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Cluster analysis of chinook salmon stocks by scale characters

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は じ め に

鱗相分析による系群識別には次の３つの問題点がある。つまり，１）基準群の設定，２）形質の選択，３）識別手法である。これらの問題点は相互に関連している。例えば，各河川の標本をどのような地理的区分にまとめて基準群を設定するかにより，識別に有効な形質および基準群の識別精度は異なってくる。

本研究では，どのような鱗相形質を用いた時に，地理的分布と良く対応する基準群の設定ができるのかをクラスター分析により検討した。

材 料 と 方 法

材料は北太平洋沿岸各地におけるマスノスケ系群の1973年級群および1977年級群の1.3および1.4歳魚の鱗相形質データである。標本の採集位置は図１に示されている。分析には淡水帯形質，海洋帯形質,* および採鱗部位の違いによる影響を除くために比率に変換した形質(Knudsen et al. 1985)を用いた（表１）。各年級群の年齢込みの系群別個体数および各鱗相形質の平均値は表２および表３に示されている。これらのデータは米国ワシントン大学漁業研究所（ＦＲＩ）より提供されたものである。

クラスター分析には農林ライブラリのＣＯＮＴＡＸ（ Conversational Numerical Taxonomy Packaged Program ）を用いた。なお，分析には各形質の平均値を式(1)により標準正規化（ standard normalization ）した値を用いた。標本間の距離としてユークリッド距離(Euclidean distance)（式２）を，クラスターの形成には単一連関法（ Single linkage method ）用いた。

$$Y_{ai} = (X_{ai} - X_{\cdot i}) \Big/ \sqrt{\sum_{a=1}^{n} (X_{ai} - X_{\cdot i})^2 \,/\, (n-1)} \quad \cdots\cdots (1)$$

$$D(a, b) = \left[\sum_{i=1}^{p} (Y_{ai} - Y_{bi})^2 \right]^{1/2} \quad \cdots\cdots (2)$$

なお，X_{ai} は a 系群の i 形質の平均値

$X_{\cdot i}$ は各系群の i 形質の平均値をさらに平均した値

Y_{ai} ,Y_{bi} は a 系群および b 系群の i 形質の標準化された値

n は系群数，p は形質数

脚注　＊本研究ではMyers et al.（1984）の zone 2 を海岸帯の１部と見なした。

結　　　果

３つの淡水帯形質によると，２つの年級群ともアジアの２標本(1,2)とＳＥＢＣのAlsek River（ 11 ）の標本が１つのクラスターを形成した。中部アラスカのCopper River(10 ）は西部アラスカの標本とクラスターを形成した。中部アラスカのCook Inlet（ 9 ）の標本は年級群によってクラスターの形成のされ方が異なった。全体としては３つのクラスターが認められた。しかし，各クラスター内には異なる地理的区分に属する標本が含まれており，地理的分布との対応は良くなかった（図２）。

海洋帯形質によるとアジアの２標本間の距離は淡水帯形質の場合より大きかった（図３）。同様の傾向は３つの海洋帯形質（４，５，６）に限った場合も認められた（図４）。中部アラスカの２標本（ 9 ,10 ）は，1973年級群の場合アジアおよびＳＥＢＣと，1977年級群の場合西部アラスカおよびＳＥＢＣと，クラスターを形成した。全体として淡水帯形質より海洋帯形質による結果の方が地理的分布と良く対応した。

淡水帯形質と海洋帯形質とを同時に用いた結果は海洋帯形質のみによる結果と類似した。しかし，地理的分布との対応はあまり改善されなかった（図５）。また比率形質でも地理的分布との対応は改善されなかった（図６－９）。

考　　　察

一般に淡水期をもつ魚種では淡水帯形質が系群識別に有効であると考えられている。しかし，淡水帯形質によって各標本を地理的区分に対応したクラスターにまとめることは困難であった。これは淡水生活期の環境が同一地理的区分の中でも，各河川によって大きく異なるためであろう。一方，海洋帯形質によると，地理的区分との対応はいくぶん改善された。これは降海後の海洋環境の均一性が地理的区分内では高いためであると考えられる。Myers et al.（ 1984 ）でも1973年級群の分析に使用された11形質中９形質が海洋帯形質であり，1977年級群の場合も16形質中11形質が海洋帯形質であった。系群識別において地理的分布と良く対応する基準群を設定するためには海洋帯形質を重視する必要があろう。

次に今回の分析から，アジア・西部アラスカ・中部アラスカ・ＳＥＢＣの４基準群を用いて系群識別を行なう場合の問題点として次の２点が指摘できる。

１）　アジアの２標本の距離は淡水帯形質では小さいものの海洋帯形質では大きく異なる。これはBolshaya標本(1)がオホーツク海に，Kamchatka標本(2)がベーリング海に面していることと関連するものと考えられる。北米の地理的区分に対応させるためには，アジアの２標本を分離して扱う必要がある。

２）　中部アラスカの標本は形質・年級群によりクラスターの形成のされ方が変化する。この原因としてａ）環境，特に淡水生活期の環境の年変動が大きい，ｂ）系群内の構造が複雑である，

c ）標本採集による変動（ Myers, 1985)などが考えられる。標本をさらに充実して検討することが必要である。

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Table 1. Scale characters used for the analysis.

Character code	Character definition	
	Non-ratio character	Ratio character
1	Number of circuli in freshwater zone	1/(1+4)
2	Size of freshwater zone	2/(2+5)
3	Distance circulus 1-3 in freshwater zone	3/(2+5)
4	Number of circuli in first ocean zone	4/(1+4)
5	Size of first ocean zone	5/(2+5)
6	Distance circulus 1-3 in first ocean zone	6/(2+5)
7	Distance circulus 4-6 "	7/(2+5)
8	Distance circulus 7-9 "	8/(2+5)
9	Distance circulus 10-12 "	9/(2+5)
10	Distance circulus 13-15 "	10/(2+5)
11	Distance circulus 16-18 "	11/(2+5)

Table 2. Number of individuals and mean values of scale characters of chinook salmon of 1973 brood year. Character 1 and 4 are in number of circuli, and other characters are in mm.

Stock code	N	Character code 1	2	3	4	5	6	7	8	9	10	11
1	115	7.90	.242	.095	24.63	.970	.087	.100	.119	.132	.137	.136
2	100	8.66	.253	.091	28.32	1.125	.074	.080	.100	.122	.138	.143
3	219	10.37	.320	.099	28.72	1.297	.086	.103	.124	.139	.150	.162
4	76	10.49	.322	.101	28.76	1.270	.080	.095	.116	.131	.145	.165
7	32	10.94	.327	.099	28.75	1.273	.080	.102	.117	.134	.147	.162
8	228	9.89	.288	.090	30.59	1.323	.084	.106	.115	.109	.133	.153
9	156	8.58	.252	.084	26.88	1.044	.082	.090	.111	.129	.136	.136
10	58	9.69	.313	.097	32.47	1.300	.097	.102	.115	.128	.138	.137
11	32	8.19	.232	.092	30.75	1.169	.086	.101	.117	.119	.118	.120
12	62	13.06	.336	.092	31.84	1.199	.091	.110	.114	.122	.124	.121
13	31	12.45	.329	.098	34.23	1.254	.094	.115	.105	.108	.116	.119
15	36	11.81	.292	.085	35.61	1.323	.086	.094	.104	.111	.123	.128
16	87	12.01	.303	.084	31.34	1.152	.097	.110	.117	.122	.124	.118

Table 3. Number of individuals and mean values of scale characters of chinook salmon of 1977 brood year. Character 1 and 4 are in number of circuli, and other characters are in mm.

Stock code	N	Character code 1	2	3	4	5	6	7	8	9	10	11
1	30	8.20	.251	.093	25.13	1.019	.093	.112	.127	.127	.139	.134
2	106	8.94	.237	.086	27.17	1.086	.076	.080	.098	.121	.139	.153
3	354	10.97	.341	.104	31.48	1.390	.077	.092	.119	.131	.143	.157
4	181	11.34	.333	.106	32.97	1.396	.081	.088	.114	.128	.137	.144
5	59	12.68	.346	.101	34.29	1.492	.082	.074	.108	.130	.145	.149
6	26	11.65	.321	.099	34.81	1.501	.082	.075	.103	.125	.146	.148
7	40	12.23	.340	.106	35.73	1.542	.085	.095	.115	.124	.136	.147
8	261	10.67	.300	.104	36.69	1.547	.085	.095	.109	.115	.123	.142
9	126	10.32	.305	.093	30.73	1.210	.079	.090	.107	.116	.130	.136
10	164	10.55	.338	.108	35.36	1.360	.085	.099	.110	.124	.132	.133
11	8	8.00	.251	.101	35.38	1.291	.080	.086	.108	.116	.120	.108
12	14	11.00	.296	.101	32.57	1.234	.079	.107	.109	.120	.130	.131
13	35	11.11	.305	.094	34.97	1.260	.093	.116	.118	.119	.117	.109
14	68	13.59	.346	.092	34.76	1.318	.088	.119	.123	.125	.123	.125
15	14	11.07	.252	.075	37.57	1.285	.074	.086	.095	.111	.113	.114
16	98	14.40	.333	.090	36.32	1.311	.084	.107	.121	.128	.128	.117

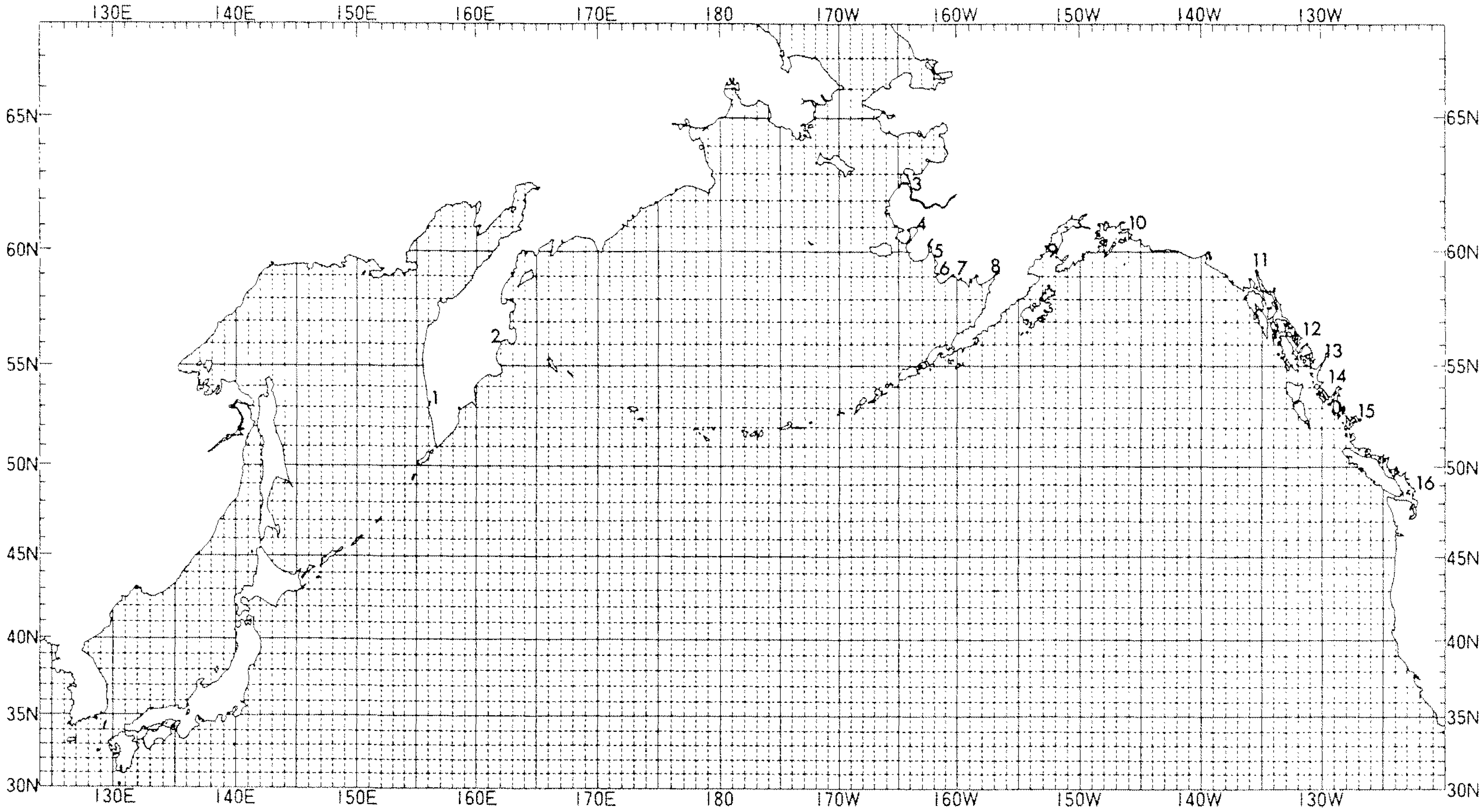


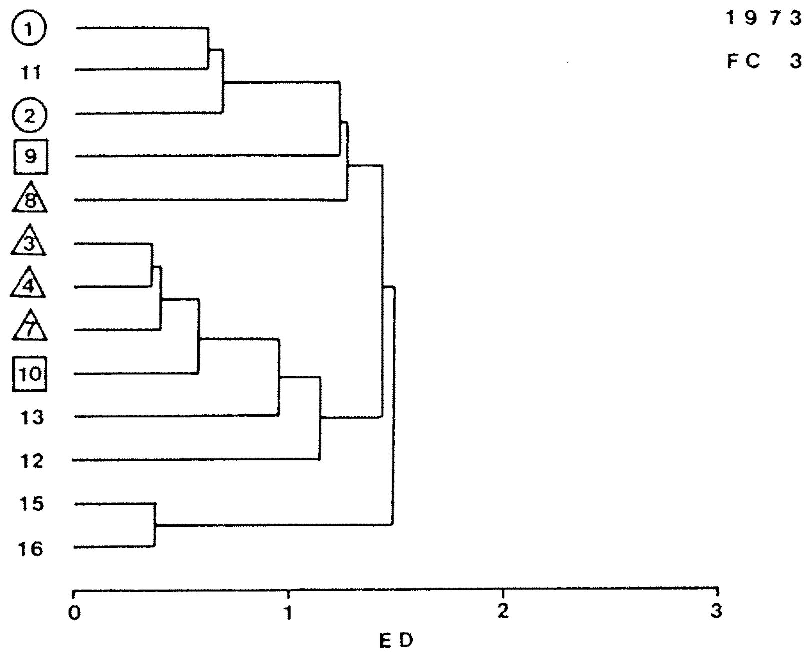
Fig. 1. Sampling locations and their code of chinook salmon.

Asian chinook salmon
1. Bolshaya River
2. Kamchatka River

Western Alaska chinook salmon
3. Yukon River
4. Kuskokwim River
5. Kanektok River
6. Goodnews Bay
7. Togiak River
8. Nushagak River

Central Alaska chinook salmon
9. Cooper River
10. Cook Inlet

Southeast Alaska/British Columbia chinook salmon
11. Alsek River
12. Stikine River
13. Nass River
14. Skeena River
15. Bella Coola River
16. Fraser River



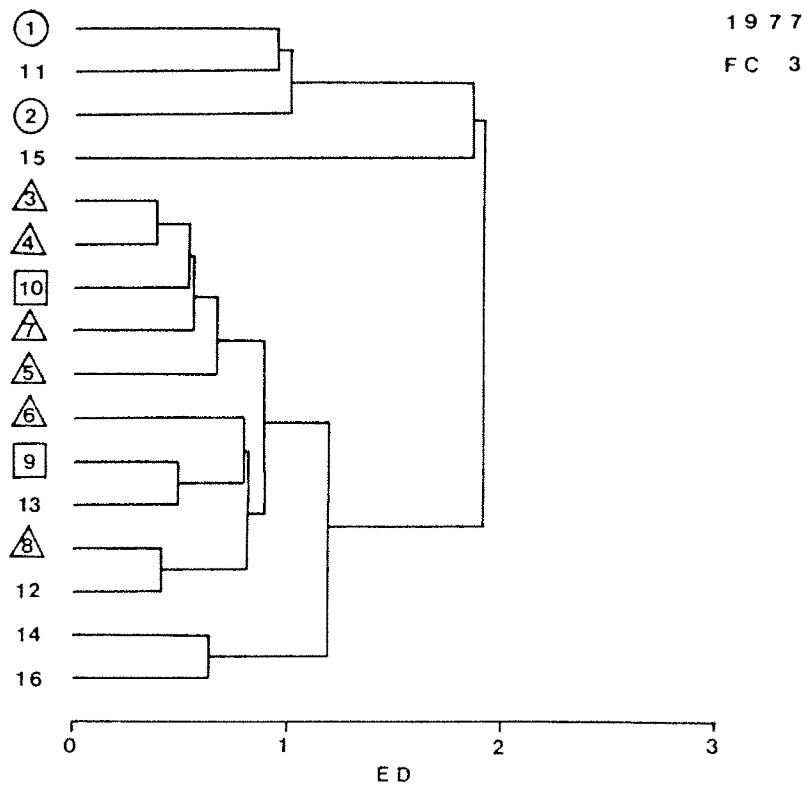
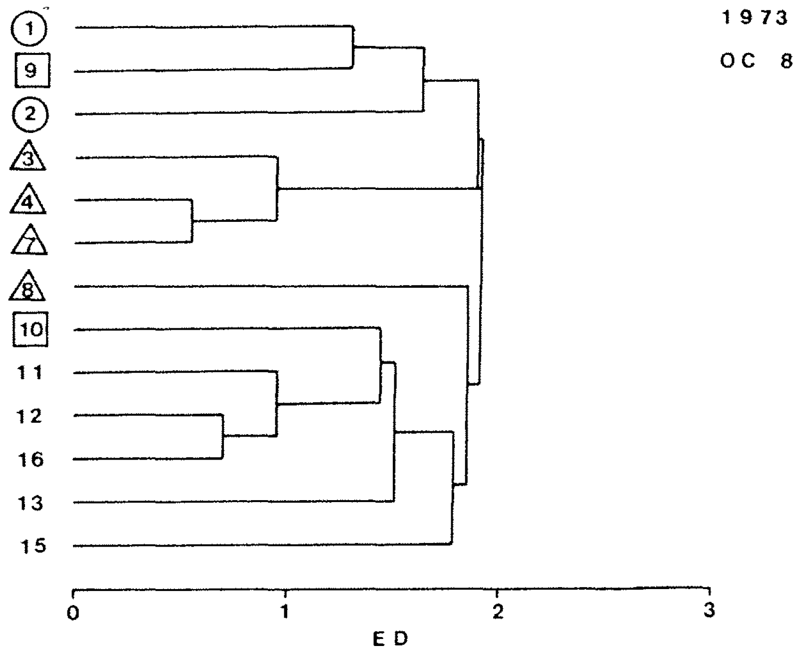


Fig. 2. Dendrogram drawn from indices of Euclidean distance (ED) based on three characters in the freshwater zone. Circle indicates Asian chinook, triangle indicates Western Alaska chinook, square indicates Central Alaska chinook and others are Southeast Alaska/British Columbia chinook.



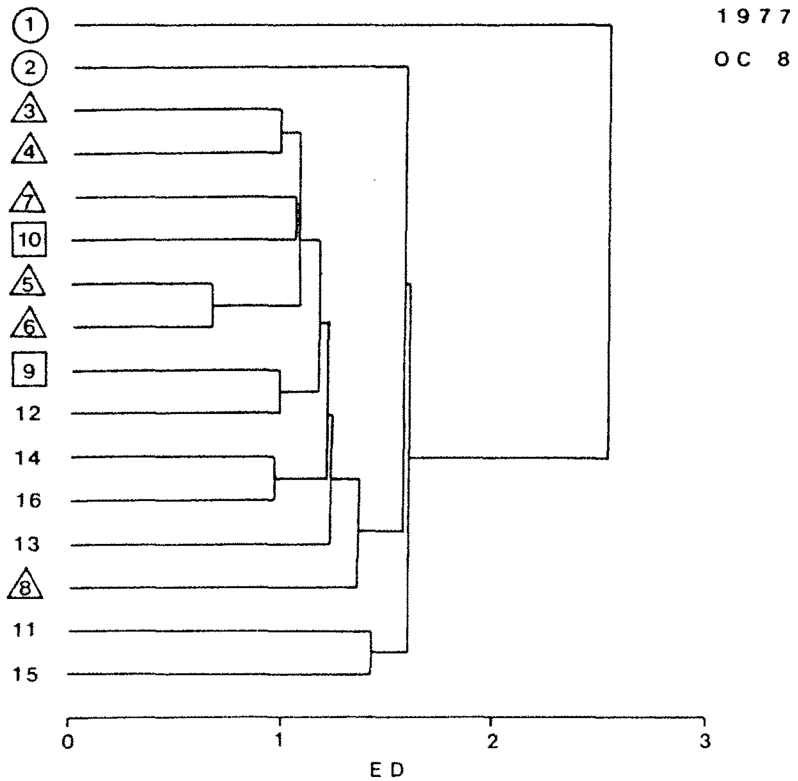
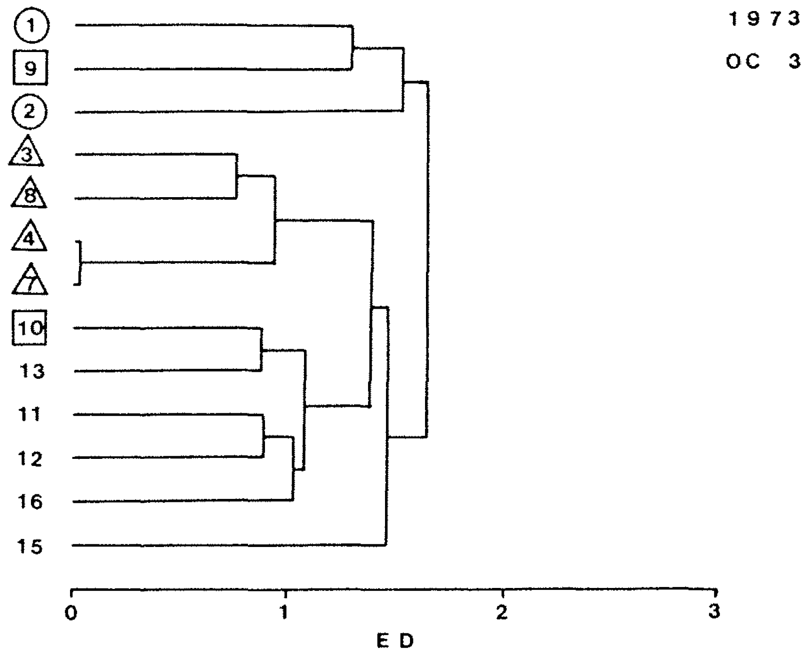


Fig. 3. Dendrogram drawn from indices of Euclidean distance (ED) based on eight characters in the first ocean zone. Circle indicates Asian chinook, triangle indicates Western Alaska chinook, square indicates Central Alaska chinook and others are Southeast Alaska/British Columbia chinook.



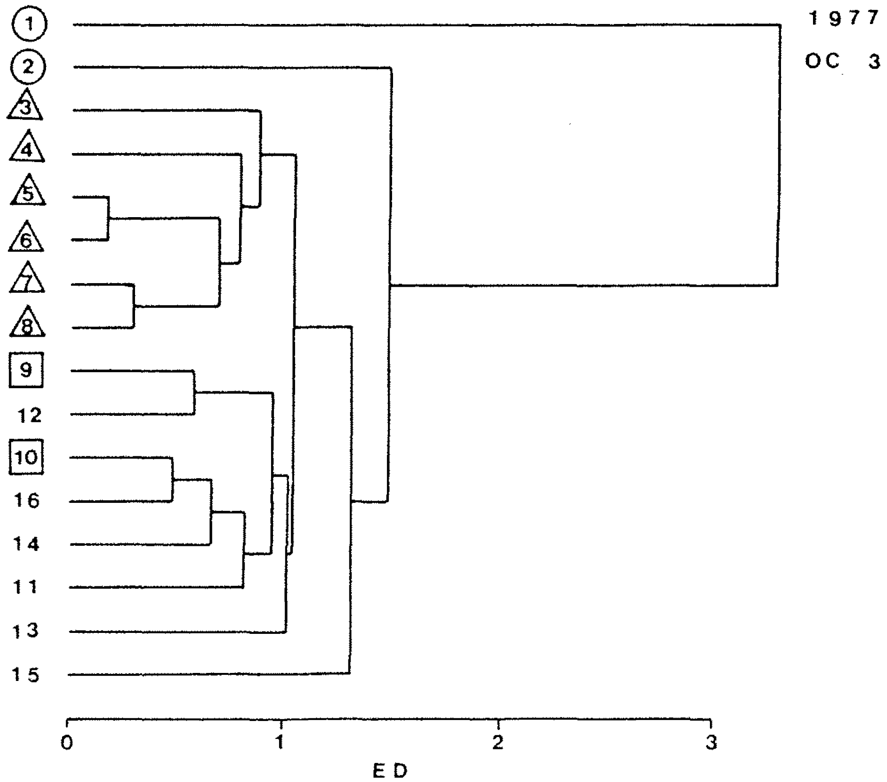
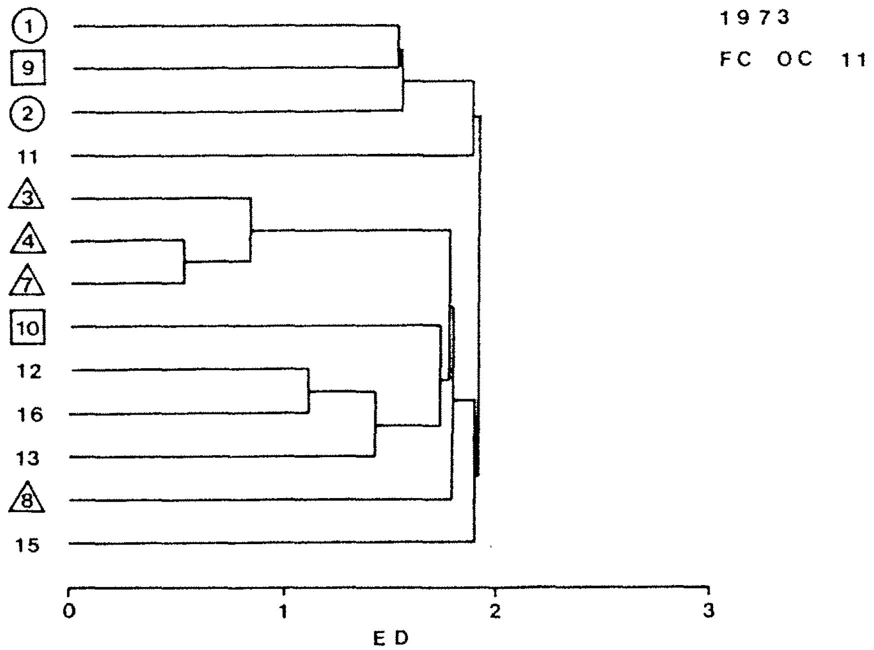


Fig. 4. Dendrogram drawn from indices of Euclidean distance (ED) based on three characters in the first ocean zone. Circle indicates Asian chinook, triangle indicates Western Alaska chinook, square indicates Central Alaska chinook and others are Southeast Alaska/British Columbia chinook.



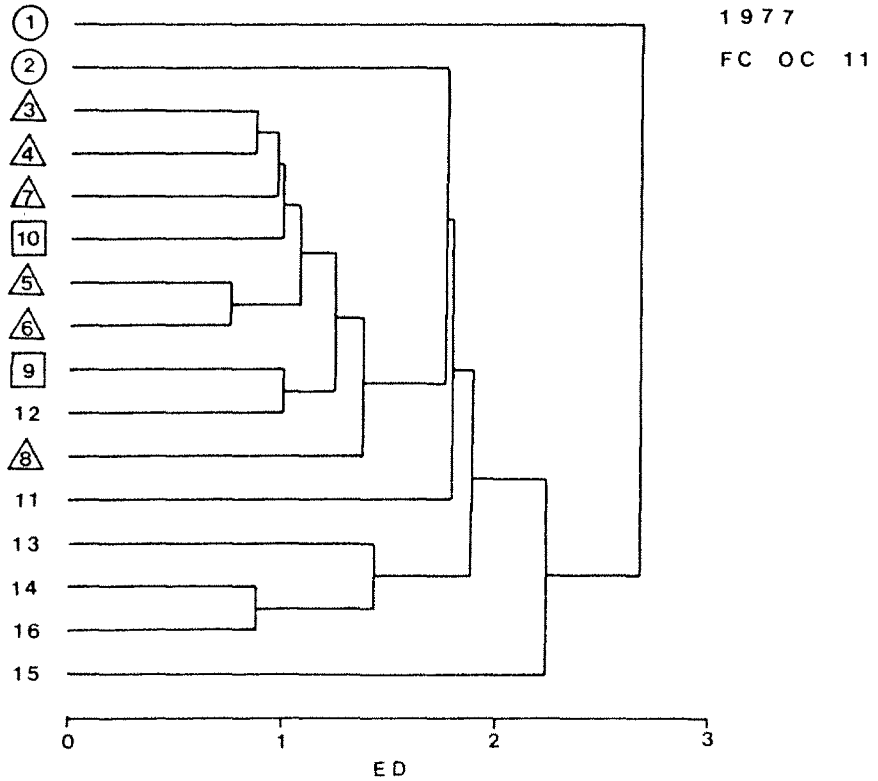
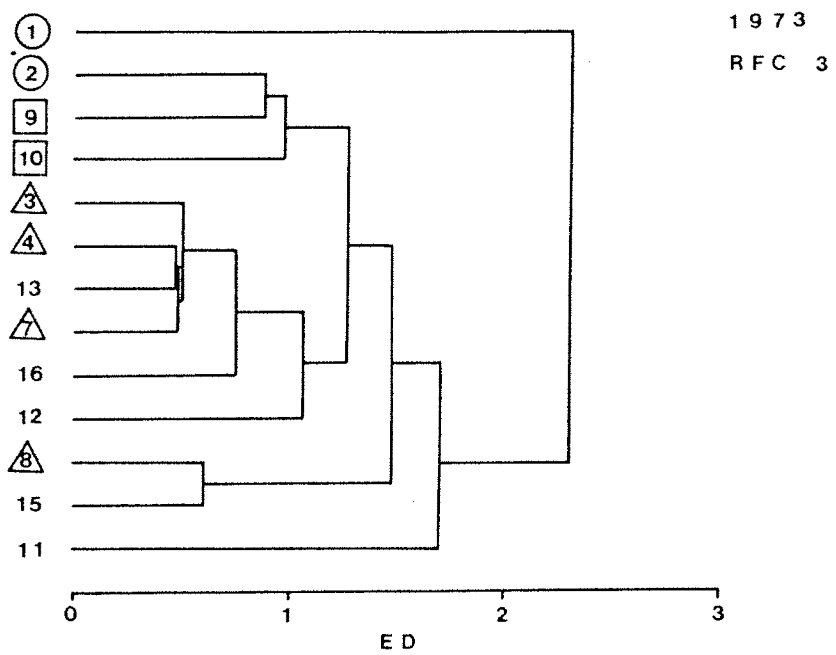


Fig. 5. Dendrogram drawn from indices of Euclidean distance (ED) based on eleven characters in the freshwater and first ocean zone. Circle indicates Asian chinook, triangle indicates Western Alaska chinook, square indicates Central Alaska chinook and others are Southeast Alaska/British Columbia chinook.



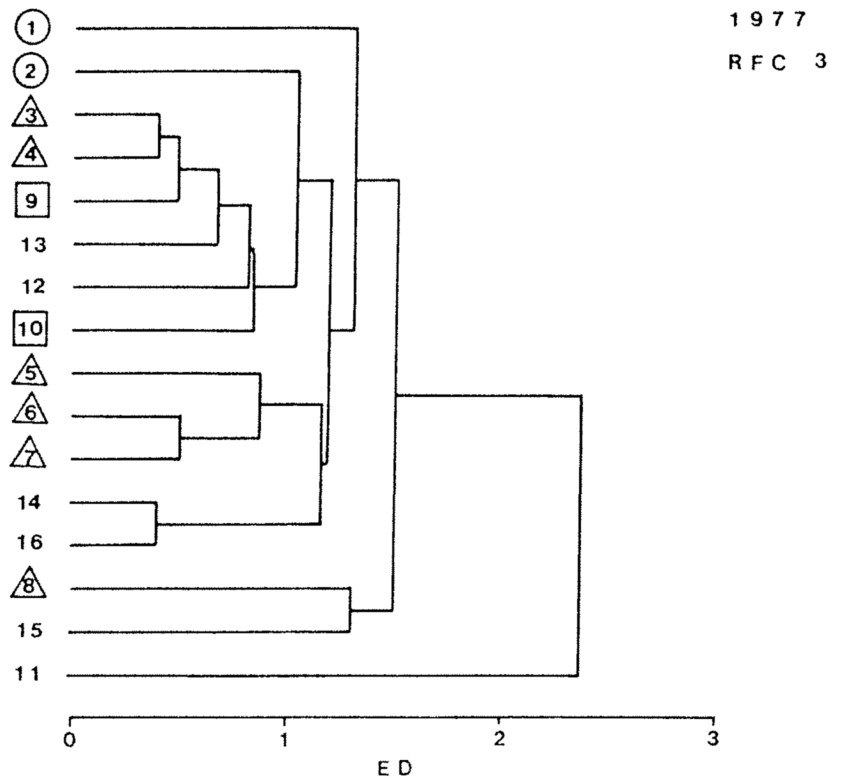
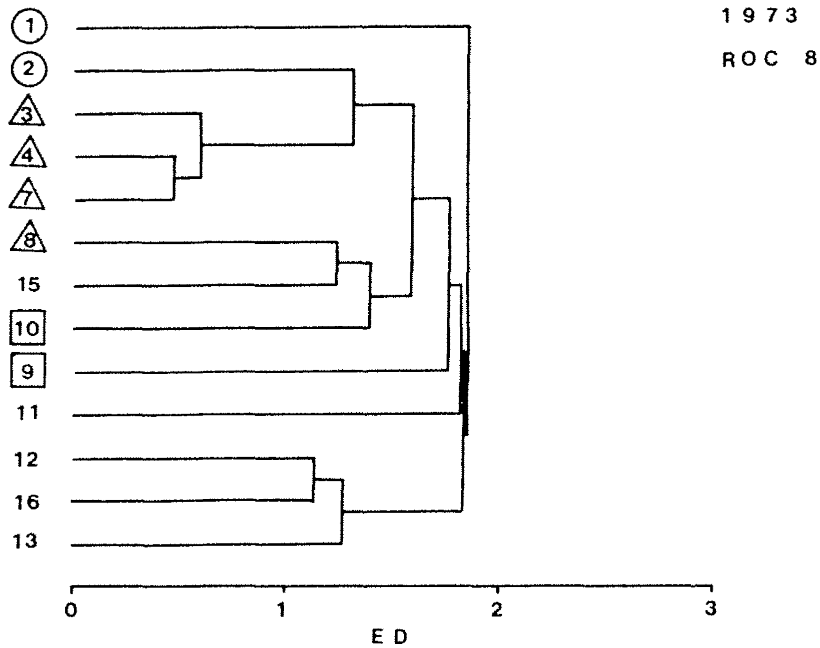


Fig. 6. Dendrogram drawn from indices of Euclidean distance (ED) based on three ratio characters in the freshwater zone. Circle indicates Asian chinook, triangle indicates Western Alaska chinook, square indicates Central Alaska chinook and others are Southeast Alaska/British Columbia chinook.



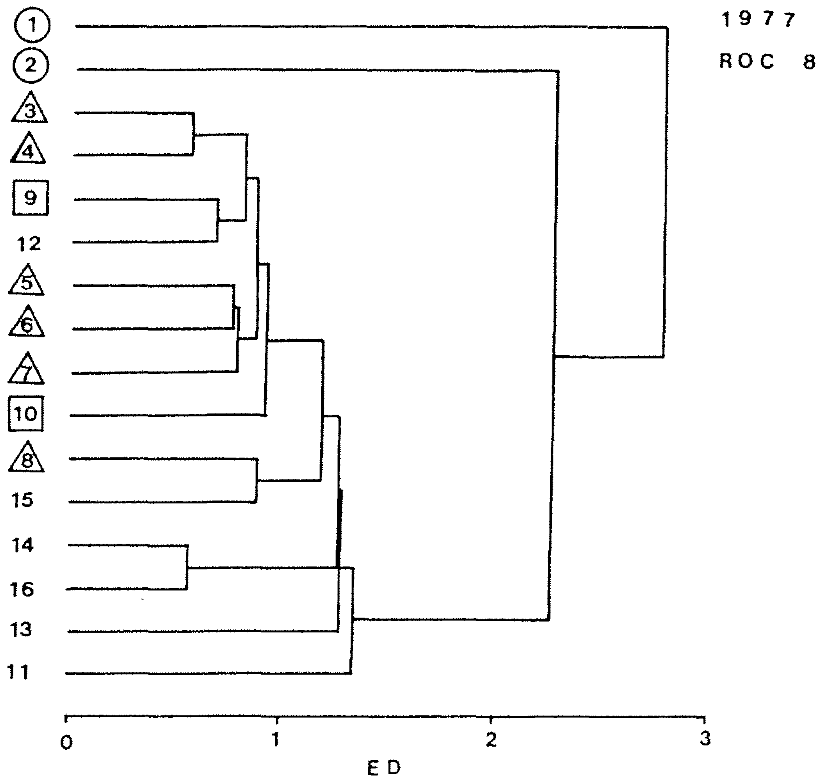


Fig. 7. Dendrogram drawn from indices of Euclidean distance (ED) based on eight ratio characters in the first ocean zone. Circle indicates Asian chinook, triangle indicates Western Alaska chinook, square indicates Central Alaska chinook and others are Southeast Alaska/British Columbia chinook.

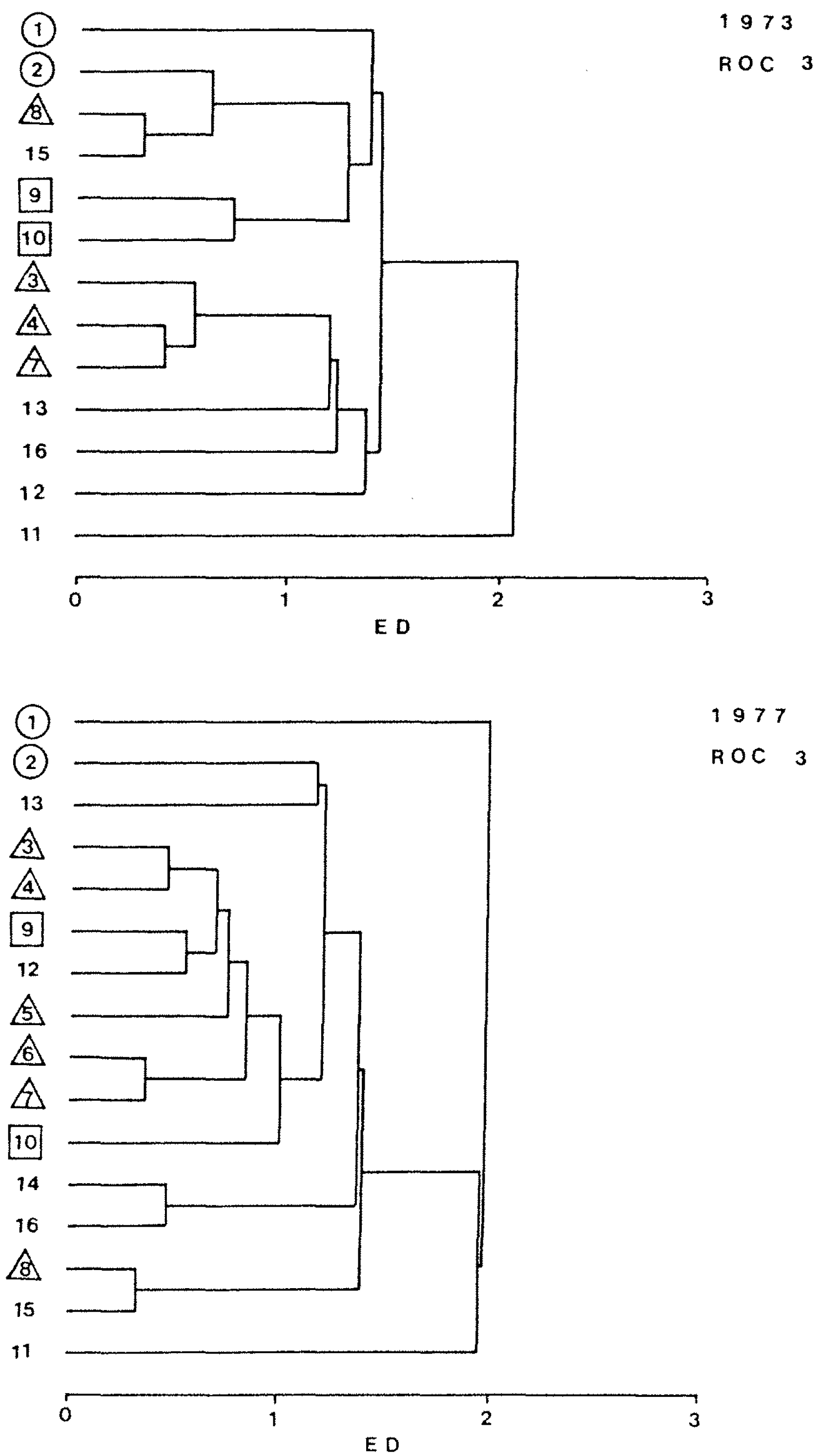
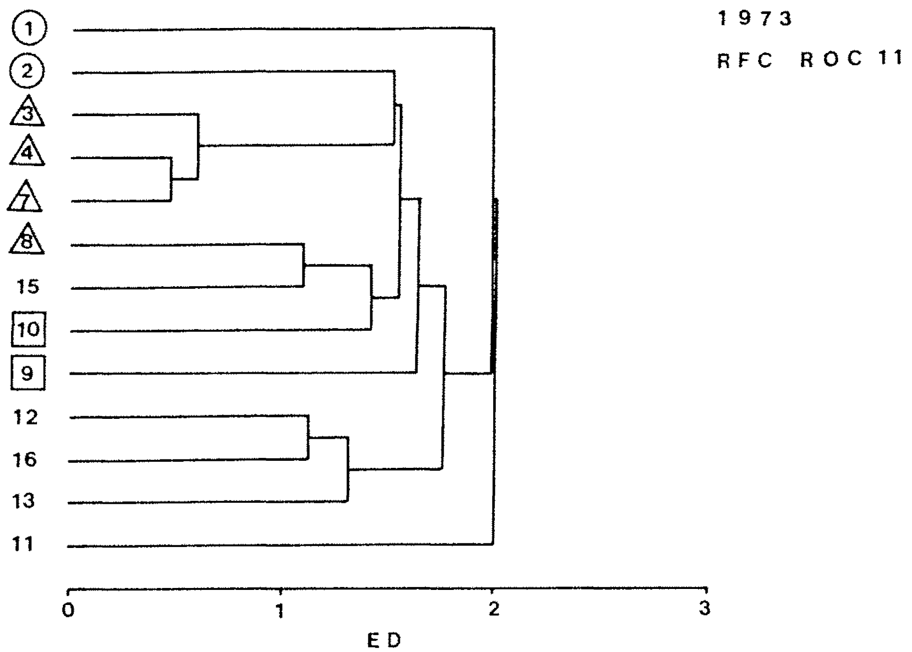


Fig. 8. Dendrogram drawn from indices of Euclidean distance (ED) based on three ratio characters in the first ocean zone. Circle indicates Asian chinook, triangle indicates Western Alaska chinook, square indicates Central Alaska chinook and others are Southeast Alaska/British Columbia chinook.



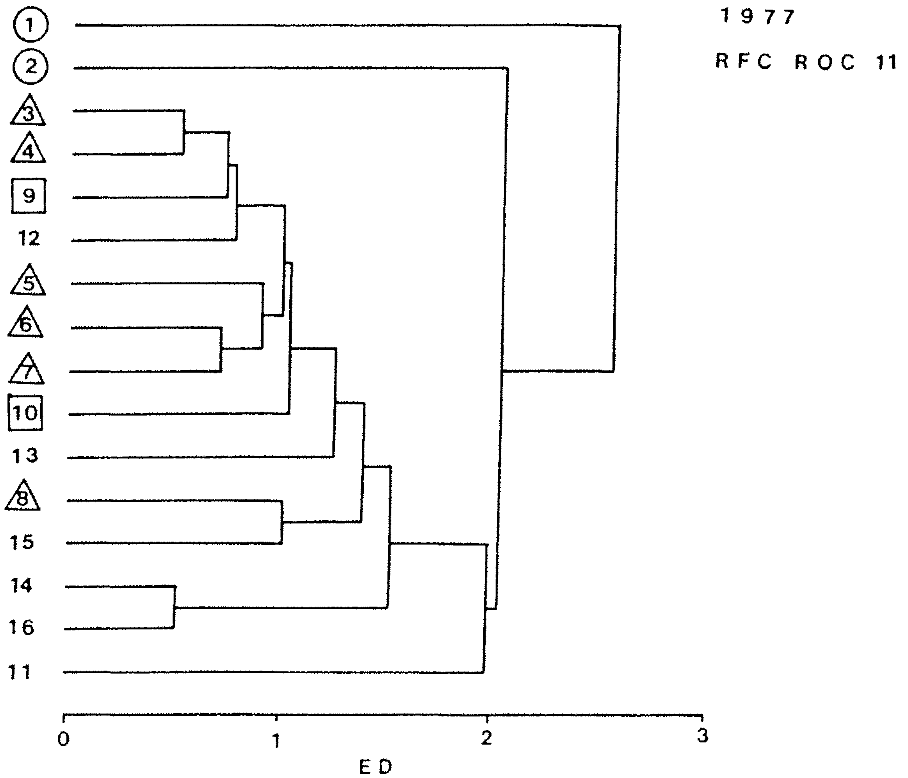


Fig. 9. Dendrogram drawn from indices of Euclidean distance (ED) based on eleven ratio characters in the freshwater and first ocean zone. Circle indicates Asian chinook, triangle indicates Western Alaska chinook, square indicates Central Alaska chinook and others are Southeast Alaska/British Columbia chinook.

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TRANSLATION

CLUSTER ANALYSIS OF CHINOOK SALMON STOCKS BY SCALE CHARACTERS

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Introduction

There are three points in identifying the salmon stock by scale pattern analysis. They are 1) the construction of standard samples, 2) the selection of scale characters, and 3) the selection of statistical methodology. These points are related to one another. For example, scale characters effective to identification and the identification accuracy of standard samples will vary depending on how we construct the standard samples.

This paper describes our study in which we examined through cluster analysis what kinds of scale characters can provide good standard samples corresponding well to the actual geographical distribution of each stock.

Materials and Methods

The scale data of ages 1.3 and 1.4 chinook salmon stocks of 1973 and 1977 brood years of the North Pacific were used in this analysis. Sampling locations are shown in Figure 1. Used in this analysis were fresh zone scale characters, ocean zone scale characters* and the characters converted to the ratio to remove the effect of difference in the body area. (Knudsen et al. 1985) (Table 1) The number of individual and mean values of each scale character of each stock are shown in Tables 2 and 3. These data were provided by Fisheries Research Institute, University of Washington (FRI).

Conversational Numerical Taxonomy Packaged Program (CONTAX) of Agriculture, Forestry and Fisheries Computer Library was used for this cluster analysis. The mean values of each scale characters were standarized by the equation (1). The Euclidean distance (2) was used as the distance between two stocks, and the single linkage method was used to construct the cluster.

$$Yai = (Xai - X,i) \Big/ \sqrt{\sum_{a=1}^{n} (Xai - X,i)^2/(n-1)} \qquad \text{.......... (1)}$$

$$D(a, b) = \left[\sum_{i=1}^{p} (Yai - Ybi)^2 \right]^{1/2} \qquad \text{.......... (2)}$$

* In this paper, zone 2 of Myers et al. (1984) was regarded as the ocean zone

Where: "Xai" is the mean value of the scale character i of the stock a.
"X,i" is the mean value of the scale character i over all stocks.
"Yai" and "Ybi" are the standardized scale character i of stocks a and b.
"n" is the number of stocks, and "p" is the number of scale characters.

Results

Based on three freshwater characters, two Asian samples (1, 2) and the Alsek River sample (11) of SEBC formed one cluster in both brood years. The Copper River (10) of Central Alaska made the cluster with samples of Western Alaska. Cook Inlet (9) of Central Alaska was included in the different clusters depending on the brood years. As a whole, three clusters were observed, but each cluster had several samples from the different geographical areas and did not correspond well to the actual geographical distribution of each stock. (Fig. 2)

Based on eight ocean characters, the distance between two Asian samples was larger than that based on freshwater characters. (Fig. 3) The same tendency was observed in the case of three ocean characters (4, 5, 6)(Fig. 4). Two samples (9, 10) of Central Alaska formed the cluster with Asia and SEBC in the case of 1973 brood year and that with Western Alaska and SEBC in the 1977 brood year. As a whole, the result of the cluster based on the ocean characters corresponds to the geographical distribution better than that of freshwater characters.

Based on both freshwater and ocean characters, the results were similar to those based on only the ocean characters. But there was little improvement in the correspondence with the actual distribution of the stocks. (Fig. 5) In case of ratio character, correspondence with a geographical distribution was not improved. (Fig. 6 - 9)

Discussion

In general, freshwater characteristics are expected to be useful for stock identification. But, it was difficult to construct a good cluster corresponding well to the actual distribution of the stocks by using the freshwater characters. This is because the environment of the freshwater is very much different from one another even within the same geographical area. On the other hand, ocean characters provide a better results. This is because the ocean environment after outmigration into the sea is much more uniform within the region. In Myers et al. (1984), they used 9 ocean characters among 11 characters for 1973 brood year and 11 ocean characters among 16 characters for 1977 brood year. In order to construct the standard sample corresponding well to the actual distribution of the stocks, importance should be attached to the ocean character.

From this analysis, the following two points can be pointed out in the case of the four standard samples such as those in Asia, Western Alaska, Central

Alaska and SEBC.

1) Two Asian stocks are similar to each other in the freshwater characters but very different from each other in the ocean characters. This may be attributable to the fact that the Bolshaya stock faces the Sea of Okhotsk and the stock of Kamchatka faces the Berling Sea. These two Asian stocks should be treated separately in order to let them correspond to the scale of the geographical areas in the North America.

2) The stocks of central Alaska were clustered differently depending upon the characters and brood year. The reason for this may be: a) Year-to-year changes in environment, especially in the freshwater b) Complicated stock structure c) Changes caused by the sampling (Myers, 1985)

More samples should be necessary to obtain correct information.

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