8		10.04	9.05	11.10	12.18	12.26	9.73
		1.71	1.22	1.04	.70	.78	1.08
9		10.85	9.86	11.99	13.18	13.29	10.50
		1.84	1.29	1.13	.75	.80	1.17
10		0.349	0.317	0.329	0.340	0.321	0.310
		0.049	0.041	0.052	0.045	0.043	0.054
11		0.275	0.277	0.280	0.269	0.280	0.312
		0.029	0.027	0.031	0.032	0.036	0.052
12		0.206	0.227	0.218	0.217	0.221	0.216
		0.028	0.029	0.032	0.024	0.028	0.034
13		0.096	0.098	0.099	0.098	0.100	0.090
		0.019	0.017	0.018	0.016	0.018	0.021
14		0.074	0.082	0.074	0.076	0.077	0.073
		0.016	0.016	0.017	0.016	0.015	0.018

Table 4. Sample sizes (n), means and standard deviations for 1982 age 5 scale characters - cont'd.

Scale char- acter number	Location					
	Norton Sound (200)	Cape Romanzof (200)	Nelson Island (200)	Security Goodnews Bay (200)	Cove Togiak (200)	Port Moller (200)
15	82.4 10.4	75.5 9.7	80.4 12.2	85.3 11.4	82.9 11.5	78.6 14.7
16	147.4 8.4	141.6 8.3	149.2 10.2	153.0 9.7	157.2 10.7	157.6 13.4
17	196.1 8.6	195.8 9.4	202.8 9.4	207.4 8.2	212.4 8.5	212.4 12.1
18	218.8 9.3	219.2 9.9	227.0 9.8	232.1 7.8	238.3 7.8	235.1 11.5
19	236.5 10.4	238.7 9.7	245.0 9.8	251.1 7.7	258.3 7.5	253.6 12.9
20	0.624 0.041	0.594 0.032	0.609 0.044	0.609 0.035	0.601 0.036	0.621 0.044
21	0.830 0.027	0.820 0.025	0.828 0.027	0.826 0.024	0.822 0.023	0.838 0.032
22	0.926 0.016	0.918 0.016	0.926 0.017	0.924 0.015	0.923 0.015	0.927 0.018
23	0.376 0.041	0.406 0.032	0.391 0.044	0.391 0.035	0.399 0.036	0.379 0.044
24	0.756 0.130	0.827 0.132	0.789 0.149	0.817 0.132	0.806 0.156	0.714 0.164
25	0.801 0.222	0.856 0.225	0.768 0.216	0.786 0.192	0.794 0.214	0.838 0.245

Table 5. Sample sizes (n), means and standard deviations for 1983 age 5 scale characters.

Scale char- acter number	Location						
	Norton Sound (200)	Cape Romanzof (104)	Security Cove (200)	Togiak (200)	Port Moller (148)	Dutch Harbor unknown (n = 78)	
1	\bar{X} S.D.	3.92 .64	3.43 0.64	4.04 .62	4.03 .58	3.96 .62	4.14 .48
2		4.22 .54	3.44 0.59	3.92 .64	4.33 .52	4.14 .65	4.36 .44
3		2.06 .35	1.64 0.28	1.95 0.34	2.07 0.31	2.01 .39	2.08 .28
4		1.57 .30	1.31 0.23	1.50 .31	1.65 .30	1.50 .28	1.65 .26
5		.75 .18	0.58 0.15	0.69 0.17	.79 .16	0.72 0.17	.84 .18
6		8.15 .58	6.87 .90	7.96 .90	8.36 .76	8.10 1.04	8.50 .65
7		10.20 .60	8.52 1.00	9.91 1.04	10.43 .82	10.11 1.21	10.58 .73
8		11.77 .69	9.82 1.01	11.41 1.19	12.08 .89	11.62 1.37	12.23 .85
9		12.52 .69	10.40 1.06	12.10 1.26	12.87 .93	12.33 1.45	13.07 .93
10		.314 .051	.330 .049	.335 .047	.313 .039	.322 .039	.317 .032
11		.337 .039	.330 .041	.323 .036	.337 .034	.336 .033	.334 .027
12		.164 .024	.158 .023	.161 .022	.161 .021	.163 .024	.159 .018
13		.125 .021	.127 .023	.124 .020	.128 .021	.122 .017	.126 .016
14		.060 .014	.055 .013	.057 .012	.061 .011	.058 .012	.064 .012

Table 5. Samples sizes (n), means and standard deviations for 1983 age 5 scale characters - cont'd.

Scale char- acter number	Location					
	Norton Sound (200)	Cape Romanzof (104)	Security Cove (200)	Togiak (200)	Port Moller (148)	Dutch Harbor unknown (n = 78)
15	75.0 12.4	79.0 12.4	83.0 12.0	79.2 10.0	84.3 10.1	84.2 9.0
16	155.6 10.7	158.0 11.3	163.2 11.8	164.6 11.4	172.4 11.7	172.7 9.4
17	194.8 8.8	195.8 10.3	203.1 10.4	205.3 10.4	215.1 10.5	214.9 8.5
18	224.7 9.3	226.1 9.0	233.8 9.0	237.8 9.5	247.0 10.6	248.3 7.7
19	239.0 8.8	239.4 8.9	248.0 8.8	253.3 9.7	262.2 10.5	256.4 8.2
20	.651 .039	.660 .039	.658 .040	.650 .039	.658 .039	.651 .032
21	.815 .025	.818 .029	.819 .028	.810 .026	.820 .023	.810 .022
22	.940 .014	.945 .013	.943 .012	.939 .011	.942 .012	.936 .012
23	.349 .039	.340 .039	.342 .040	.350 .039	.342 .039	.349 .032
24	.494 .108	.488 .109	.506 .104	.484 .095	.491 .097	.480 .076
25	.498 .166	.448 .120	.469 .100	.485 .101	.483 .105	.516 .108

Table 6. Sample sizes (n), means and standard deviations for 1983 age 6 scale characters.

Scale character number	Location											Unknowns (443)
	Norton Sound (200)	Cape Romanzof (177)	Nelson Island (131)	Security Cove (200)	Togiak (199)	Port Moller (200)	Port Moller (100)	Port Moller (1) (100)	Port Moller (2) (100)	Dutch Harbor (200)	Unknowns (443)	
1	4.38	3.69	3.96	4.32	4.19	4.03	4.29	3.77	3.40	4.36		
S.D.	.58	.58	.54	.64	.58	.71	.60	.71	.51	.66		
2	3.39	2.85	3.36	3.30	3.75	3.45	3.76	3.14	3.46	3.59		
	.42	.42	.44	0.59	.54	.69	.63	.60	.43	.48		
3	2.52	2.29	2.70	2.62	2.83	2.41	2.61	2.22	2.83	2.76		
	.43	.37	.35	0.40	.43	.48	0.44	0.44	.36	.42		
4	1.17	1.03	1.26	1.23	1.36	1.14	1.24	1.04	1.41	1.32		
	.22	.20	.23	.25	.25	.25	.22	.23	.23	.25		
5	1.02	.83	1.07	1.01	1.11	.95	1.03	.86	.83	1.08		
	.20	.18	.21	.23	.20	.22	.19	.22	.15	.20		
6	.60	.44	.50	.51	0.56	.44	.48	.39	.36	.58		
	.16	.12	.12	.12	0.12	.12	.10	.11	.07	.13		
7	7.78	6.55	7.32	7.62	7.94	7.48	8.05	6.91	6.85	7.96		
	.58	.75	.60	.82	.71	1.05	.81	.96	.72	.69		
8	10.29	8.82	10.02	10.24	10.77	9.89	10.66	9.13	9.68	10.72		
	.69	.94	.73	.99	.78	1.25	.83	1.12	.80	.79		
9	11.46	9.85	11.29	11.47	12.13	11.03	11.90	10.16	11.09	12.04		
	.76	1.01	.81	1.13	.81	1.37	.86	1.24	.84	.88		
10	12.48	10.68	12.36	12.48	13.24	11.98	12.93	11.02	11.92	13.12		
	.85	1.09	.87	1.26	.92	1.50	.94	1.35	.86	.96		
11	13.08	11.12	12.86	12.99	13.79	12.42	13.42	11.42	12.28	13.70		
	.86	1.12	.90	1.32	.95	1.56	0.98	1.40	.88	1.00		

Table 6. Sample sizes (n), means and standard deviations for 1983 age 6 scale characters - cont'd.

Scale character number	Location											Unknowns (443)
	Norton Sound (200)	Cape Romanzof (177)	Nelson Island (131)	Security Cove (200)	Togiak (199)	Port Moller (200)	Port Moller (100)	Port Moller (1)	Port Moller (2)	Dutch Harbor (200)	Unknowns (443)	
12	.336 .046	.332 .042	.308 .041	.334 .047	.304 .043	.326 .047	.321 .045	.331 .048	.277 .037	.319 .046		
13	.259 .026	.256 .026	.262 .028	.254 .033	.272 .032	.277 .039	.280 .038	.275 .041	.281 .026	.262 .030		
14	.192 .027	.206 .025	.210 .022	.202 .024	.205 .026	.194 .029	.195 .028	.194 .031	.230 .023	.201 .025		
15	.089 .014	.093 .017	.098 .015	.094 .015	.099 .017	.091 .015	.092 .015	.090 .016	.115 .017	.096 .015		
16	.077 .014	.074 .014	.083 .015	.077 .014	.080 .012	.076 .014	.077 .012	.075 .015	.068 .012	.079 .013		
17	.046 .012	.039 .010	.039 .009	.039 .008	.040 .008	.035 .008	.036 .007	.034 .008	.029 .006	.042 .009		
18	83.3 10.3	83.8 10.6	79.5 10.8	88.7 12.5	81.5 11.3	87.9 13.4	89.8 13.3	86.1 13.3	70.2 10.1	87.1 12.8		
19	147.7 8.4	148.4 10.2	147.0 9.6	156.0 10.2	154.4 11.2	162.8 15.0	167.9 14.2	157.6 14.0	141.4 12.4	158.7 11.2		
20	195.5 9.4	200.4 10.1	201.2 9.7	209.6 8.9	209.3 8.7	215.2 12.6	222.3 10.4	208.1 10.4	199.6 11.2	213.6 9.4		
21	217.8 10.1	223.8 10.8	226.5 8.6	234.6 8.3	235.7 7.8	239.9 12.2	248.1 8.9	231.6 9.2	228.7 9.7	239.9 8.6		
22	237.0 11.5	242.6 11.2	247.8 7.2	255.2 8.4	257.2 8.7	260.4 12.6	269.6 8.4	251.3 8.9	245.9 8.9	261.4 8.6		

Table 6. Sample sizes (n), means and standard deviations for 1983 age 6 scale characters - cont'd.

Scale character number	Location										Unknowns (443)
	Norton Sound (200)	Cape Romanzof (177)	Nelson Island (131)	Security Cove (200)	Togiak (199)	Port Moller (200)	Port Moller (100)	Port Moller (100)	Dutch Harbor (200)	Dutch Harbor (200)	
23	248.4 11.3	252.5 11.1	257.8 7.1	265.6 8.6	267.9 8.7	269.9 12.8	279.6 8.2	260.2 8.6	253.3 8.9	266.3 8.3	
24	0.595 0.037	.588 .034	.570 .034	.588 .037	.576 .041	.603 .046	.600 .045	.606 .047	.558 .041	.581 .038	
25	0.787 0.025	.794 .025	.780 .028	.789 .026	.781 .027	.797 .028	.795 .027	.800 .029	.788 .028	.783 .026	
26	0.877 0.018	.886 .017	.878 .019	.884 .018	.880 .015	.889 .017	.887 .016	.890 .019	.903 .015	.879 .017	
27	0.213 0.025	.206 .025	.220 .028	.211 .026	.219 .027	.203 .028	.205 .027	.200 .029	.212 .028	.217 .026	
28	0.745 0.118	.813 .133	.811 .113	.807 .134	.768 .149	.720 .168	.712 .156	.727 .180	.826 .125	.778 .132	
29	0.613 0.216	.547 .168	.479 .111	.520 .127	.514 .123	.473 .119	.475 .092	.471 .142	.441 .094	.545 .133	
30	0.283 0.052	.286 .050	.320 .057	.294 .054	.313 .060	.282 .060	.286 .058	.278 .062	.332 .069	.304 .055	

Table 7. Final decision arrays for the (a) 1982 age 5 PDF analysis, (b) 1983 age 5 PDF analysis, (c) 1983 age 6 PDF analysis, and (d) 1983 age 6 LDF analysis.

(a) Calculated decision	Correct decision (%)			Overall accuracy: 73.4%
	Nelson Is.	Togiak	Port Moller	
Nelson Is.	122 (65.6)	36	32	
Togiak	35	152 (76.0)	11	
Port Moller	29	12	157 (78.5)	
Total	186	200	200	

(b) Calculated decision	Correct decision (%)				Overall accuracy: 65.2%
	Norton Sd.	C. Romanzof	Togiak/SC/GB	Port Moller	
Norton Sd.	140 (70.0)	14	30	3	
Cape Romanzof	12	78 (75.7)	13	18	
Togiak/SC/GB	47	5	100 (50.0)	31	
Port Moller	1	7	57	96 (64.9)	
Total	200	104	200	148	

(c) Calculated decision	Correct decision (%)				Overall accuracy: 63.0%
	Norton Sd.	Nelson Is.	Togiak	Port Moller 1	
Norton Sd.	140 (70.0)	24	21	3	
Nelson Is.	37	78 (59.5)	37	6	
Togiak	22	25	96 (48.2)	39	
Port Moller 1	1	4	45	138 (74.2)	
Total	200	131	199	186	

(d) Calculated decision	Correct decision (%)				Overall accuracy: 64.3%
	Norton Sd.	Nelson Is.	Togiak	Port Moller 1	
Norton Sd.	133 (66.5)	13	15	0	
Nelson Is.	43	84 (64.1)	32	8	
Togiak	22	31	107 (53.8)	43	
Port Moller 1	2	3	45	135 (72.6)	
Total	200	131	199	186	

Table 8a. Mixing proportion estimates of age 6 herring in the 1983 Dutch Harbor fishery (percentages with 90% confidence intervals).

Date	Sample size	Standards (spawning stocks)			
		Norton Sd.	Nelson Is.	Togiak	Port Moller 1
7/20-25	25	22.3(0-65)	28.3(0-90)	49.4(0-100)	0(0-33)
7/26-30	86	1.9(0-22)	28.8(0-65)	69.3(19-100)	0(0-23)
8/1-5	99	0(0-18)	0(0-34)	100.0(48-100)	0(0-26)
8/8-12	129	0(0-13)	10.1(0-40)	88.7(42-100)	1.2(0-27)
8/16-20	104	0(0-16)	12.0(0-42)	79.0(31-100)	9.1(0-36)
All	443	0(0-11)	12.5(0-34)	87.5(54-100)	0(0-18)

Table 8b. Mixing proportion estimates of age 6 herring in the 1983 Dutch Harbor fishery, as determined by linear discriminant analysis (percentages with 90% confidence intervals).

Date	Sample size	Standards (spawning stocks)			
		Norton Sd.	Nelson Is.	Togiak	Port Moller 1
7/20-25	25	38.9(0-80)	18.0(0-70)	43.2(0-100)	0(0-32)
7/26-30	86	14.0(0-34)	2.4(0-30)	83.6(37-100)	0(0-25)
8/1-5	99	0(0-15)	0(0-26)	100.0(53-100)	0(0-26)
8/8-12	129	0(0-13)	6.8(0-31)	93.1(50-100)	0.2(0-26)
8/16-20	104	0(0-14)	3.6(0-29)	96.4(50-100)	0(0-28)
All	443	3.1(0-13)	3.0(0-20)	93.8(62-100)	0(0-19)