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by

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Density Dependent Growth of Pink Salmon (*Oncorhynchus gorbuscha*) in the Bering Sea and Western North Pacific

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ABSTRACT

Growth variations of pink salmon and the factors influencing them were examined using data collected by Japanese salmon research vessels in the Bering Sea and Western North Pacific during 1972-1995. Catch-per-unit-effort (CPUE) of pink salmon changed between odd and even year stocks in the Bering Sea and western North Pacific. Coefficients of variation (C.V.) in the second year ocean growth (8.1-11.8%) were larger than those for coastal growth (3.2-4.8%) or the first year ocean growth (4.0-5.0%) for all stocks in both areas. Analysis of relationships between fork length and scale measurements demonstrated that pink salmon growth variations occur in the first and second ocean life, but not in the coastal period. The first and second year ocean growth was negatively related to CPUE, especially strong for the second year ocean growth for odd year stocks. CPUEs of other salmon species partly showed a significant negative relationship with pink salmon growth, but sea surface temperature and zooplankton biomass did not show such a relationship. These results suggest that density of pink salmon is one of the major factors influencing growth variations in pink salmon, especially in the second year ocean life.

INTRODUCTION

Salmon catch in the North Pacific has increased in recent years and the total catches in 1980s exceeded the historical peak catch recorded in the late 1930s. Among five species of Pacific salmon, pink salmon (*Oncorhynchus gorbuscha*) contribute approximately 40% of the commercial catch in the North Pacific (Beamish and Bouillon 1993). A prominent feature of pink salmon is a two-year dominance cycle (Heard 1991). The changes in pink salmon abundance affect growth not only of pink salmon themselves but also of other Pacific salmon such as sockeye and coho salmon (Krogius 1965; Ogura et al. 1991; Ishida and Ito 1994). Therefore, pink salmon are considered one of the most important key species for salmon production in the North Pacific.

The purpose of this paper is to clarify variations in growth of pink salmon during three life history stages: coastal life, first year ocean life, and second year ocean life, and to identify factors affecting the growth of pink salmon in the Bering Sea and Western North Pacific.

MATERIALS AND METHODS

Data and scale samples used in this study were collected by Japanese salmon research vessels in the Western North Pacific (45° -51° N, 164° -166° E) and Bering Sea (55° -59° N, 175° E-175° W) between July 1 and 15 from 1972 to 1995 (Fig.1). Catch-per-unit-effort (CPUE) is calculated as the number of fish caught by non-selective gillnets (Takagi 1975). Mean and standard deviation (SD) of fork length and body weight were calculated for each region by year based on the data collected by non-selective gillnets. Approximately 50 male and 50 female scale samples per year were selected from fish whose length and weight within one SD of the mean. If scales were not available from fish caught by non-selective gillnets, scale samples collected from fish caught by commercial gillnets were also used using the same selection criteria. Scale measurements were made using a BioSonics Optical Pattern Recognition System (OPRS). Each scale was measured from the focus to the end of the first year ocean growth zone (L1) and from the end of the first year ocean growth zone to the outer edge of the scale (L2) along the longest axis of the scale. "Coastal" growth (W10) was defined as a width from the focus to the 10th circuli (Welch 1994). A total of 1,707 scales from the Bering Sea and 1,015 scales from the Western North Pacific were measured, respectively. CPUEs of pink and other salmon, sea surface temperature collected by the Japanese salmon research vessels, and zooplankton abundance from the literature (Odate 1994; Sugimoto and Tadokoro, personal communication) were examined as possible factors of salmon growth.

RESULTS

Catch per Unit Effort

The abundance trends for pink salmon differ for odd and even year stocks. The abundance of the odd year stock in the Bering Sea and the even year stock in the Western North Pacific have increased in recent years (Fig. 2). Pink salmon in the Bering Sea showed a very clear CPUE fluctuation: high in odd years and low in even years. CPUEs in odd years increased after 1989, but those in even years remained at a low level. Chum (*Oncorhynchus keta*) and sockeye salmon (*O. nerka*) were also abundant in the Bering Sea, and chum salmon demonstrated an opposite CPUE fluctuation: low in odd years and high in even years. In the Western North Pacific, pink salmon showed high CPUE in odd years and low in even years, but after 1993, CPUEs of pink were low in odd years in 1993 and 1995 and extremely high in 1994.

Fork Length and Body weight

Growth variations of pink salmon were also different depending on even and odd year stocks in each region, like changes in CPUE.

In the Bering Sea, mean fork lengths of pink salmon in odd years were larger than those in even years from 1974 to 1987 (except 1980). But mean fork lengths in odd years decreased to the size of the fish in even years during 1989 and 1993 and increased again in 1995. Mean fork lengths ranged from 445 to 489 mm, and mean body weight from 1055 to 1577g. Coefficient of variations (C.V.) in fork length were 2.5% for even and odd year stocks in the Bering Sea.

Mean fork length in the Western North Pacific did not show the same odd and even year fluctuations. Mean fork length ranged from 409 to 494 mm, and mean body weight from 795 to 1528g. These variations were greater than those in the Bering Sea. C.V. in fork length was 3.4% for even year stock and 5.4% for odd year stock in the Western North Pacific (Fig. 3). Mean body weight of pink salmon also showed a similar trend in both regions (Fig. 4).

Scale Measurements

Growth variations of pink salmon occur primarily in the second and/or first ocean life, but not in the coastal life (defined as scale side to the 10 circuli) (Table 1).

Changes in the coastal growth, first ocean growth, and second ocean growth did not show clear odd and even year changes, as found in the fork length and body weight. However, C.V. in the second ocean growth (8.1-11.8%) was larger than that in coastal growth (3.2-4.8%) and the first ocean growth (4.0-5.0%) for odd and even year stocks in both waters (Fig. 5).

Relationships between fork length and scale measurements were analyzed to identify the life stage in which variations in body size were determined. Coastal growth did not show significant correlation with fork length. The second year ocean growth was more highly correlated with fork length than was first year ocean growth, except in the case of the even year stock in the Bering Sea.

Factors affecting on Growth Variation

The density of pink salmon is one of the possible factors affecting growth variations, and especially strong in the second ocean growth. Coastal growth was also reduced when pink salmon were abundant in the Bering Sea, but not in the western North Pacific (Table 2).

Negative relationships between fork length and pink salmon CPUE were observed both in the Bering Sea and western North Pacific, and were especially significant for odd year stocks (Fig. 6). Coastal growth also showed a negative relationship with CPUE in the Bering Sea, especially significant for odd year stock, but not in the western North Pacific (Fig. 7). The first and second year ocean growth was negatively related to CPUE, with the effect especially strong for the second year ocean growth for odd year stocks, and significant in the western North Pacific (Figs. 8 and 9).

The influence of abundance of other salmon species did not show a clear pattern, but strong negative coefficient was found between the first year ocean growth of odd year pink salmon with the CPUE of sockeye salmon (r=-0.708*) in the Bering Sea and between the second year ocean growth of the even year stock with CPUE of sockeye (r=-0.654) and chum (r=-0.712) salmon in the western North Pacific. A strong negative coefficient (r=-0.701*) was found between CPUE of coho salmon (*O. kisutch*) and the first year ocean growth of odd year pink salmon in the Bering Sea (Table 3).

Sea surface temperature and zooplankton biomass did not show any significant relationship with pink salmon growth. However data on zooplankton biomass were not collected with data on pink salmon at the same time on the research vessels (Table 4).

DISCUSSION

The most interesting fact found in this study is that density effect on growth is stronger in the second year ocean life than in the first year ocean life in both the Bering Sea and Western North Pacific. Pink salmon juveniles migrate into the North Pacific, and over-winter with those originating from different coastal areas overlapping in their ocean distribution during the second year ocean life (Ogura 1994). Food habit of pink salmon also change from lower trophic level organisms such as copepods and amphipods in the first year ocean life to higher trophic level animals (squids and fishes) in the second year ocean life (Heard 1991). Body size during winter is approximately 300 mm fork length and 600 g body weight, and then subsequently increases to 450 mm and 1500g. Thus, growth in the second year is far greater than in the first year, especially in weight. These changes may contribute to differences in the effect of density on growth between in the first and the second year ocean life.

The second interesting fact is that effects of fish density on coastal growth differ between the Bering Sea and Western North Pacific. In the Bering Sea, density effects on coastal growth were very clear both for odd and even year stocks, but were not observed in the western North Pacific. These differences may be due to the life history differences during the coastal period.

Pink salmon caught in the Western North Pacific inhabit the Sea of Okhotsk as juveniles, and those caught in the Bering Sea live in coastal waters off the east coast of Kamchatka as juveniles (Shuntov 1989a,1989b). Zooplankton density in coastal waters of the Sea of Okhotsk are higher than coastal waters of the Bering Sea (Dulepova 1994). This may explain the difference in density effects on growth of pink salmon in these two waters.

The last interesting fact is that no significant effect of zooplankton biomass on pink salmon growth was found in this study. However, several studies indicate that the feeding activity of pink salmon affects zooplankton biomass (Cooney 1988; Shiomoto 1994). There is thus a possibility that amount of food organisms per fish changes due to fish density. It is necessary to compare pink salmon stomach content index between odd and even years or between high and low CPUE stations to examine this possibility.

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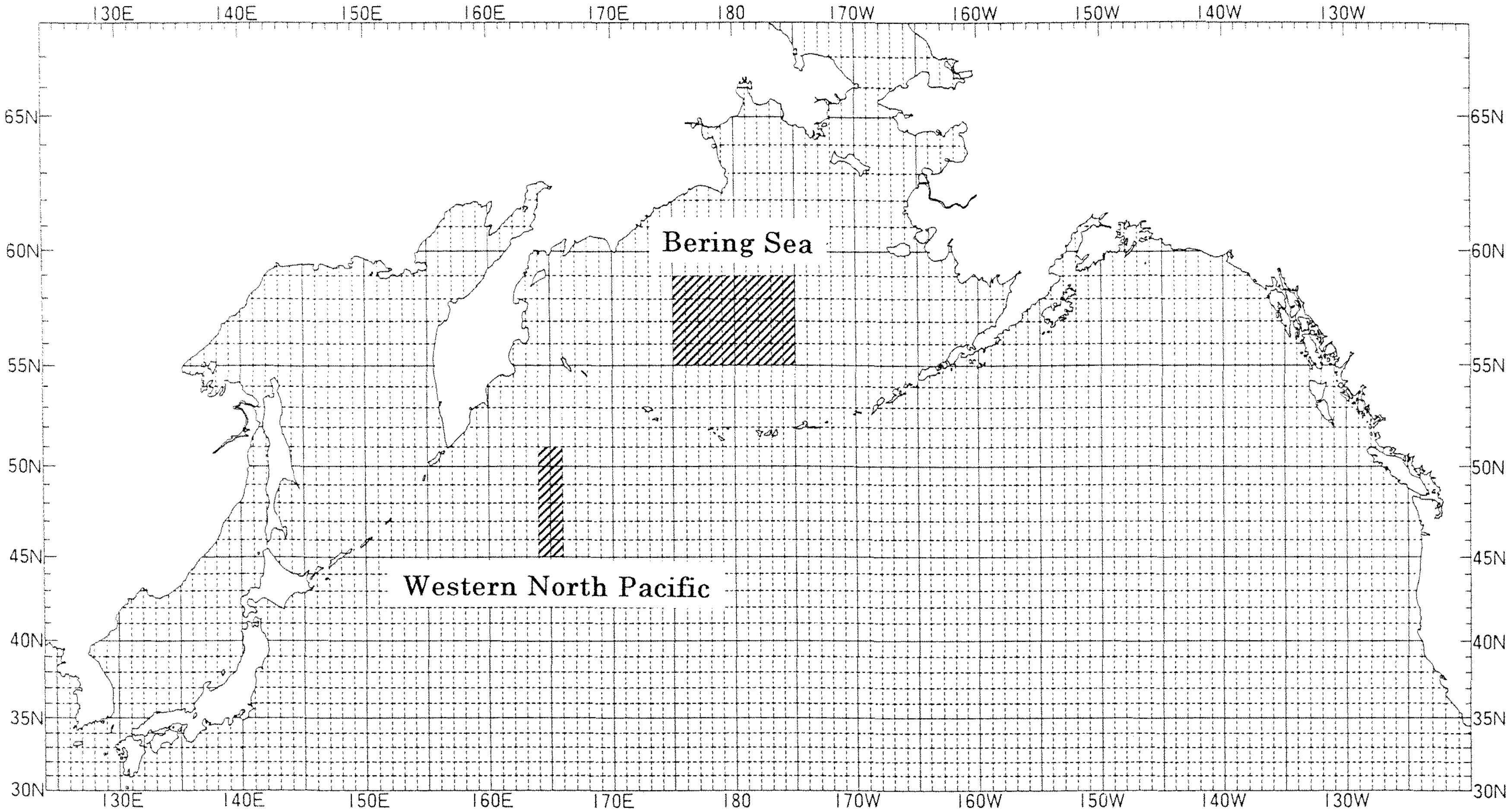
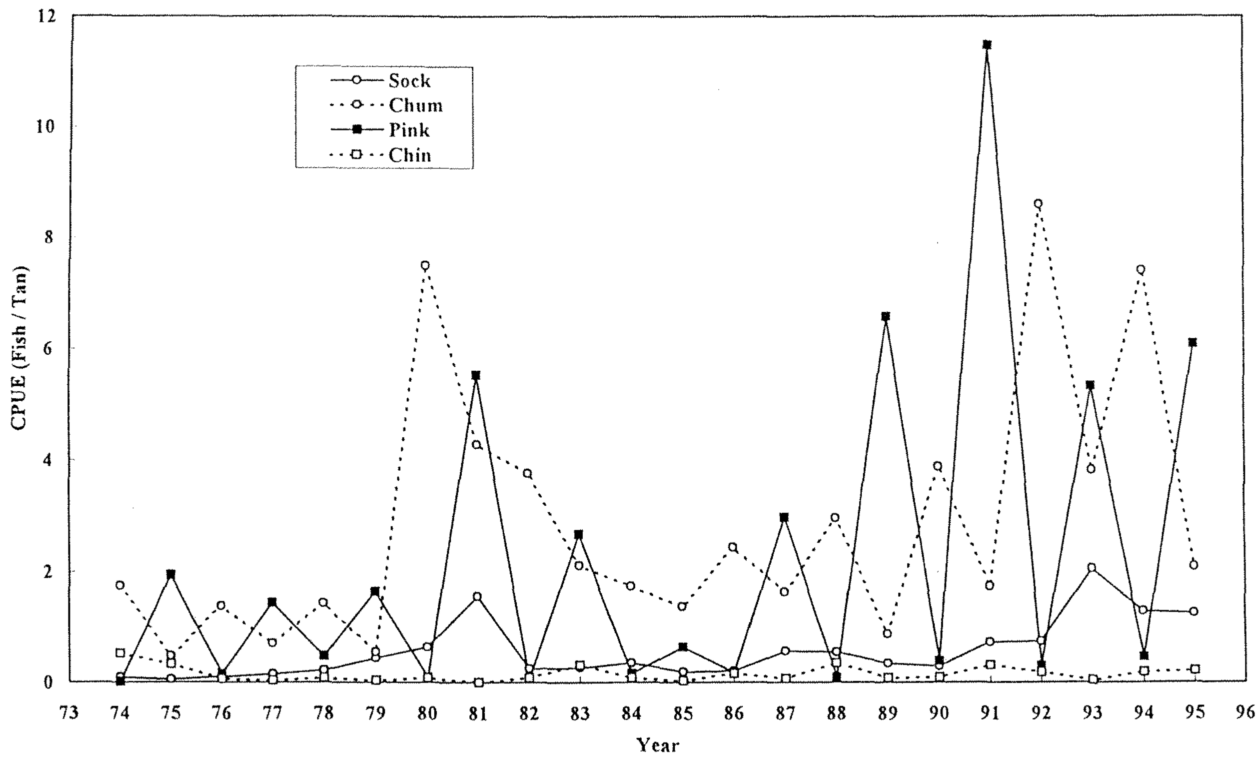


Fig. 1. Sampling locations in the Bering Sea and the western North Pacific.

Bering Sea



Western North Pacific

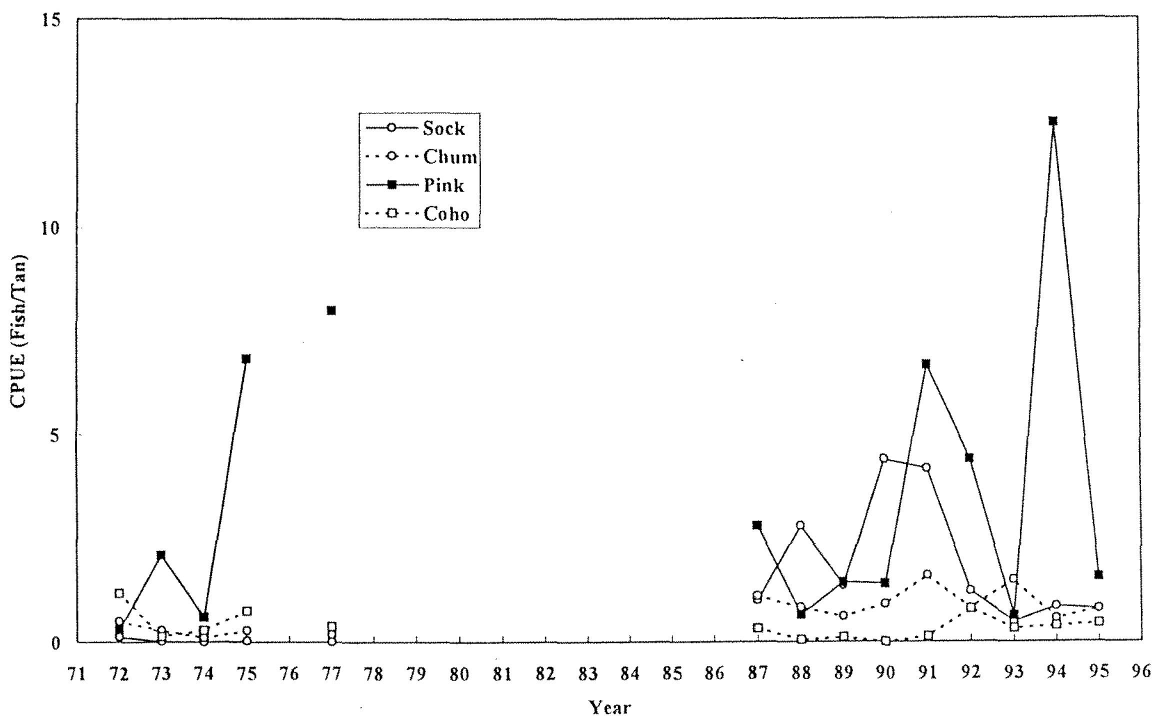
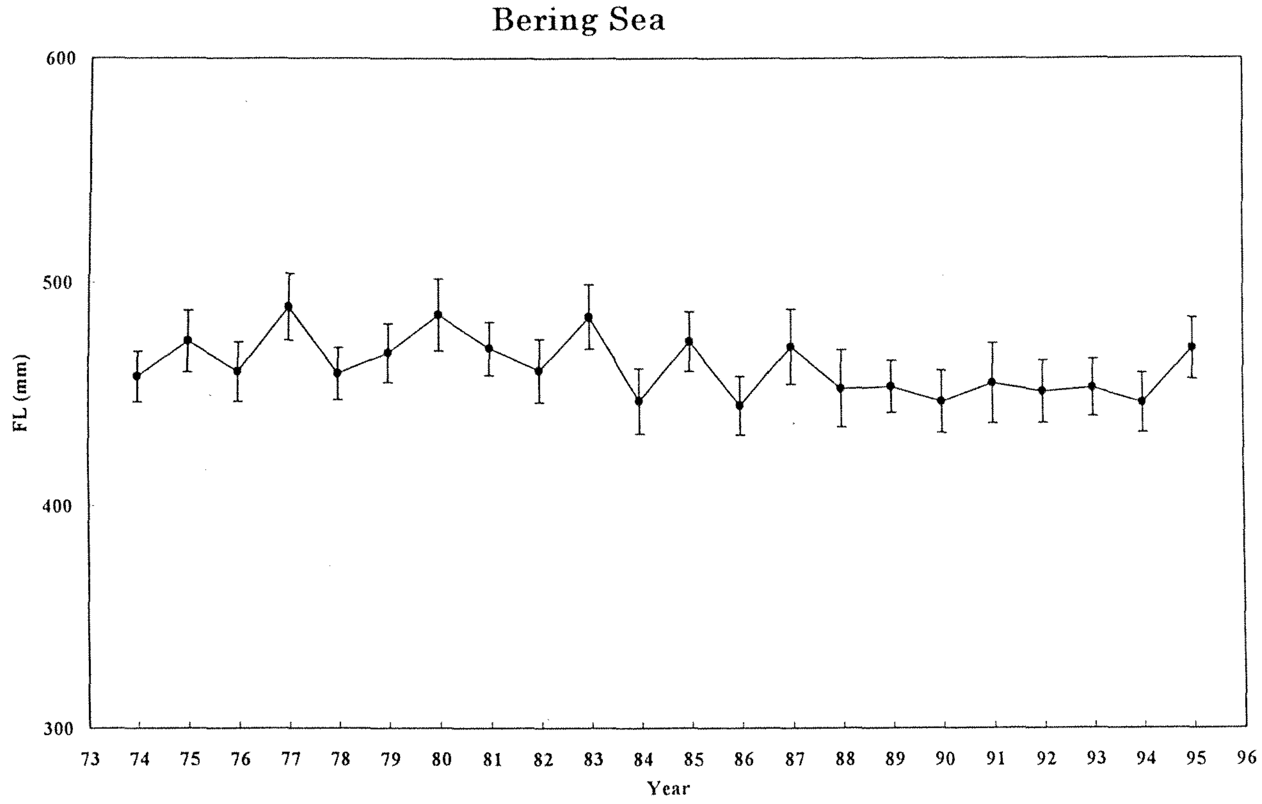


Fig. 2. Changes in CPUE of salmon in the Bering Sea and the western North Pacific.



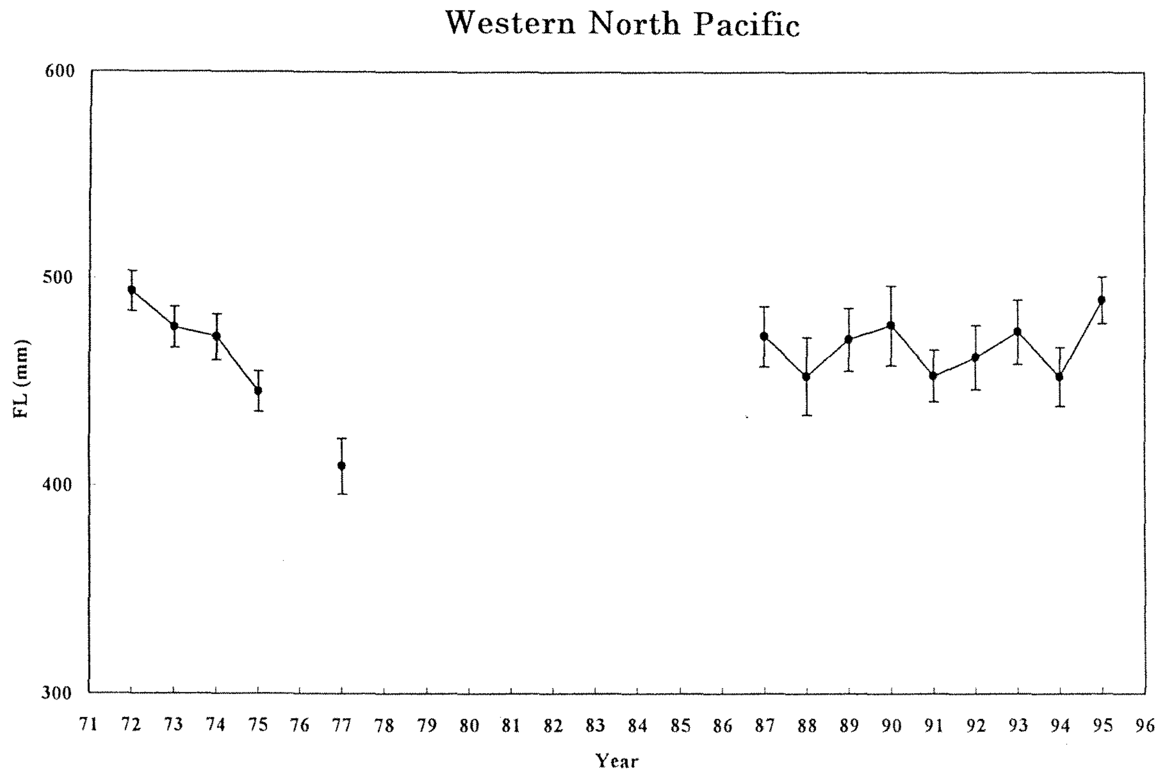
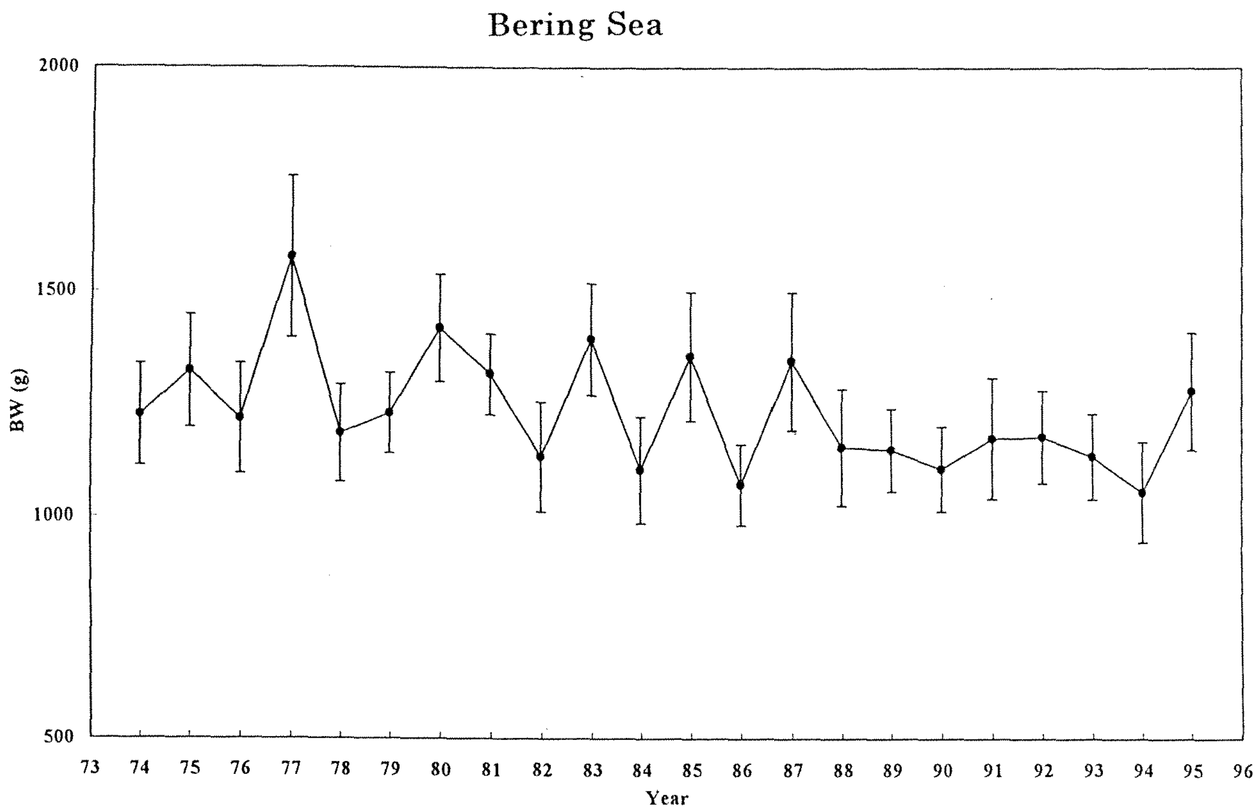


Fig. 3. Changes in fork length of pink salmon in the Bering Sea and the western North Pacific.



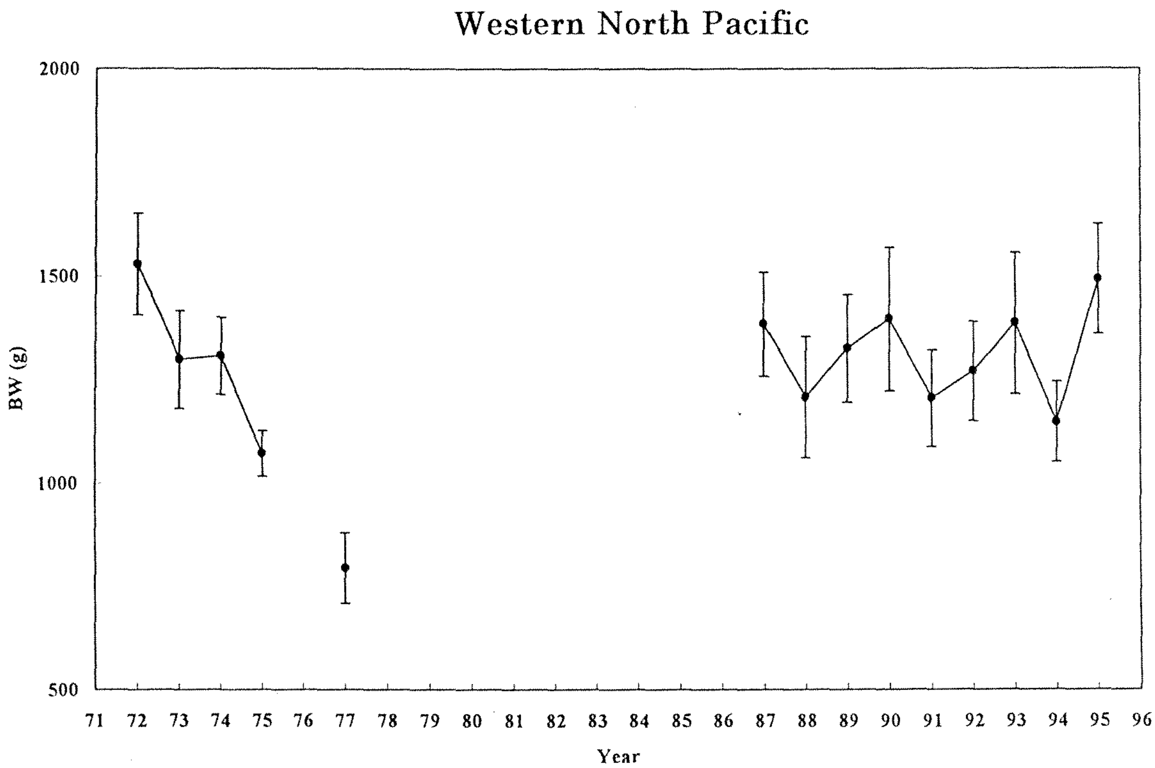
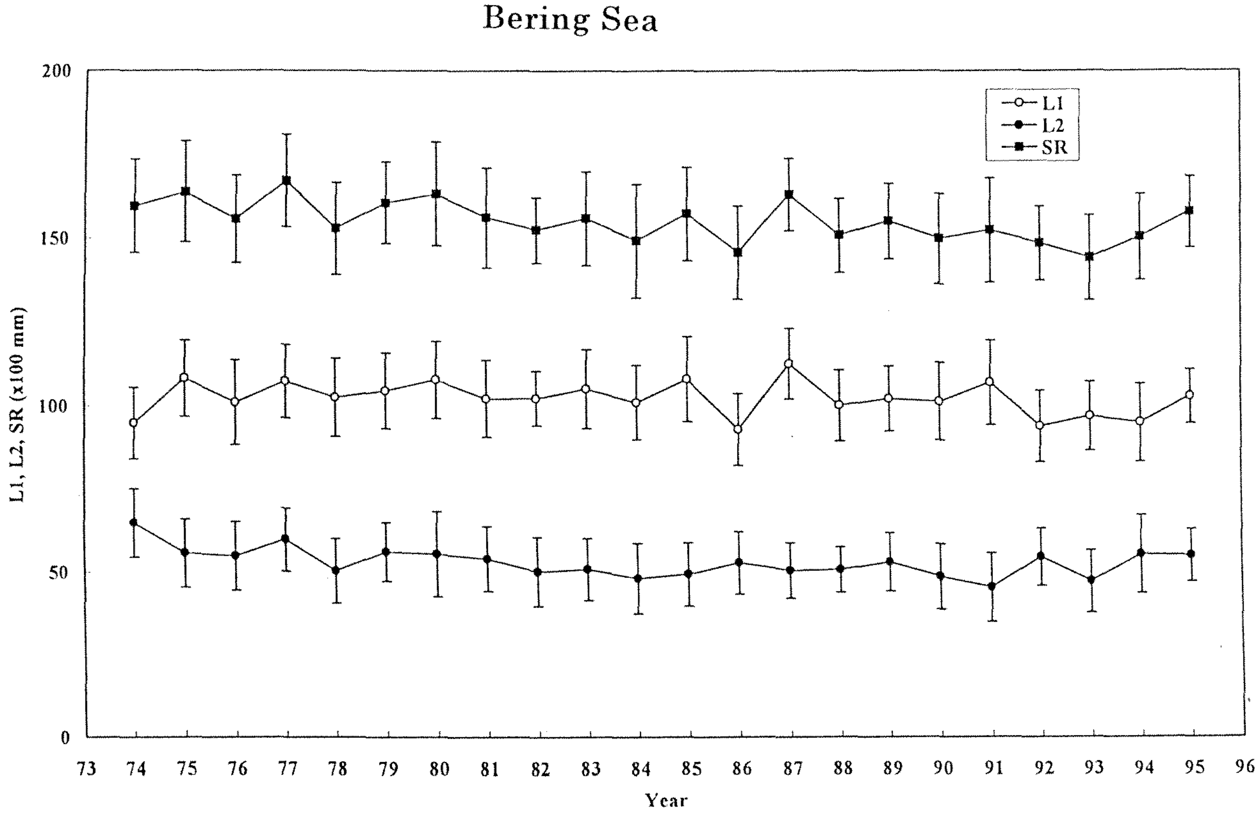


Fig. 4. Changes in body weight of pink salmon in the Bering Sea and the western North Pacific.



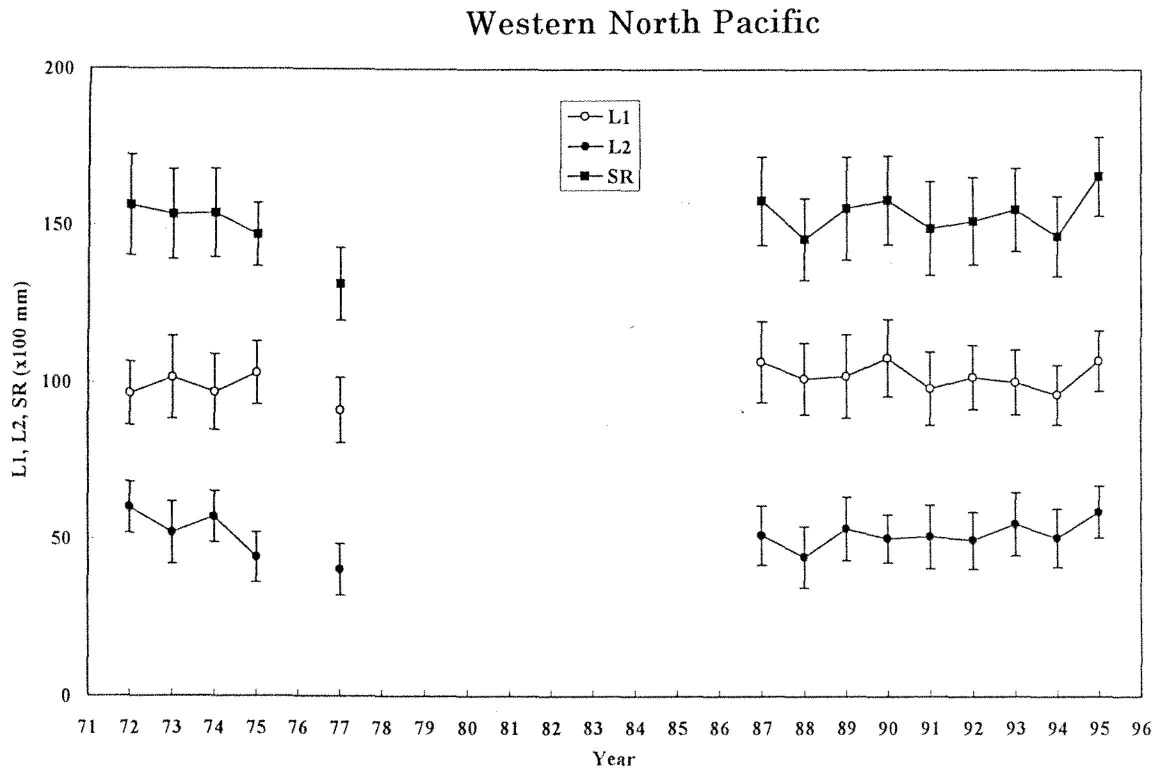
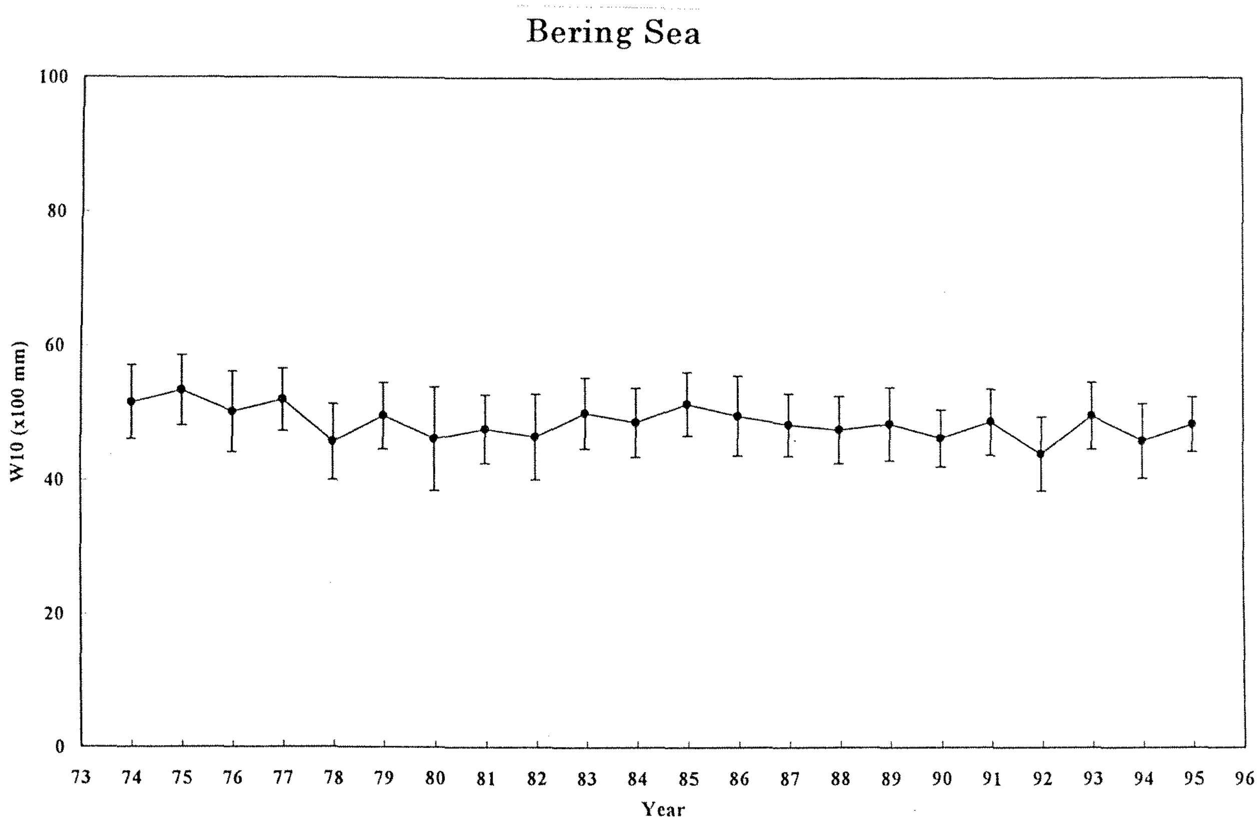


Fig. 5-1. Changes in scale measurements of pink salmon in the Bering Sea and the western North Pacific.



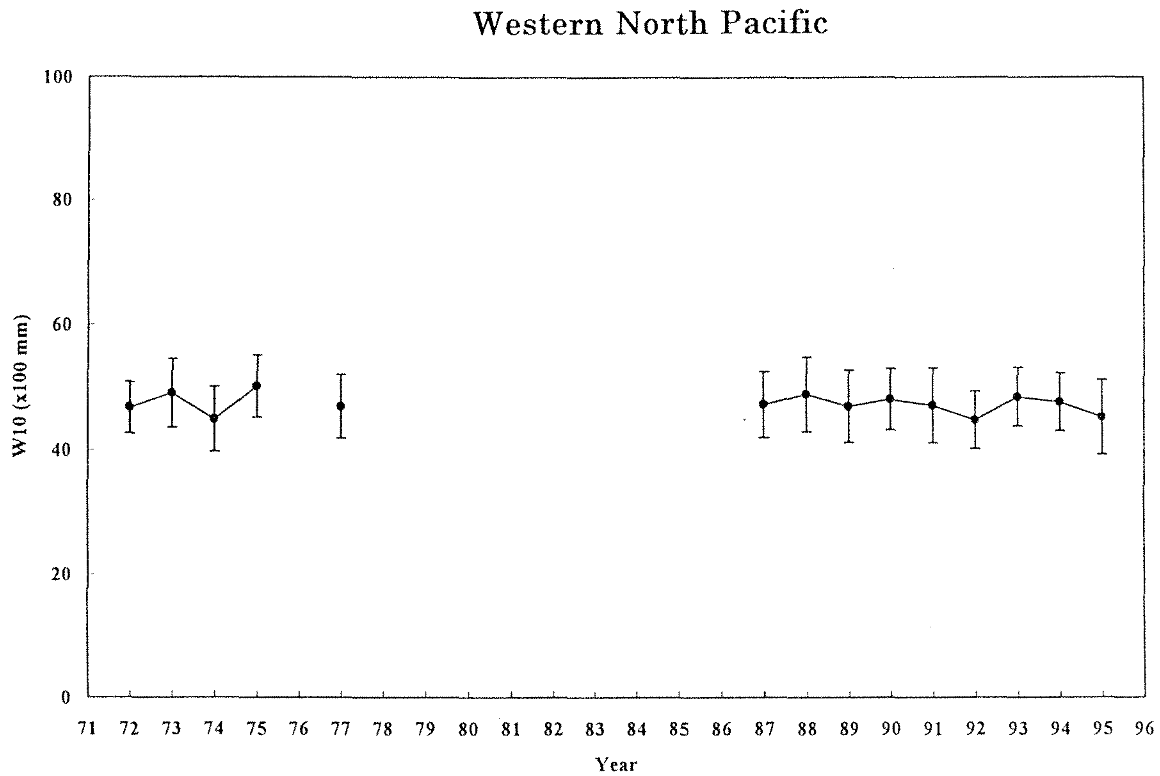
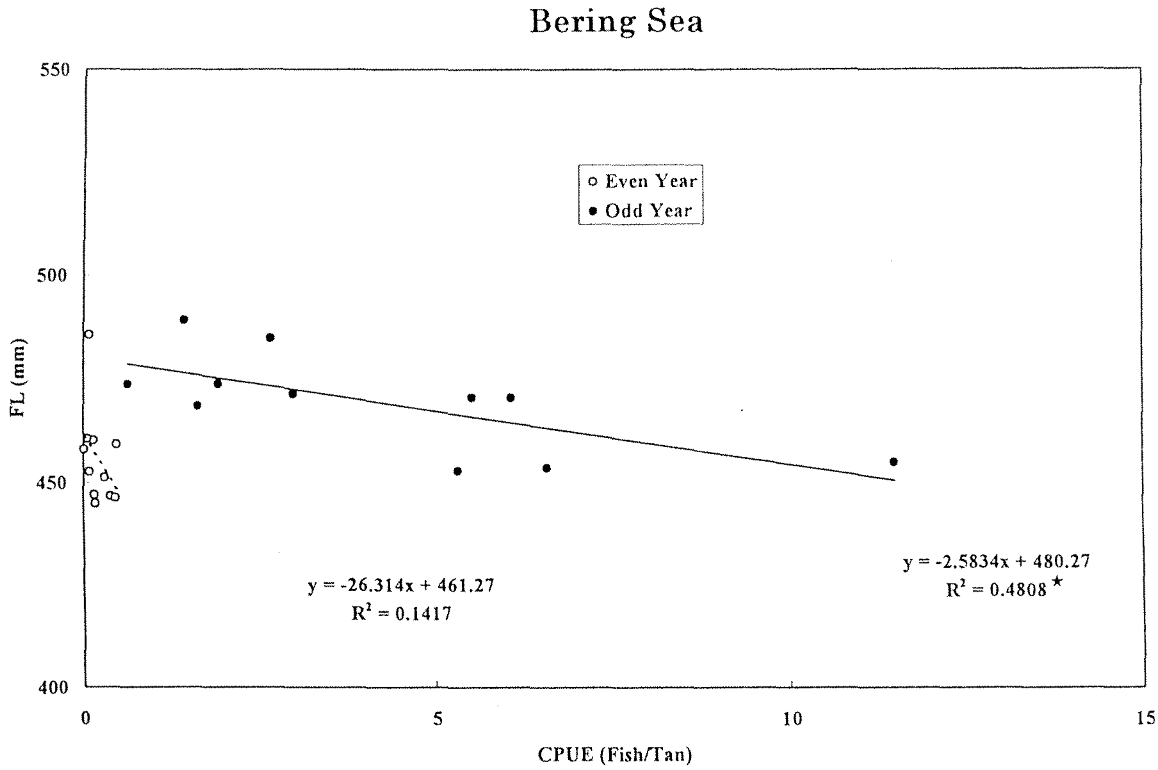


Fig. 5-2. Changes in scale measurements of pink salmon in the Bering Sea and the western North Pacific.



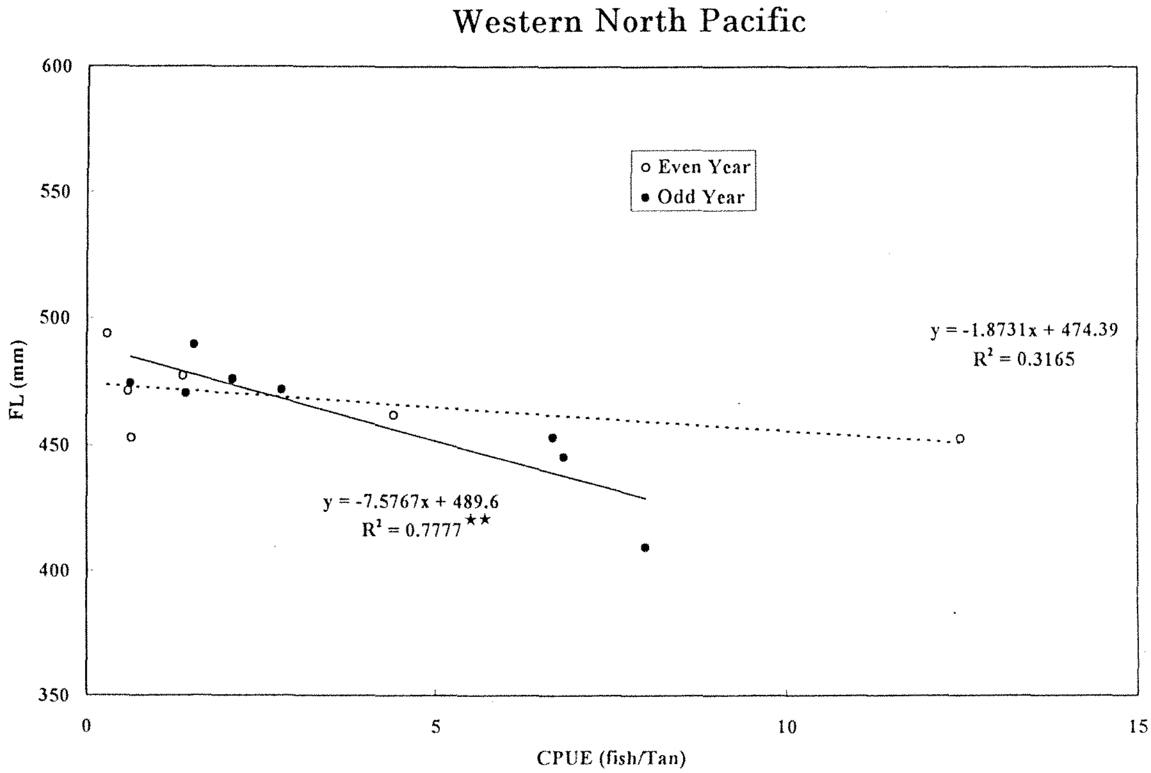
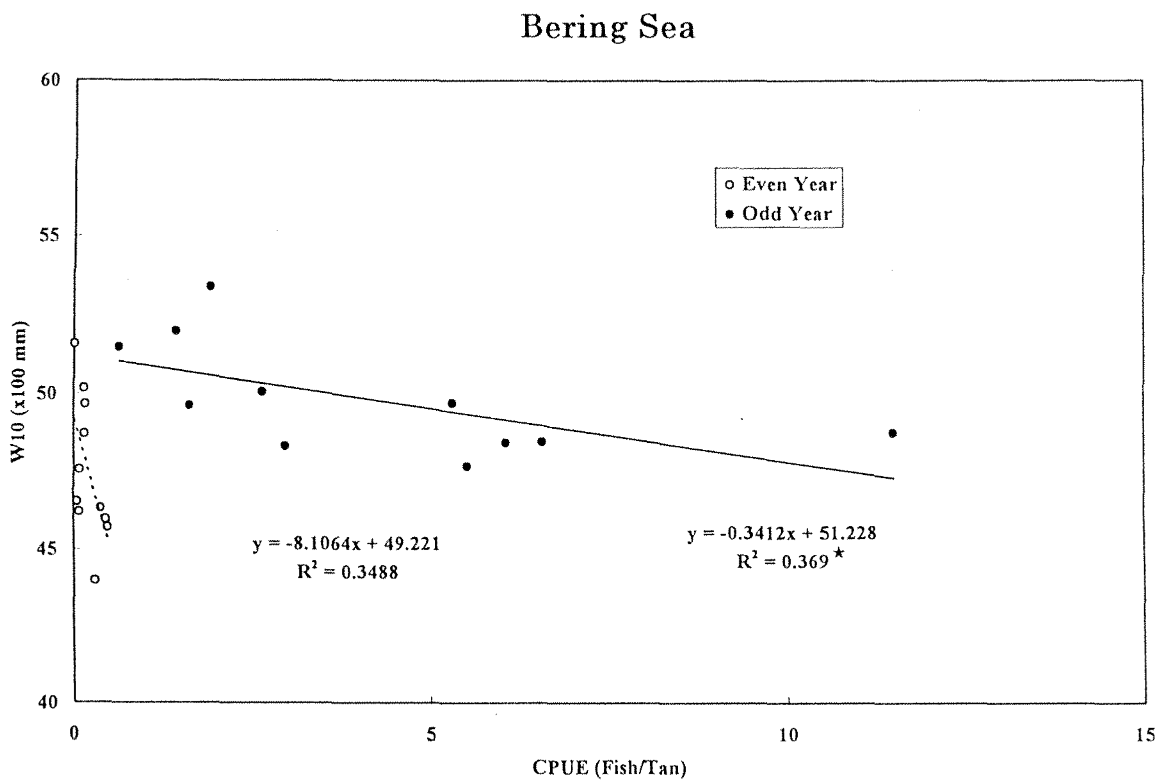


Fig. 6. Relationship between fork length and CPUE of pink salmon.
Solid line:odd year stock, dotted line:even year stock



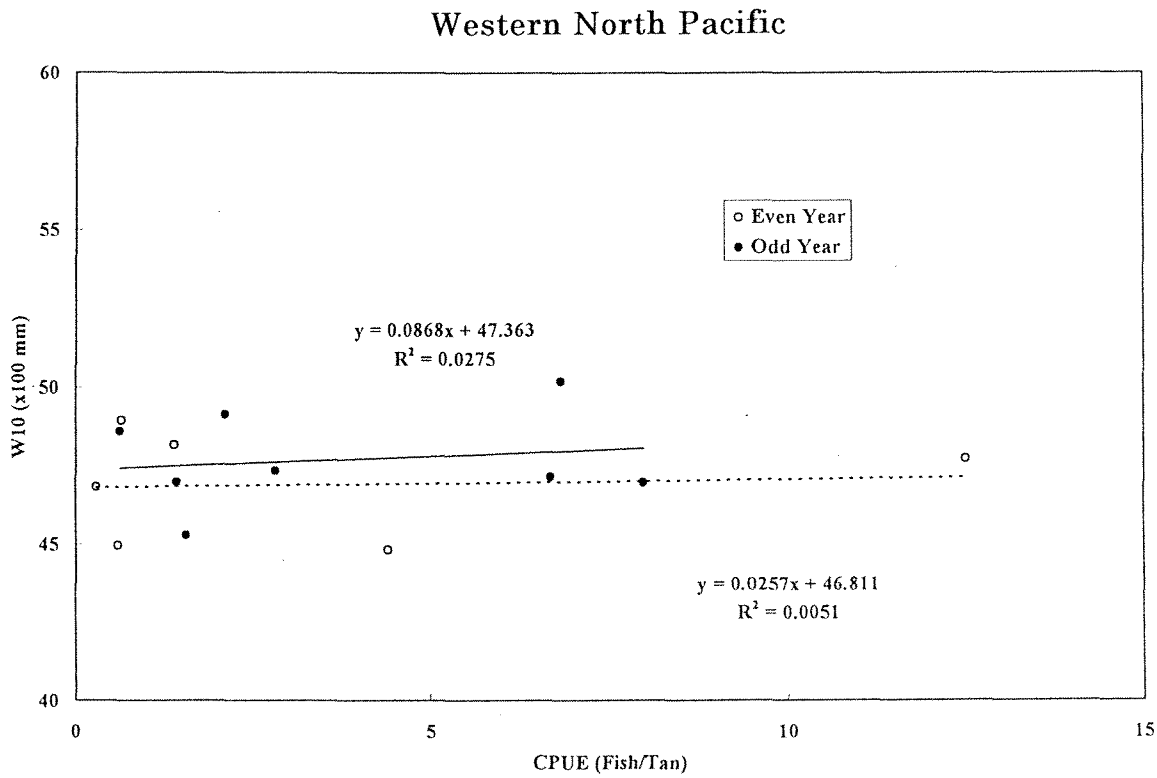
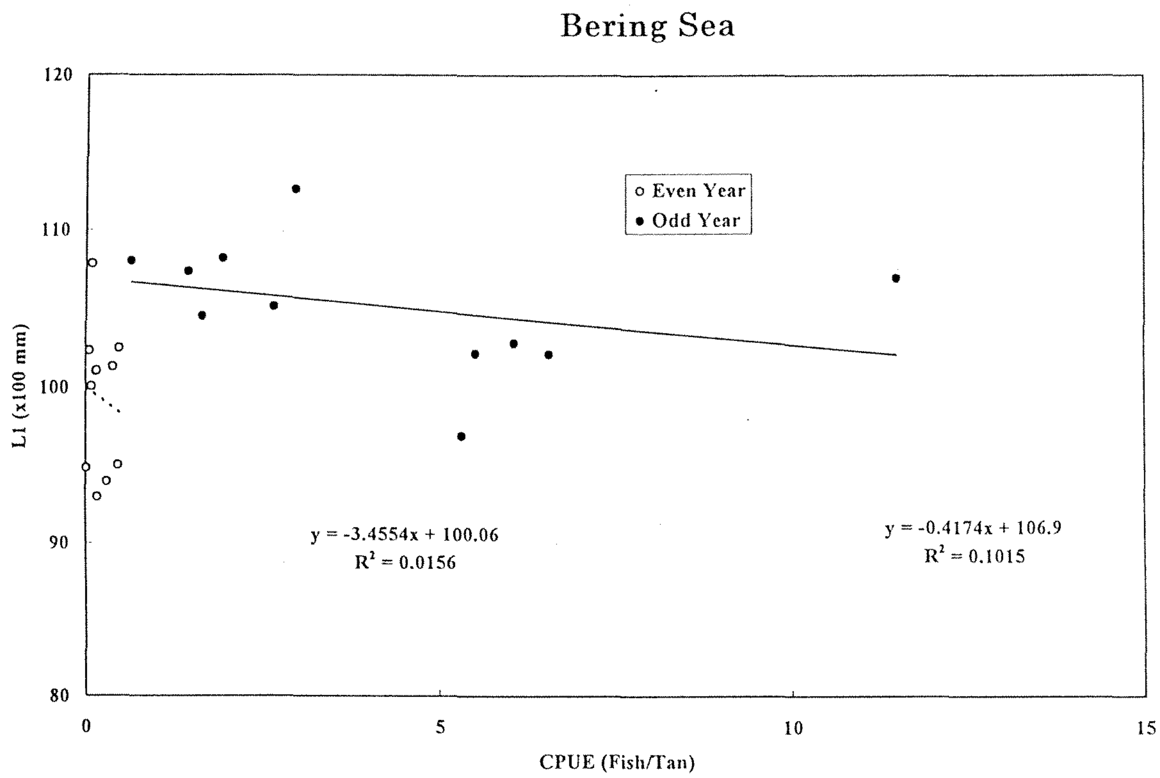


Fig. 7. Relationship between coastal growth and CPUE of pink salmon.
Solid line:odd year stock, dotted line:even year stock



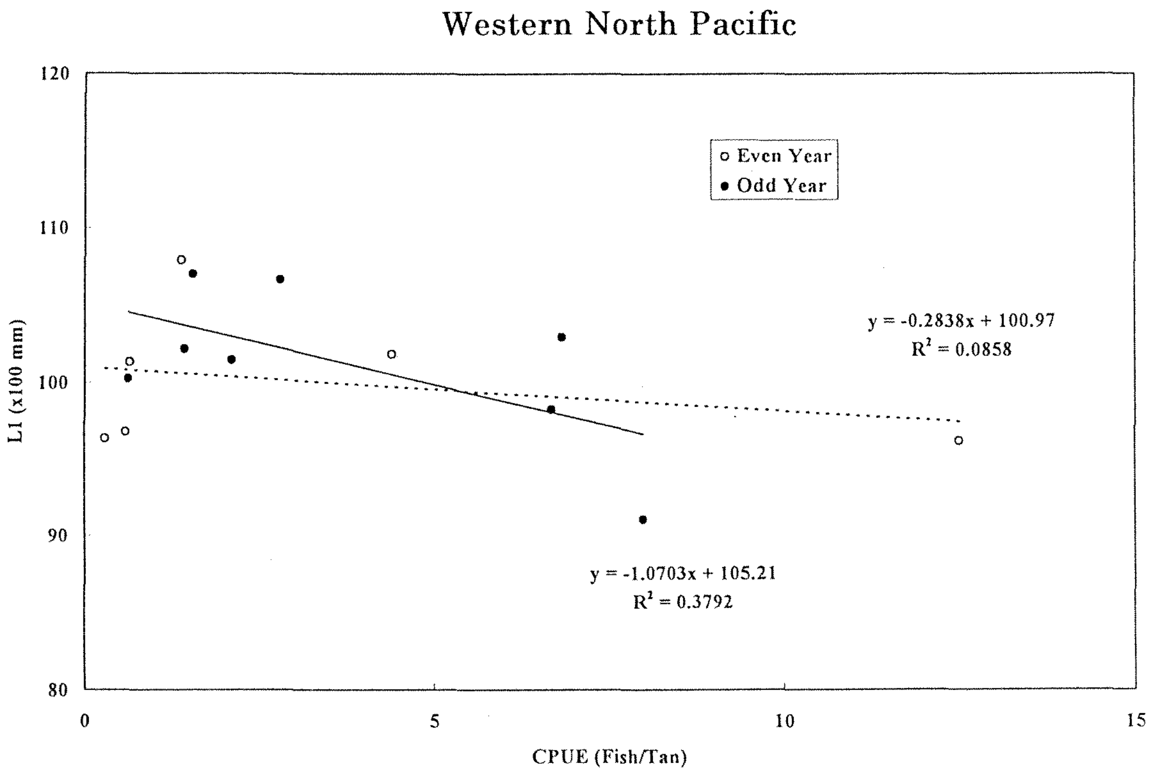
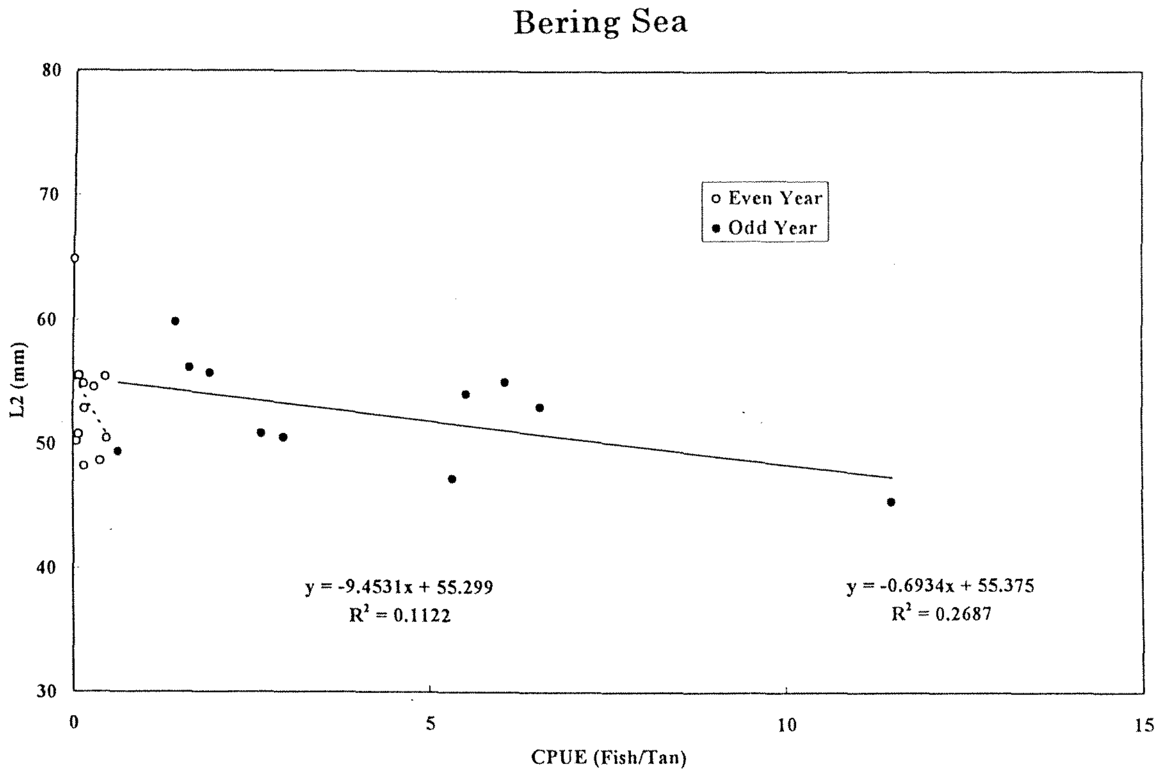


Fig. 8. Relationship between the first year of ocean growth and CPUE of pink salmon. Solid line:odd year stock, dotted line:even year stock



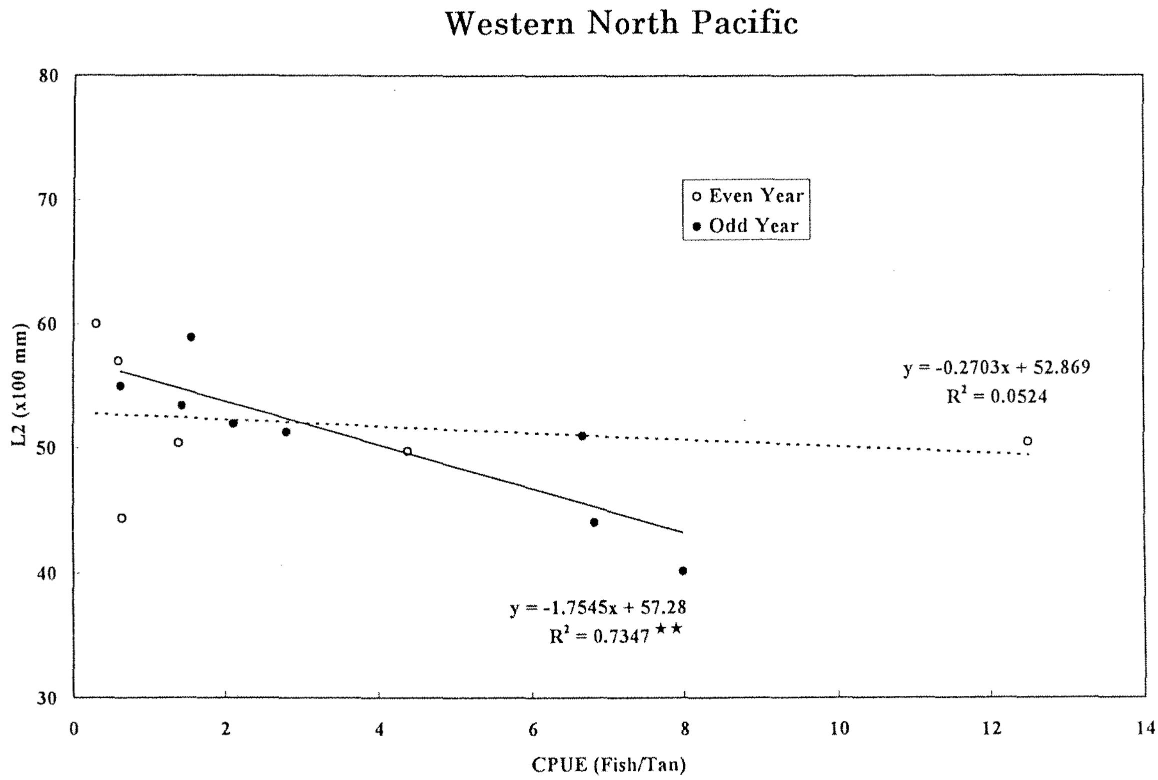


Fig. 9. Relationship between the second year of ocean growth and CPUE of pink salmon. Solid line:odd year stock, dotted line:even year stock

Table 1. Correlation coefficient between fork length and scale characters of pink salmon. FL:fork length, SR:scale radius, W10:width from the focus to the 10th circuli, L1:distance from the focus to the end of the 1st year ocean growth zone, L2:distance from the end of the 1st year ocean growth zone to the outer edge of the scale.

	Bering Sea		Western North Pacific	
Y-X	Even Year	Odd Year	Even Year	Odd Year
FL-SR	+0.876**	+0.772*	+0.881*	+0.975**
FL-W10	-0.082	+0.389	-0.204	-0.164
FL-L1	+0.707*	+0.478	+0.008	+0.837**
FL-L2	+0.272	+0.593	+0.806	+0.942**

Table 2. Correlation coefficient between CPUE and growth of pink salmon. FL:fork length, W10:width from the focus to the 10th circuli, L1:distance from the focus to the end of the 1st year ocean growth zone,
L2:distance from the end of the 1st year ocean growth zone to the outer edge of the scale.

	Bering Sea		Western North Pacific	
Y-X	Even Year	Odd Year	Even Year	Odd Year
CPUE(pink)-FL	-0.376	-0.693*	-0.563	-0.882**
CPUE(pink)-W10	-0.591	-0.608*	+0.071	+0.166
CPUE(pink)-L1	-0.125	-0.319	-0.293	-0.616
CPUE(pink)-L2	-0.335	-0.518	-0.229	-0.857**

Table 3. Correlation coefficient between CPUE of other salmon species and pink salmon growth. FL:fork length, L1:distance from the focus to the end of the 1st year ocean growth zone, L2:distance from the end of the 1st year ocean growth zone to the outer edge of the scale.

	Bering Sea		Western North Pacific	
Y-X	Even Year	Odd Year	Even Year	Odd Year
CPUE(sock)-FL	-0.075	-0.491	-0.154	+0.070
CPUE(sock)-L1	-0.168	-0.708*	+0.923**	-0.033
CPUE(sock)-L2	+0.017	-0.332	-0.654	+0.235
CPUE(chum)-FL	+0.210	-0.257	-0.233	+0.375
CPUE(chum)-L1	-0.062	-0.570	+0.755	+0.184
CPUE(chum)-L2	+0.114	-0.406	-0.712	+0.522
CPUE(coho)-FL	-0.128	-0.390	+0.521	-0.260
CPUE(coho)-L1	-0.392	-0.701*	-0.506	+0.154
CPUE(coho)-L2	+0.091	-0.370	+0.630	-0.378
CPUE(chinook)-FL	-0.140	+0.067	+0.195	+0.577
CPUE(chinook)-L1	-0.506	+0.214	-0.276	+0.393
CPUE(chinook)-L2	+0.305	-0.187	+0.450	+0.424

Table 4. Correlation coefficient between SST, plankton biomass, and pink salmon growth. FL:fork length, L2:distance from the end of the 1st year ocean growth zone to the outer edge of the scale.

	Bering Sea		Western North Pacific	
Y-X	Even Year	Odd Year	Even Year	Odd Year
SST-FL	+0.134	-0.396	-0.104	+0.030
SST-L2	+0.061	-0.028	+0.279	-0.041
Plankton-FL	+0.055	+0.137	+0.028	+0.039
Plankton-L2	-0.079	+0.281	+0.513	-0.217