NPAFC

Doc. No. 156

Rev. No.

Stock interactions in sockeye salmon in the eastern North Pacific Ocean

by

Skip McKinnell

Department of Fisheries and Oceans
Ocean Science and Productivity Division
Pacific Biological Station
Nanaimo, B.C. V9R 5K6
CANADA

submitted to the

NORTH PACIFIC ANADROMOUS FISH COMMISSION

by

CANADA

October 1995

This paper may be cited in the following manner:
McKinnell, S. 1995. Stock interactions in sockeye salmon in the eastern North Pacific Ocean. (NPAFC Doc. No. 156). 20 p. Dept. of Fisheries and Oceans, Ocean Science and Productivity Division, Pacific Biological Station, Nanaimo, B.C. Canada. V9R 5K6

Abstract

For most of the 20th century (1912-late 1960's), age *1.3* sockeye salmon from the Nass and Skeena Rivers, and Rivers Inlet in central and northern British Columbia have returned to spawn at a smaller size when Western Alaska (Bristol Bay) sockeye catches (numbers) have been high. In all of these river systems, the size of age *1.2* sockeye has not been affected by the abundance of Western Alaska sockeye. The mean weights of sockeye in these systems follow a similar pattern. The slopes of mean body weight versus Western Alaska sockeye catch is negative, however, fewer of the age *1.3* strata are significant. As with mean length, none of the mean weights age *1.2* strata were significantly affected by the abundance of Western Alaska sockeye. For their condition factor (weight/length^3), only one stratum was significantly correlated with Western Alaska sockeye abundance. Mean lengths, weights, and condition factors are significantly correlated within and between stocks. The pattern of covariation is examined using principal components ordination and provides some insight into the relative importance of genetic and environmental factors in determining characteristics of sockeye growth.

Introduction

One of the major concerns of the International North Pacific Fisheries Commission was the high seas distribution of salmon by nation of origin. High seas salmon tagging programs were a significant part of the annual research plans for almost 40 years (Margolis 1992, Burgner 1992). The major finding of that research was that salmon from different nations and continents shared common feeding grounds in the North Pacific. Another finding was that the distributions were not uniform throughout the North Pacific. Stocks and species were contagiously distributed. Chinook salmon tended to be found in coastal waters while sockeye, chum, pink, steelhead, and coho ranged widely. Asian salmon were generally found more frequently in the western Pacific and Bering Sea, and North American salmon in the Gulf of Alaska and Bering Sea. Canadian salmon and those from the U.S. Pacific northwest tend not be be found frequently in the Bering Sea. Canadian Yukon River salmon are the obvious exception. A major focus of the tagging research was to determine the extent of species ranges by nation. The establishment of the Commission was stimulated by concern for high seas salmon interception fisheries. The relative distribution within ranges received not so much attention.

In that latter part of the 20th century, an increasing number of scientists began to examine the relationship between climate and fisheries production in the northern hemisphere (Beamish 1995). For most of the century, climate was considered by fisheries biologists to be a stochastic process that contributed significant variation to the underlying stock and recruitment process. As climate variation was discovered to be more structured than had previously been considered (Emery and Hamilton 1985, Francis and Hare 1994, Trenberth and Hurrell 1995, Hanawa 1995, Ware 1996), fisheries scientists began to look more closely at the linkage between climate patterns and fisheries production (Hollowed and Wooster 1995, Myers et al. 1995) and other trophic levels (Venrick 1987, Brodeur and Ware 1992, 1995). Salmon fisheries have been observed to cycle through periods of good and bad production and limited attempts were made to relate these variations to the environment (Wickett, 1958, Tanaka 1962, Van Hyning 1968). A plausible linkage between salmon production and climate was not identified until the end of the century (Beamish and Bouillon 1993, Hare and Francis 1995) when patterns of climate variation were more clearly identified. The underlying mechanisms remain as hypotheses.

The winter Aleutian low pressure system that develops in the northeastern Pacific has been identified as a large-scale climatic feature that varies in magnitude and location from year to year. Beamish and Bouillon (1993) developed an index of its average annual winter intensity and found that total North Pacific catches of pink, chum, and sockeye followed similar trends during the 20th century. This relationship was demonstrated statistically by Hare and Francis (1995) for Western and Central Alaska sockeye and Central and Southeast Alaska pink salmon. Although not proven, little other than climate appears to have the potential to create such patterns at this time.

These climate studies created an interest in the effects of various temporal and spatial scales of events affecting salmon in the ocean. Of all of the things that affect salmon abundance, growth, and distribution, what are the relevant temporal and spatial scales to study and what do they affect? High seas science needs a zoom lens to provide an appropriately scaled spatial resolution for each problem. Having fixed the scale, what factors influence salmon at that scale? In the following retrospective study, the effects of adequate stratification of sockeye life history biology and the information it provides are examined. The mechanisms that may produce the observed results provide the fodder for some thoughts on modelling sockeye biology in the ocean.

Data

In 1912, Professor C.H. Gilbert, head of the Zoological Department of Stanford University (U.S.A.), was contracted by the Government of the Province of British Columbia to investigate sockeye salmon in British Columbia rivers (Gilbert 1913). He established a biological sampling system for sockeye salmon that continued, uninterrupted, until 1956 when responsibility for biological sampling of salmon was transfered to the federal government. Sampling by the former Fisheries Research Board of Canada after 1956, and the Department of Fisheries and Oceans after 1974 allow some of these series to be continued through to the present, although not as systematically as was done in the earlier period. The data collected between 1912 and 1956 include length, weight, sex, and age of sockeye sampled from catches in the Nass River, Skeena River, and Rivers Inlet. Shorter time series are available from Smith Inlet (near Rivers Inlet), and the Fraser River. Responsibility for biological sampling of sockeye in the Fraser River was transfered to the IPSFC (International Pacific Salmon Fisheries Commission) when it was established in 1937.

Summary statistics of sockeye biological data were reported annually in publications entitled *Contribution to the life history of sockeye salmon* in the reports of the B.C. Commissioner of Fisheries. Bilton et al. (1967) collated the mean length data for the Nass River, Skeena River, and Rivers Inlet up to 1963 into a single publication. Annual mean weights and condition factors had not been consolidated into a database until recently. In addition to the annual summary statistics, the original field notebooks, containing length, weight, sex, and scale samples have recently been located in the archives of the Pacific Salmon Commission. Arrangements are being made to make these data available for retrospective analyses of sockeye production in the North Pacific. Of particular importance are the original scale samples that will permit retrospective studies of temporal changes in allele frequencies from the DNA preserved in the archival material. The earliest samples from the Skeena River were collected at or before the fishery began a long decline (Milne 1955) and will be particularly useful for determining whether has been a loss of genetic diversity in these sockeye systems.

Density-dependent effects of sockeye abundance on size (length, weight, condition factor)

Sockeye age at maturity varies annually in the Nass River, the Skeena River and Rivers Inlet. Normally the dominant age-class is either age *1.2* (2 ocean winters) or *1.3* (3 ocean winters). Between 1912 and 1956, the mean lengths of age *1.3* sockeye salmon from the Nass River, Skeena River and Rivers Inlet (Figures 2 and 3) were significantly smaller in years when catches of Western Alaska (Bristol Bay) sockeye salmon were high (McKinnell 1995). The mean lengths of age *1.2* sockeye were not correlated with Western Alaska sockeye abundance. The difference between the observed pattern of variation for age *1.2* and age *1.3* sockeye may be due to varying degrees of interaction with Western Alaska sockeye. McKinnell (1995) showed that age *1.2* sockeye tend to be further east in the Gulf of Alaska than age *1.3* sockeye during the spring of maturation and therefore may avoid strong density-dependent interactions with the dominant sockeye stocks in the Pacific. Western Alaska sockeye tend not to occur in the eastern Gulf of Alaska. Variation in the annual run size of Bristol Bay sockeye accounts for most of the variation in total North Pacific sockeye production (Rogers and Ruggerone 1993).

Mean weights of age *1.3* sockeye from the Nass and Skeena Rivers, Rivers Inlet tended to be lower in years of greater sockeye catches in Western Alaska (Figures 4 and 5). The strength of the correlation was weaker than that for mean lengths. The regressions were significant for age *1.3* males in the Nass and Skeena Rivers but not in Rivers Inlet. The regressions were significant for age *1.3* females in the Skeena River only. Equal numbers of fish were sampled for length and weight so the difference between the two analyses is not due to greater imprecision in the annual estimates of mean weight. One might conclude that the density effect on age *1.3* is not so great on mean weight as it is on mean length. The mean weights of age *1.2, 2.2, and 2.3* sockeye from these systems were not significantly affected by variations in the abundance of Western Alaska sockeye.

Only age *1.3* female Nass R. sockeye had a significant decline in condition factor (weight/length^3) with increasing abundance of Western Alaska sockeye (Figures 6 and 7). Slopes for some strata were both positive and negative. Therefore, the factors that determine annual condition factors in northern B.C. sockeye stocks appear to be independent of Western Alaska sockeye abundance.

Interannual covariation in mean length, weight, and condition factor

The mean lengths of adult sockeye salmon from the Nass River, the Skeena River, and Rivers Inlet were significantly correlated among many age/sex/river strata. Principal components analysis was used the determine the relationships between the various strata based on their correlations. The highest correlations were between sexes within river/age-class strata. This produced the tight coupling of sex strata within river/age-class (Figure

8) and suggests that data for males and females could be pooled for this analysis. Two obvious factors are responsible for the ordination pattern in Figure 8. One plane separates the Nass River from a mix of Skeena and Rivers Inlet strata along principal component 1. A second plane completely separates age *x.2* sockeye from *age x.3* sockeye. Correlations among strata of the same ocean age were more important than correlations among different age classes within rivers. This suggests that the ocean experience of Nass River sockeye may be less similar than the more highly correlated time series of the Skeena River and Rivers Inlet.

Interannual covariation in mean weights was highest between sexes within river/age-class strata (Figure 9) as was observed for mean lengths. The dominant principal component had age *1.2* River Inlet sockeye at one extreme and age *x.3* Skeena River sockeye at the other. Ocean age was the major factor responsible for the ordination pattern. The effect of river was less important in determining the pattern of covariation in mean weights. Unlike the ordination of mean lengths, the Nass River does not appear as unique. Note the close proximity of age *1.3* sockeye from Rivers Inlet to Nass River sockeye of the same age.

The principal component responsible for the ordination based on condition factor was river system. Strata from each river form 3 distinct clusters of points (Figure 10). There is some suggestion that within each cluster, ocean age can be used to further separate the strata within rivers. The determination of condition factor may be entirely genetic. Despite the tendency for stocks to covary with other stocks in mean length and weight, some ratio of the two has evolved that is suited to the environment that each must face when returning to spawn. An environmental hypothesis seems less likely but cannot be ruled out. Sockeye are increasing in weight more rapidly than length during the final spring at sea. At some point in their homeward migration the stocks will experience separate ocean environments because they are destined to arrive at different geographic locations along the coast. Perhaps the final few weeks of separation are sufficient to produce the growth adjustments that create stock-specific condition factors. The latter seems less likely. Run timing of Nass and Skeena River sockeye is not that different yet they represent the ordination extremes (Figure 10). This does not appear to result from a latitudinal cline as Rivers Inlet separates Nass and Skeena stocks in the ordination. Rivers Inlet sockeye have more variable annual condition factors than Skeena or Nass stocks.

Model requirements

The major purpose of these retrospective studies is to improve the basis for modeling the marine component of sockeye life histories. The next task is to develop a model of sockeye interaction that captures the observed patterns of variation and covariation in growth. What are the relevant observations of stock interaction that need to be maintained in a sockeye marine life history model?

Factors to consider:

1. Northern B.C. sockeye that spend 3 years at sea tend to have a centre of distribution that is further west in the Gulf of Alaska than those spending 2 years in the ocean.
2. Environmental and density-dependent forcings and stock distributions need to be scaled such that they produce the observed covariances among age/sex/river strata.
3. The magnitude of Western Alaska sockeye catches will affect the length and weight of age *x.3* sockeye.
4. The mean sizes of different age-classes (eg. *1.2, 1.3*) within a brood year appear correlated up to the year of maturity of the earlier maturing age-class and are not correlated thereafter.
5. The mean sizes of sockeye differ by system.

What appears to be the most hopeful for a first modeling attempt is to create sockeye distributions that are aggregated to some unknown degree in the North Pacific. The aggregations will need to be stock- and age-specific to affect the observed covariation patterns.

References

Beamish, R.J. 1995. Climate change and northern fish populations. Can. Spec. Pub. Fish. Aquat. Sci. 121, 739p.

Beamish, R.J. and D.R. Bouillon. 1993. Pacific salmon trends in relation to climate. Can. J. Fish. Aquat. Sci. 50:1002-1016.

Bilton, H.T., E.A.R. Ball, and D.W. Jenkinson. 1967. Age, size and sex composition of British Columbia sockeye salmon catches from 1912 to 1963. Fish. Res. Bd. Canada Circular (Statistical Series) No. 25.

Brodeur, R.D. and D.M. Ware. 1995. Interdecadal variability in distribution and catch rates of epipelagic nekton in the Northeast Pacific Ocean, p. 329-356. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Brodeur, R.D. and D.M. Ware. 1992. Long-term variability in zooplankton biomass in the subarctic Pacific Ocean. Fish. Oceanogr. 1:32-38.

Burgner, R.L. 1992. Review of high seas salmonid research by the United States. p. 11-17. *In* Y. Ishida, K. Nagasawa, D.W. Welch, K.W. Myers, and A.P. Shershnev [eds.] Proceedings of the International Workshop on Future Salmon Research in the North Pacific Ocean. National Research Institute of Far Seas Fisheries, Shimizu, Japan.

Emery, W.J. and K. Hamilton. 1985. Atmospheric forcing of interannual variability in the northeast Pacific Ocean: connections with El Niño. J. Geophys. Res. 90: 857-868.

Francis, R.C. and S.R. Hare. 1994. Decadal-scale regime shifts in the large marine ecosystems of the North-east Pacific: a case for historical science. Fish. Oceanogr. 3:279-291.

Gilbert, C.H. 1913. Age at maturity of the Pacific coast salmon of the genus Oncorhynchus. p. 57-70. *In* Report of the Commissioner of Fisheries for the year ending December 31st, 1912.

Hanawa, K. 1995. Long-term variations in SST fields of the North Pacific Ocean, p. 25-36. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Hare, S.R. and R.C. Francis. 1995. Climate change and salmon production in the Northeast Pacific Ocean. p. 357-372. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Hollowed, A.B. and W.S. Wooster. 1995. Decadal-scale variations in the eastern subarctic Pacific: II. Response of Northeast Pacific fish stocks, p. 373-385. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Can. J. Fish. Aquat. Sci. 121.

Margolis, L. 1992. A brief history of Canadian research from 1955 to 1990 related to Pacific Salmon (*Oncorhynchus* species) on the high seas. p 1-10. *In* Y. Ishida, K. Nagasawa, D.W. Welch, K.W. Myers, and A.P. Shershnev [eds.] Proceedings of the International Workshop on Future Salmon Research in the North Pacific Ocean. National Research Institute of Far Seas Fisheries, Shimizu, Japan

McKinnell, Skip. 1995. Age-specific density-dependent effects of sockeye abundance on adult body size of selected British Columbia sockeye stocks. Can. J. Fish. Aquat. Sci. 52 (6): In Press.

Milne, D.J. 1955. The Skeena River salmon fishery with special reference to sockeye salmon. J. Fish. Res. Bd. Canada 12:451-485.

Myers, R.A., N.J. Barrowman, and K.R. Thompson. 1995. Synchrony of recruitment across the North Atlantic: an update. ICES J. mar. Sci. 52: 103-110.

Rogers, D.E. and G.T. Ruggerone. 1993. Factors affecting marine growth of Bristol Bay sockeye salmon. Fish. Res. 18: 89-103.

Tanaka, S. 1962. I. On the salmon stocks of the Pacific coast of the United States and Canada (Views of the Japanese national section on the abstention cases of the United States and Canada). II. Studies of the question of reproduction of salmon stocks. Bull. Int. North Pac. Fish. Comm. 9:69-90.

Trenberth, K.E. and J.W. Hurrell. 1995. Decadal coupled atmosphere-ocean variations in the North Pacific Ocean, p.15-24. *In* R.J. Beamish [ed.] Climate change and northern fish populations. Can. Spec. Publ. Fish. Aquat. Sci. 121.

Venrick, E.L., J.A. McGowan, D.R. Cayan, and T.L. Hayward. 1987. Climate and chorophyll a: long-term trends in the central North Pacific Ocean. Science (Wash. D.C.) 238:70-72.

Van Hyning, J.M. 1968. Factors affecting the abundance of fall chinook salmon in the Columbia River. Oregon State University, Ph.D. thesis. 424p.

Ware, D.M. 1996. A century and a half of change in the climate of the NE Pacific. Fisheries Oceanography. In press.

Wickett, W. P. 1958. Review of certain environmental factors affecting the production of pink and chum salmon. J. Fish. Res. Bd. Canada 15:1103-1126.

List of Figures

1. Location of the Nass River, Skeena River and Rivers Inlet (Owikeno River) in reference to the Fraser River, British Columbia, Canada

2. Annual mean hypural length (cm) of the catch of age *1.2 and 1.3* male sockeye salmon from the Nass and Skeena Rivers and Rivers Inlet from 1912-1963 (1972 for Skeena) versus Western Alaska sockeye catch.

3. Annual mean hypural length (cm) of the catch of age *1.2 and 1.3* female sockeye salmon from the Nass and Skeena Rivers and Rivers Inlet from 1912-1963 (1972 for Skeena) versus Western Alaska sockeye catch.

4. Annual mean body weight (kg) of the catch of age *1.2 and 1.3* male sockeye salmon from the Nass and Skeena Rivers and Rivers Inlet from 1912-1963 (1972 for Skeena) versus Western Alaska sockeye catch.

5. Annual mean body weight (kg) of the catch of age *1.2 and 1.3* female sockeye salmon from the Nass and Skeena Rivers and Rivers Inlet from 1912-1963 (1972 for Skeena) versus Western Alaska sockeye catch.

6. Annual mean condition factor of the catch of age *1.2 and 1.3* male sockeye salmon from the Nass and Skeena Rivers and Rivers Inlet from 1912-1963 (1972 for Skeena) versus Western Alaska sockeye catch.

7. Annual mean condition factor of the catch of age *1.2 and 1.3* female sockeye salmon from the Nass and Skeena Rivers and Rivers Inlet from 1912-1963 (1972 for Skeena) versus Western Alaska sockeye catch.

8. Ordination of sockeye age/sex/river strata from the correlation matrix of **mean lengths** among strata. Each plotted point indicates the ordination position of an age/sex/river stratum on the 3 principal components. Symbols in the figure are S=Skeena, R=Rivers, N=Nass, M=males, F=Females, 12= age *1.2* sockeye, 13= age *1.3* sockeye...., etc.

9. Ordination of sockeye age/sex/river strata from the correlation matrix of **mean weights** among strata. Each plotted point indicates the ordination position of an age/sex/river stratum on the 3 principal components. Symbols in the figure are S=Skeena, R=Rivers, N=Nass, M=males, F=Females, 12= age *1.2* sockeye, 13= age *1.3* sockeye...., etc.

10. Ordination of sockeye age/sex/river strata from the correlation matrix of **mean condition factors** among strata. Each plotted point indicates the ordination position of an age/sex/river stratum on the 3 principal components. Symbols in the figure are S=Skeena, R=Rivers, N=Nass, M=males, F=Females, 12= age *1.2* sockeye, 13= age *1.3* sockeye...., etc.

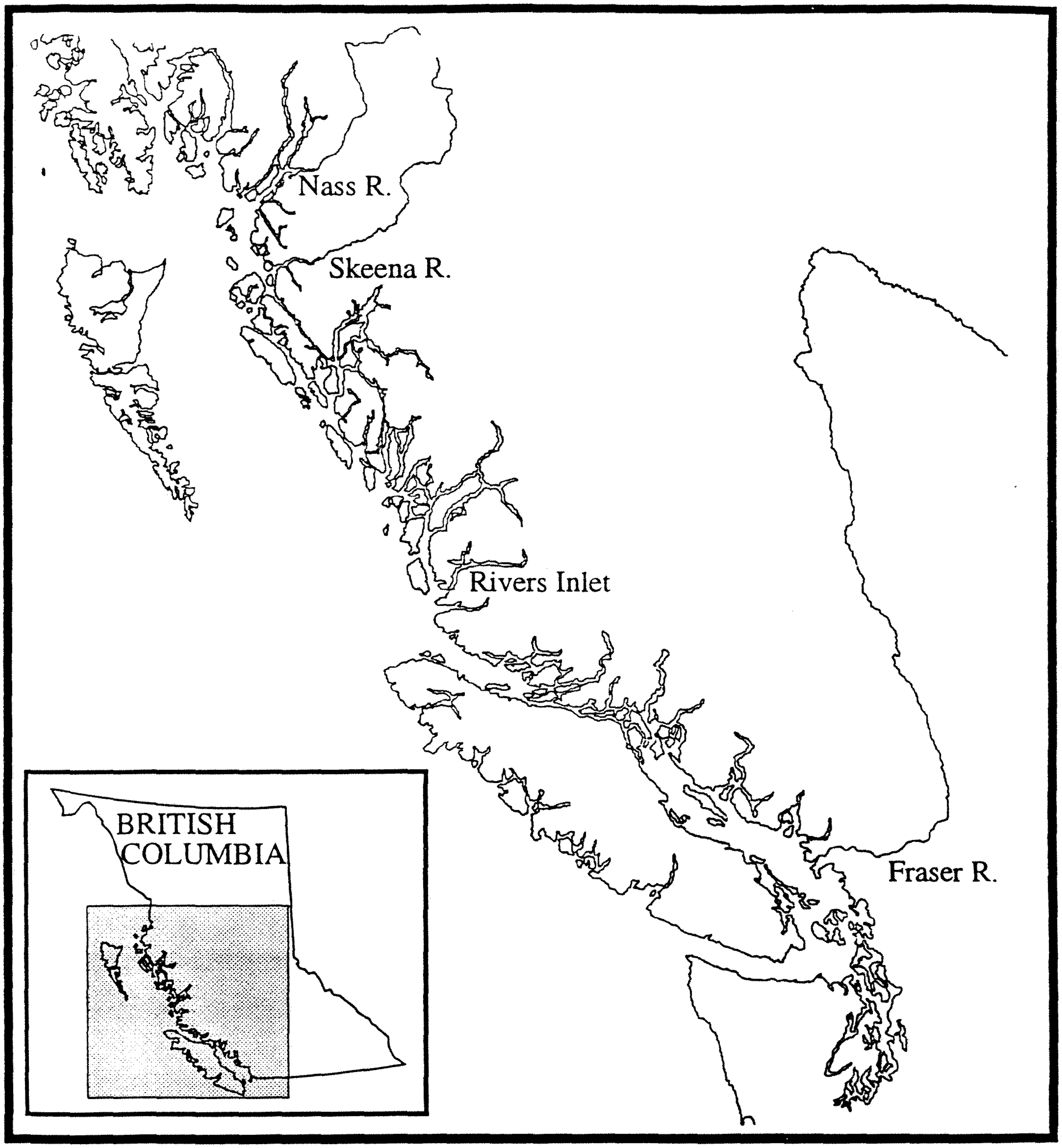


Figure 1. Location of the Nass River, Skeena River and Rivers Inlet (Owikeno River) with respect to the Fraser River in British Columbia, Canada.

Figure 2.

Sockeye Mean Length versus Sockeye Catch 1912-1963

Males

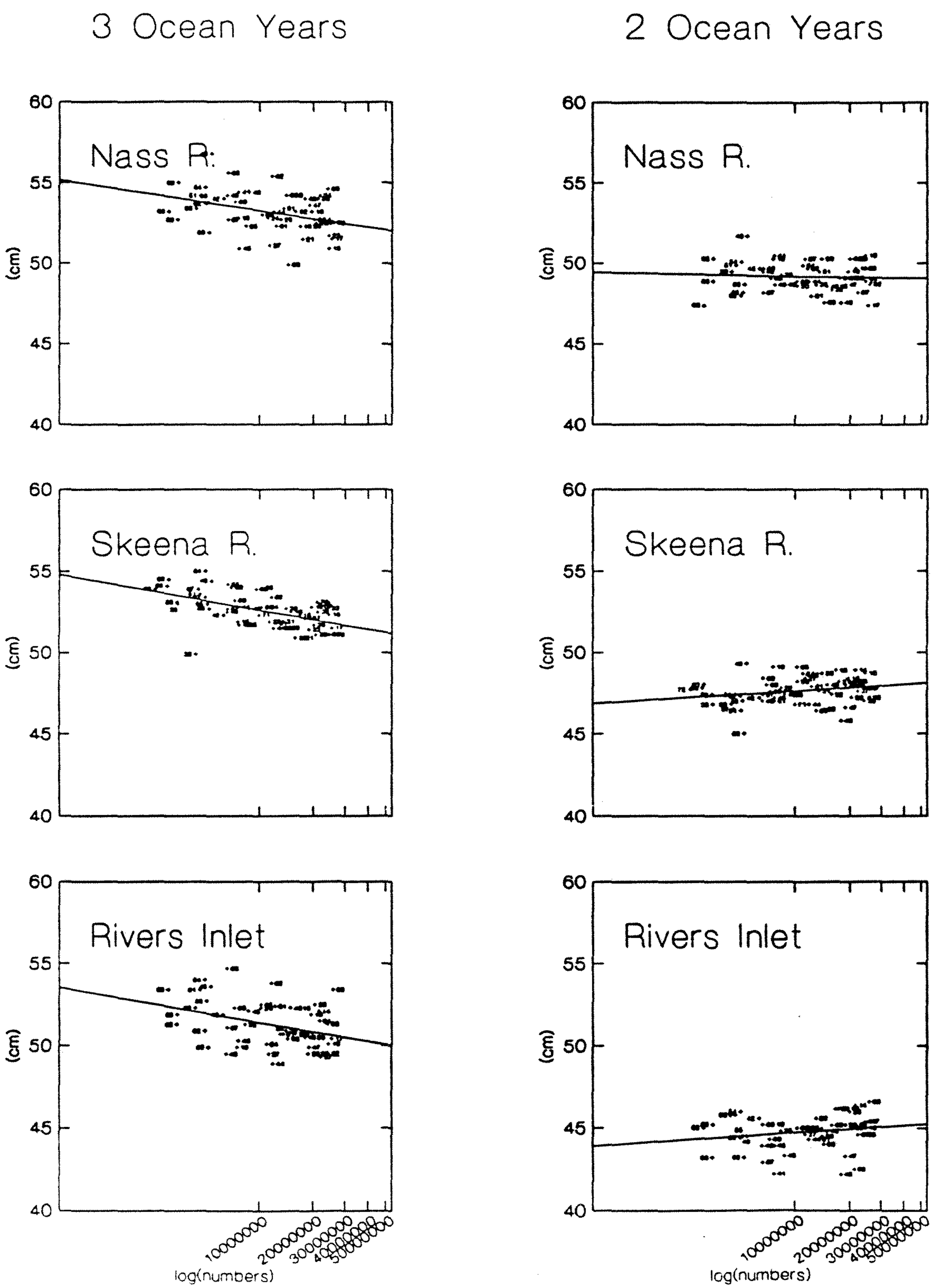


Figure 3.

Sockeye Mean Length versus Sockeye Catch 1912-1963

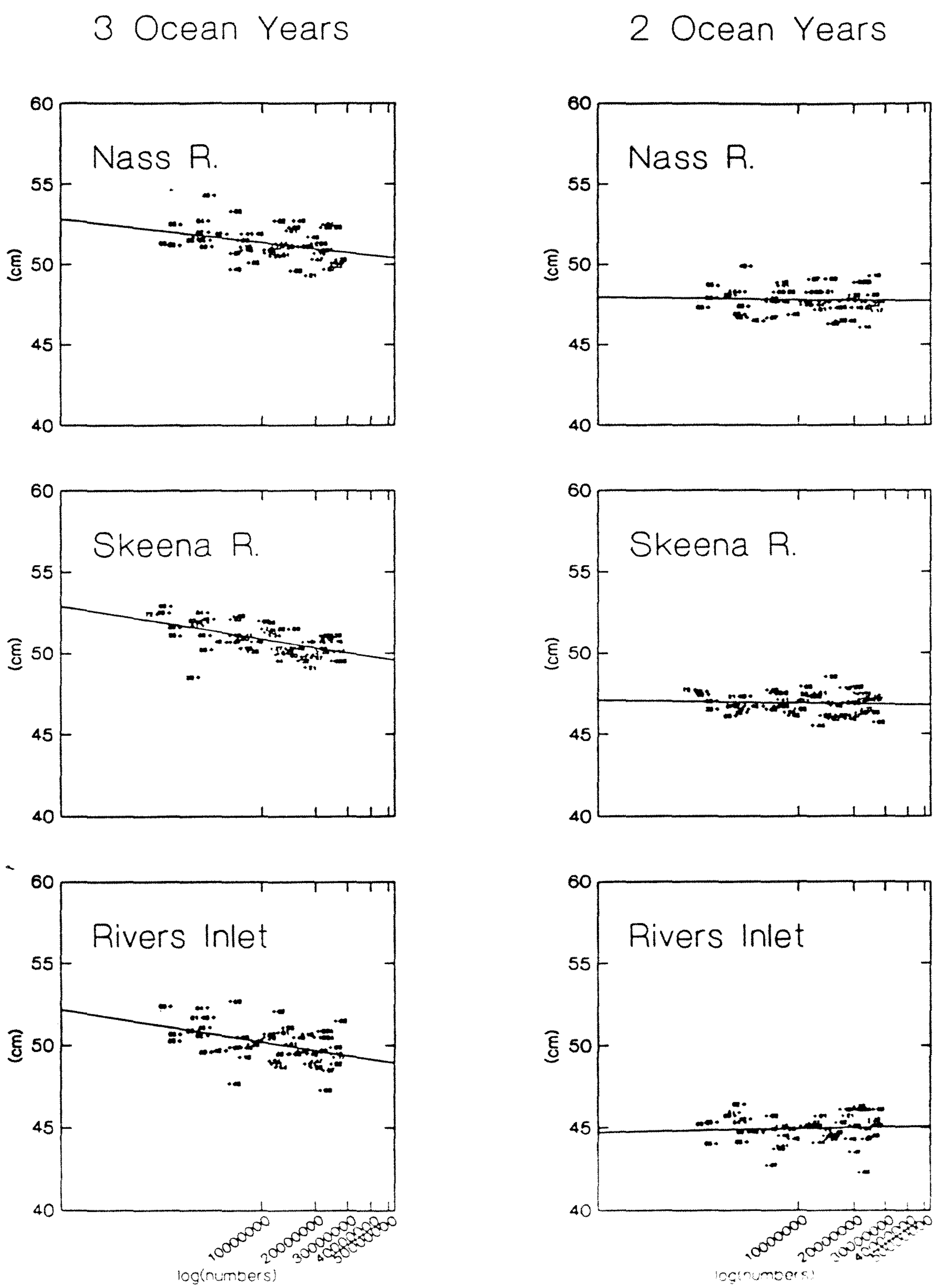


Figure 4.

Sockeye Mean Weight versus Sockeye Catch 1912-1963

Male

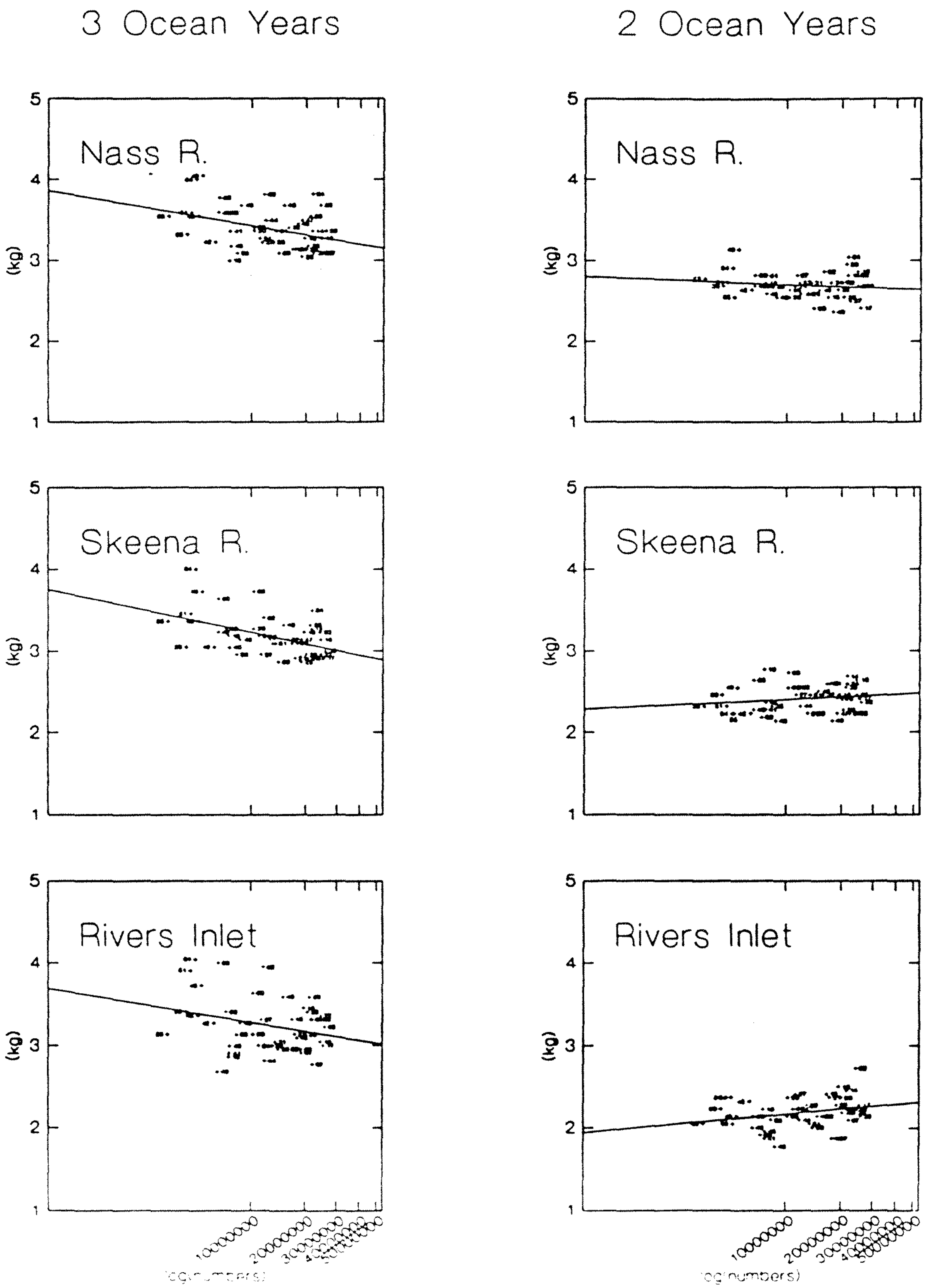


Figure 5.

Sockeye Mean Weight versus Sockeye Catch 1912-1963

Female

3 Ocean Years | 2 Ocean Years

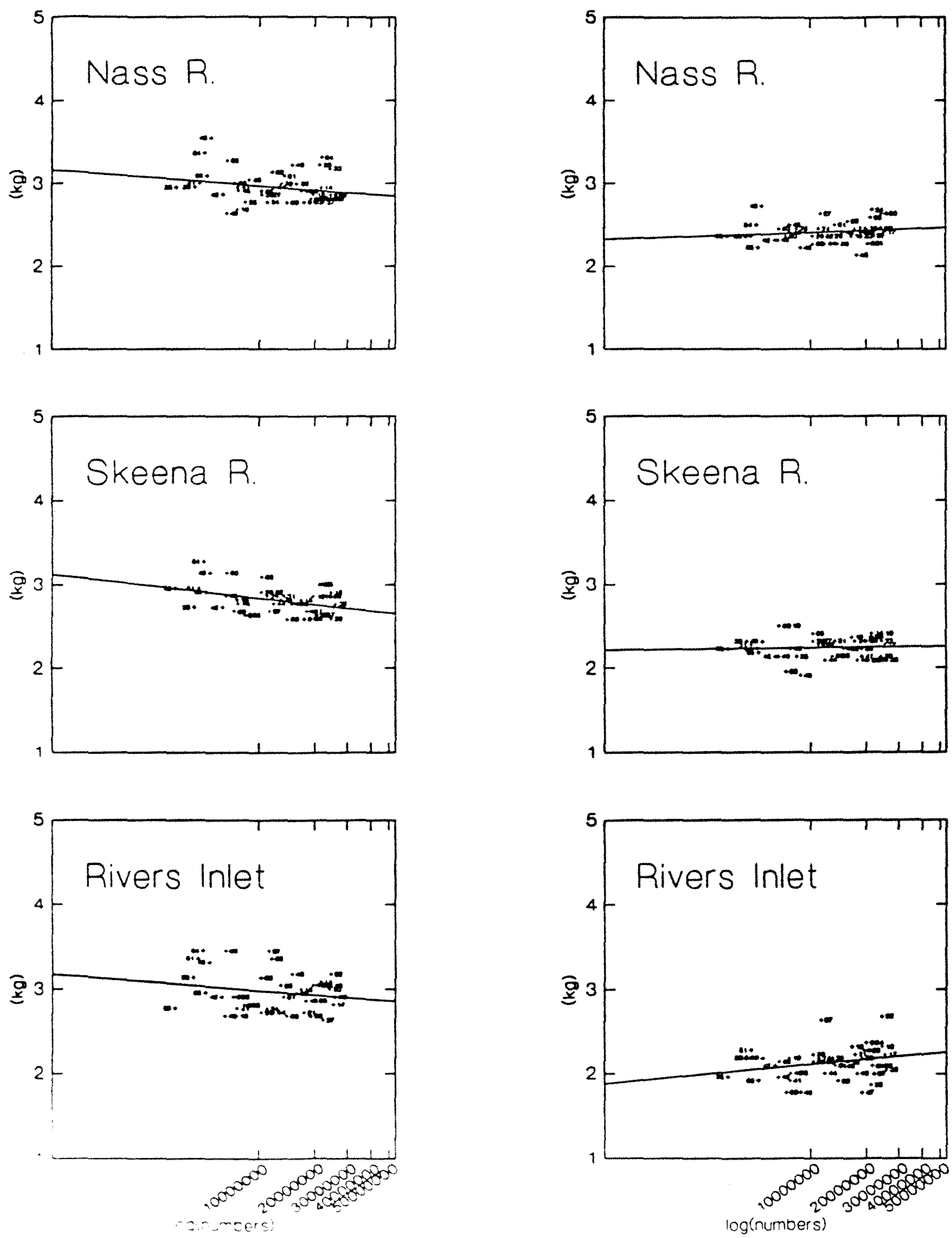


Figure 6.

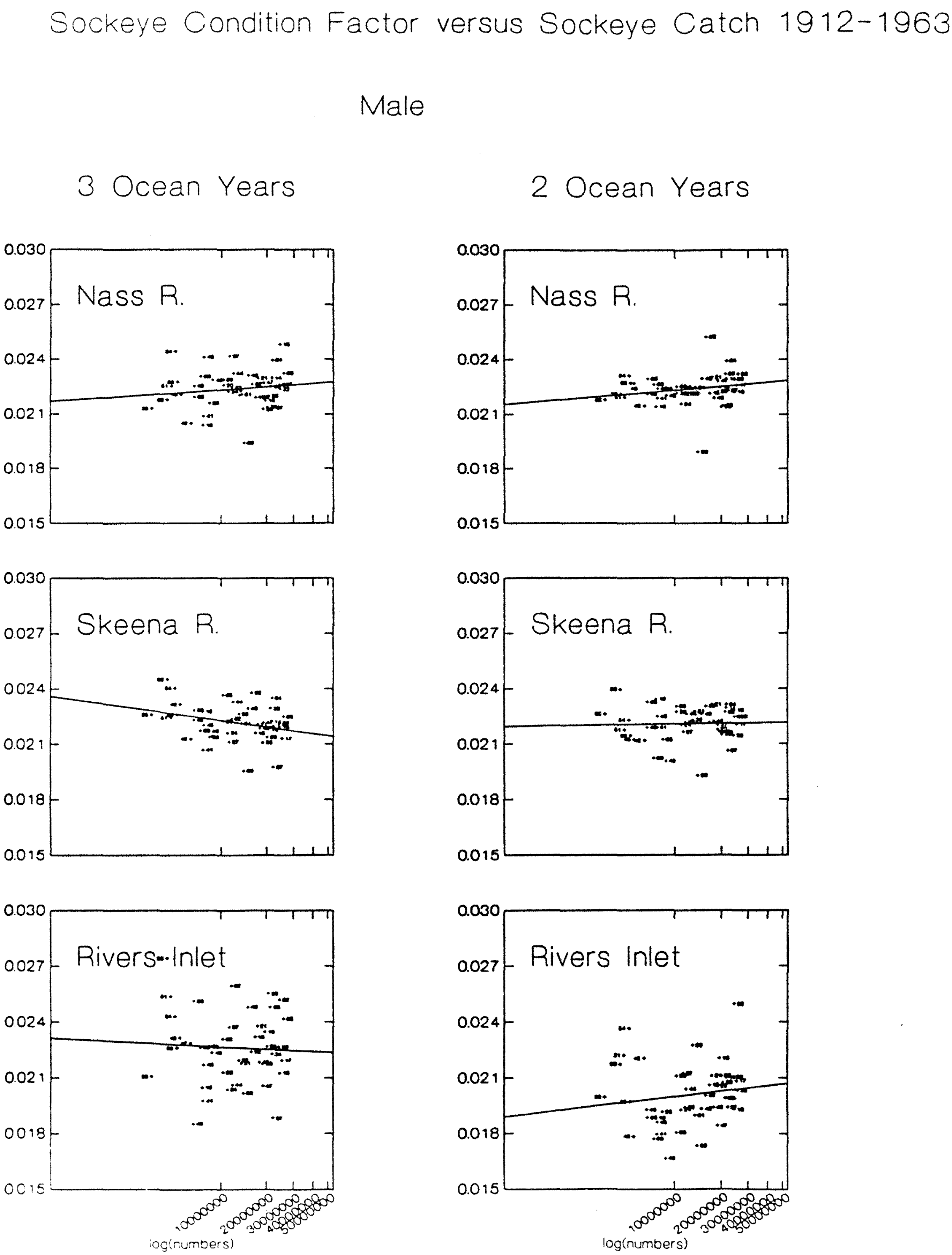

Sockeye Condition Factor versus Sockeye Catch 1912-1963
Male
3 Ocean Years
2 Ocean Years
Nass R.
Skeena R.
Rivers Inlet
0.030
0.027
0.024
0.021
0.018
0.015
10000000
20000000
30000000
40000000
50000000
log(numbers)

Figure 7.

Sockeye Condition Factor versus Sockeye Catch 1912-1963

Female

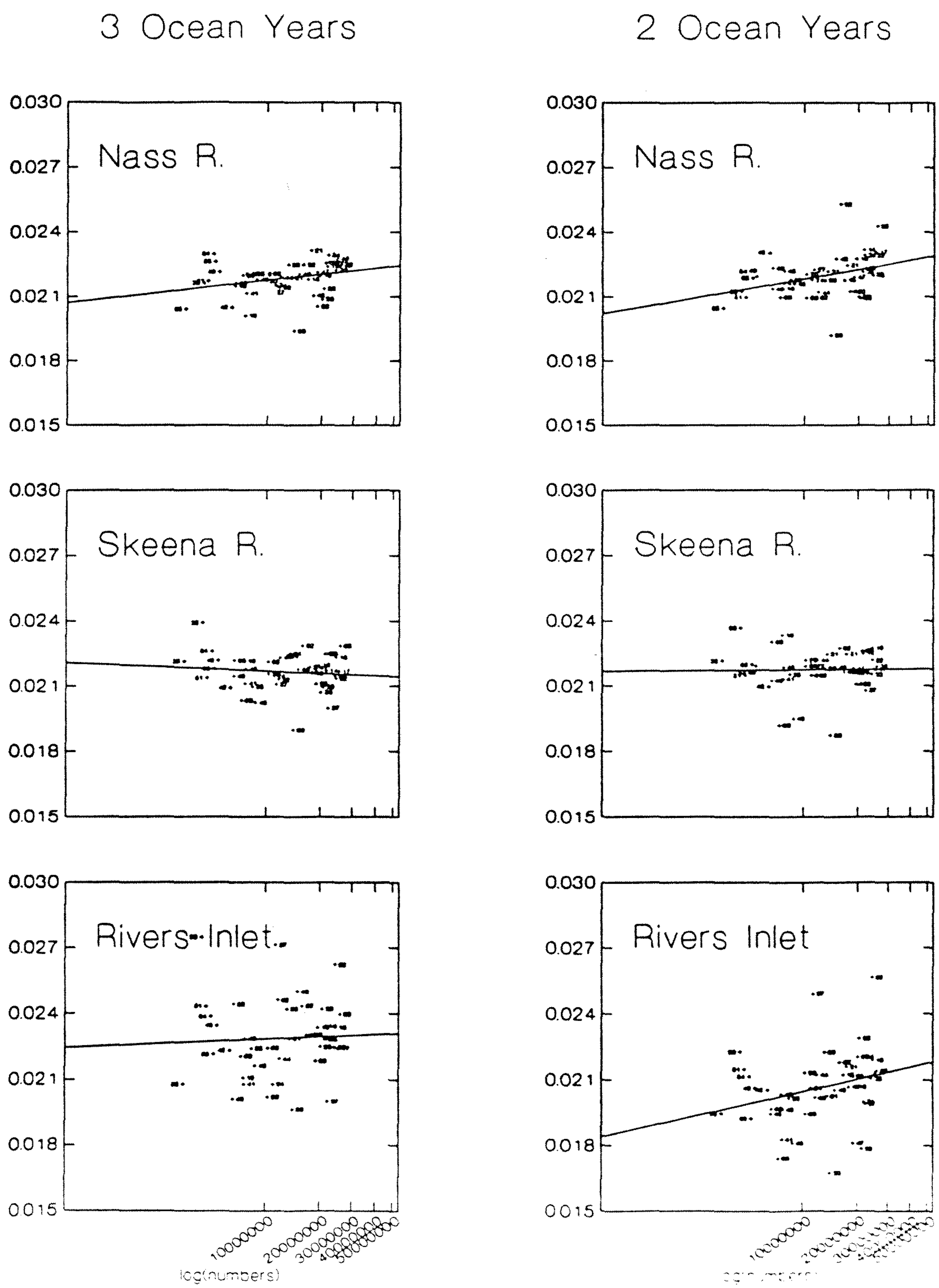


Figure 8.

PCA Mean Length

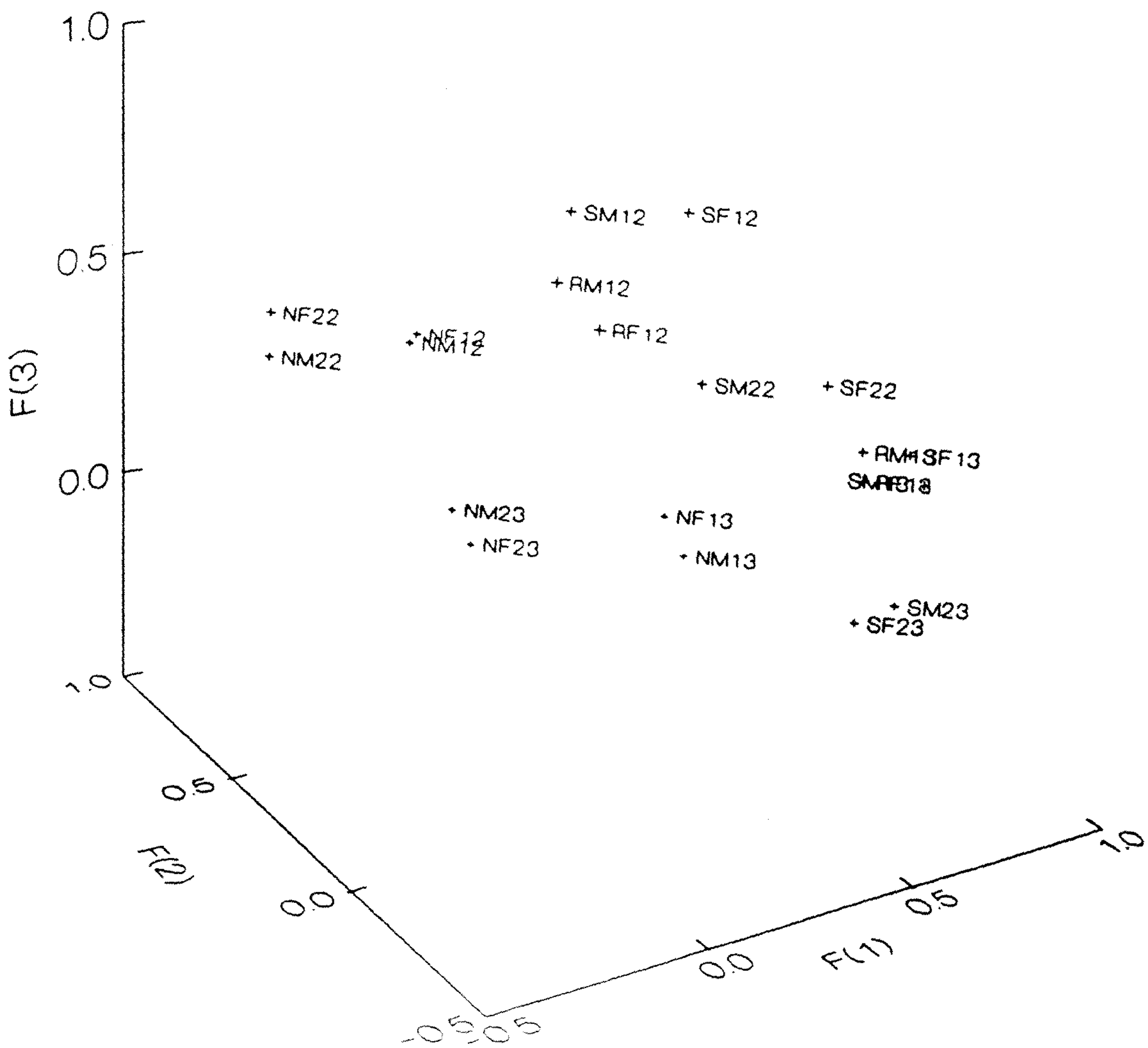
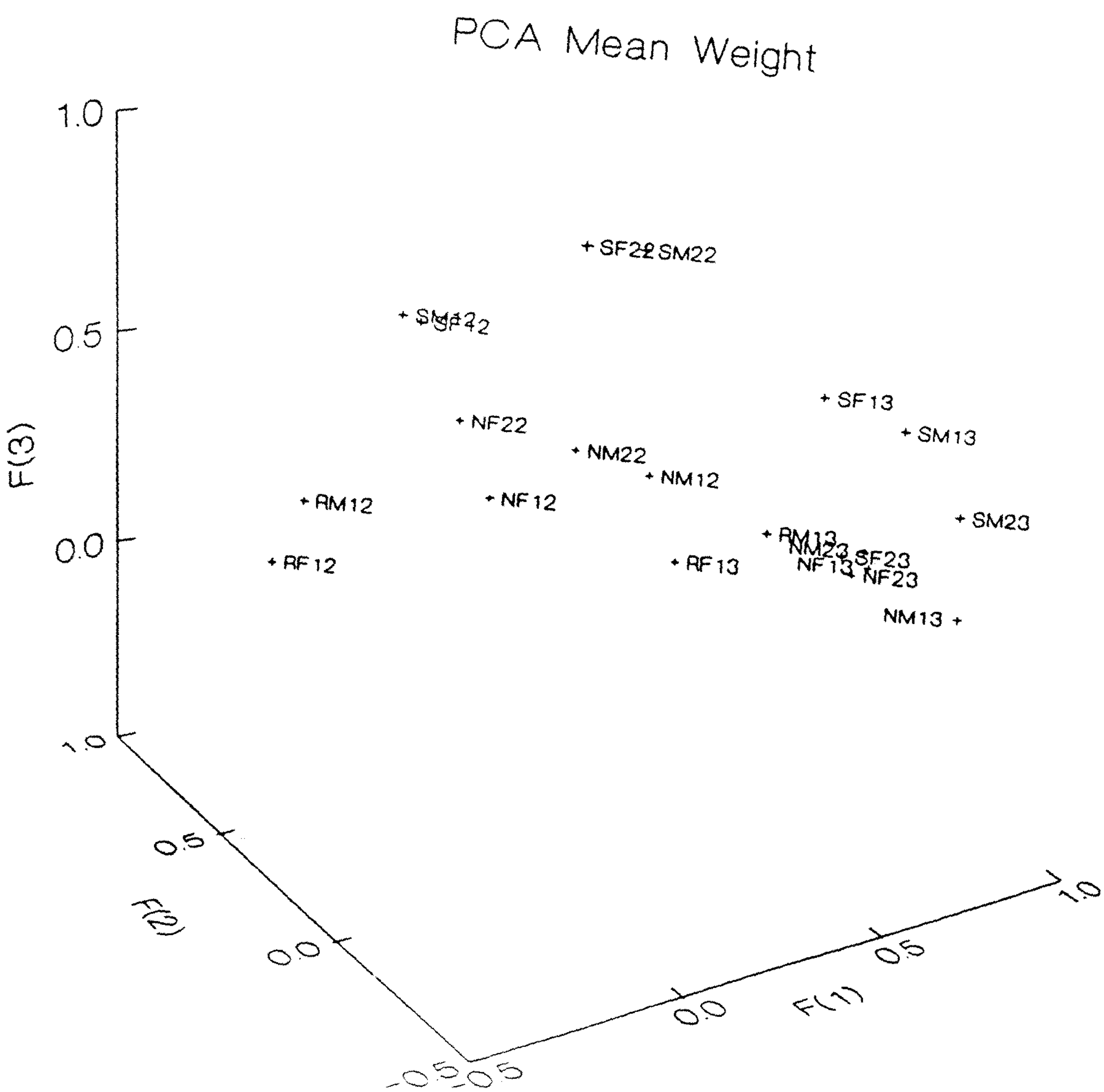
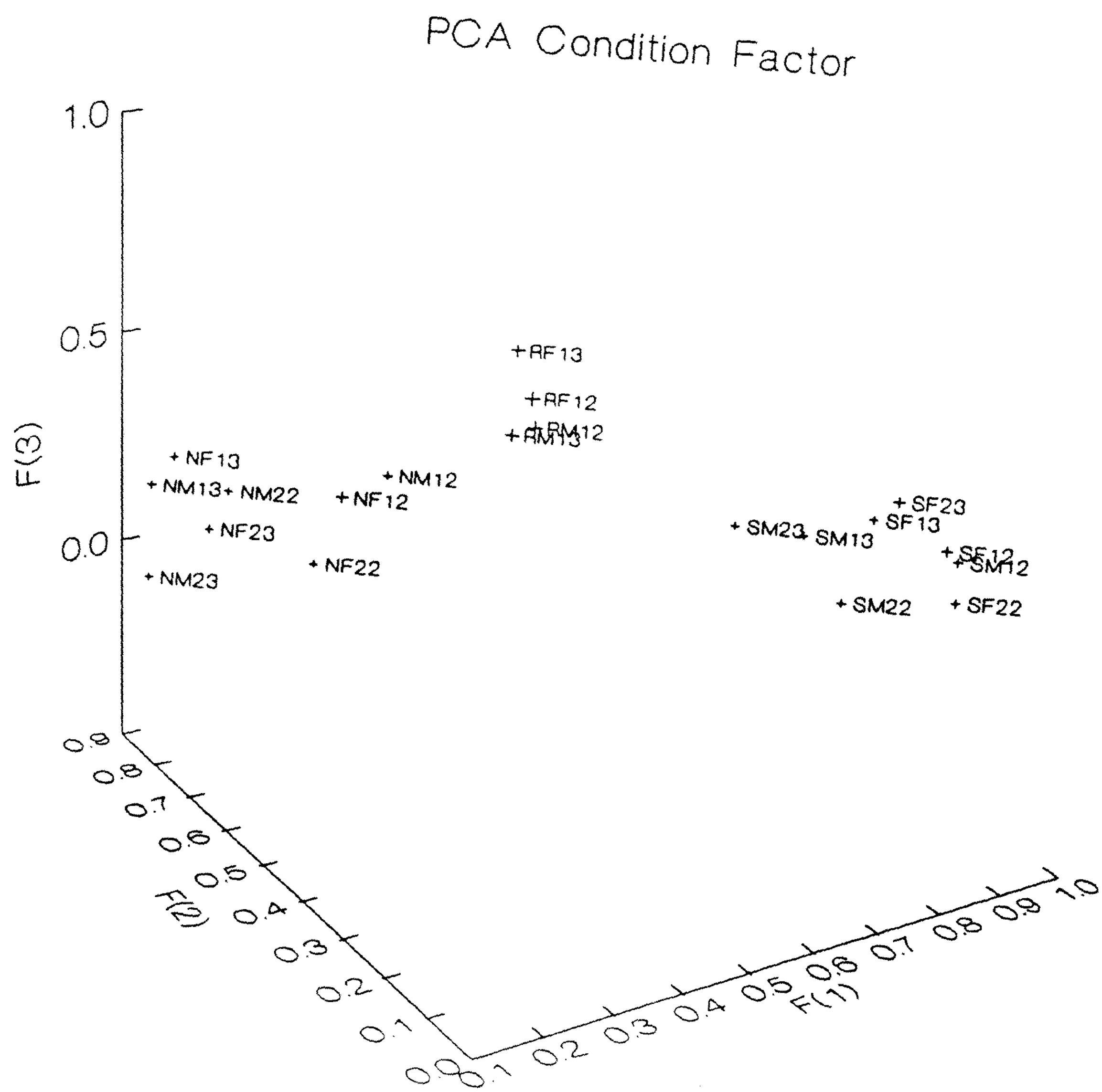


Figure 9.



PCA Mean Weight
1.0
0.5
0.0
F(3)
SF22
SM22
SM12
SF12
SF13
SM13
NF22
NM22
NM12
RM12
NF12
SM23
RM13
NM23
SF23
RF12
RF13
NF13
NF23
NM13
0.5
F(2)
0.0
-0.5
-0.5
0.0
F(1)
0.5
1.0

Figure 10.


PCA Condition Factor
F(3)
1.0
0.5
0.0
F(2)
F(1)
NF13
NM13
NM22
NF23
NM23
NF22
NF12
NM12
RF13
RF12
RM12
RM13
SM23
SM13
SF23
SF13
SF12
SM12
SM22
SF22