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# Spatio-temporal variability in biological characteristics of Pacific salmon in the western Bering Sea

by

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## Abstract

Comparative analysis of spatio-temporal variability of Pacific salmon's biological characteristics was performed based on data of three epipelagic trawl surveys conducted by TINRO-Centre during summer-autumn of 2002 and 2003 in the western Bering Sea and adjacent Pacific waters. Species-, age- and season-specific spatial distribution of immature and mature Pacific salmon was described. The most significant differences in immature salmon distribution were noted between sockeye and chinook salmon. The most significant differences in distribution were noted between oldest (.3 and older) and youngest (.1) immature salmon's age groups of all species investigated. Age specificity of distribution is much better expressed in chum and chinook salmon as compared to sockeye salmon. It was shown that species specificity of distribution increases with age of immature Pacific salmon.

Adjacent age groups of chum and chinook salmon showed similarity in spatial distribution. No similarity in distribution were noted for oldest (.3 and older) and youngest (.1) age groups of immature chum and chinook salmon. Dissimilarity in distribution of different age groups of both chum and chinook salmon resulted in dependence of catch rates from the distance to the coastline for particular age groups. Different age groups of sockeye salmon showed similarity in spatial distribution patterns. Season-specific spatial distribution of salmon resulted in greater similarity between two autumn period surveys ad compared with summer period survey. The observed differences in salmon spatial distribution patterns seem to be a result of species-specific and age-specific adaptive strategy, which is aimed at the lessening of density-dependent interactions and maximum utilization of available feeding grounds.


## Introduction

Many Asian and North American stocks of Pacific salmon intermingle in the Bering Sea during foraging period (Shuntov, 1989; Salo, 1991; Shuntov et al., 1993; Klovach, Rzhannikova and Gorodovskaya, 1996; Myers et al., 1996). Previous publications indicate that distribution of different Pacific salmon species and stocks may influence feeding conditions (Shuntov et al., 1993; Helle, Hoffman, 1995; Bigler, Welch and Helle, 1996; Walker, Myers and Ito, 1998; Ishida et al., 2001). In this connection, investigation of age- and species-specific spatial distribution patterns of Pacific salmon in the Bering Sea waters is important for elucidation of density-dependent factors in Pacific salmon populations.

## Materials and methods

The data of three complex epipelagic surveys in the western Bering Sea and adjacent Pacific waters (summer survey – June 15 – August 24, 2003, early autumn survey - August 31-October 10, 2002, and late autumn survey – September 14 –October 25, 2003), conducted by TINRO-Center, was used for analysis. During the analysis of seasonal variability, we assumed that interannual differences (between 2002 and 2003), on the whole, are less significant than seasonal ones.

All of three surveys have had a similar disposition of trawling stations (Fig. 1). Configurations of trawling systems were identical for all three surveys, which makes estimates of relative abundance (catches per 1 hour trawling) quite comparable. All trawlings were conducted using a mid-water trawl PT 80/396 m. Vertical spread of the trawl, depending on the speed of trawl towing and weather conditions, ranged between 38 and 44 m, and horizontal one – between 31 and 41 m. During 1-hour trawlings, headrope of trawl was located at the surface. The speed of trawl towing varied within the range of 3.9-5.3 knots (on the average 4.6 knots).

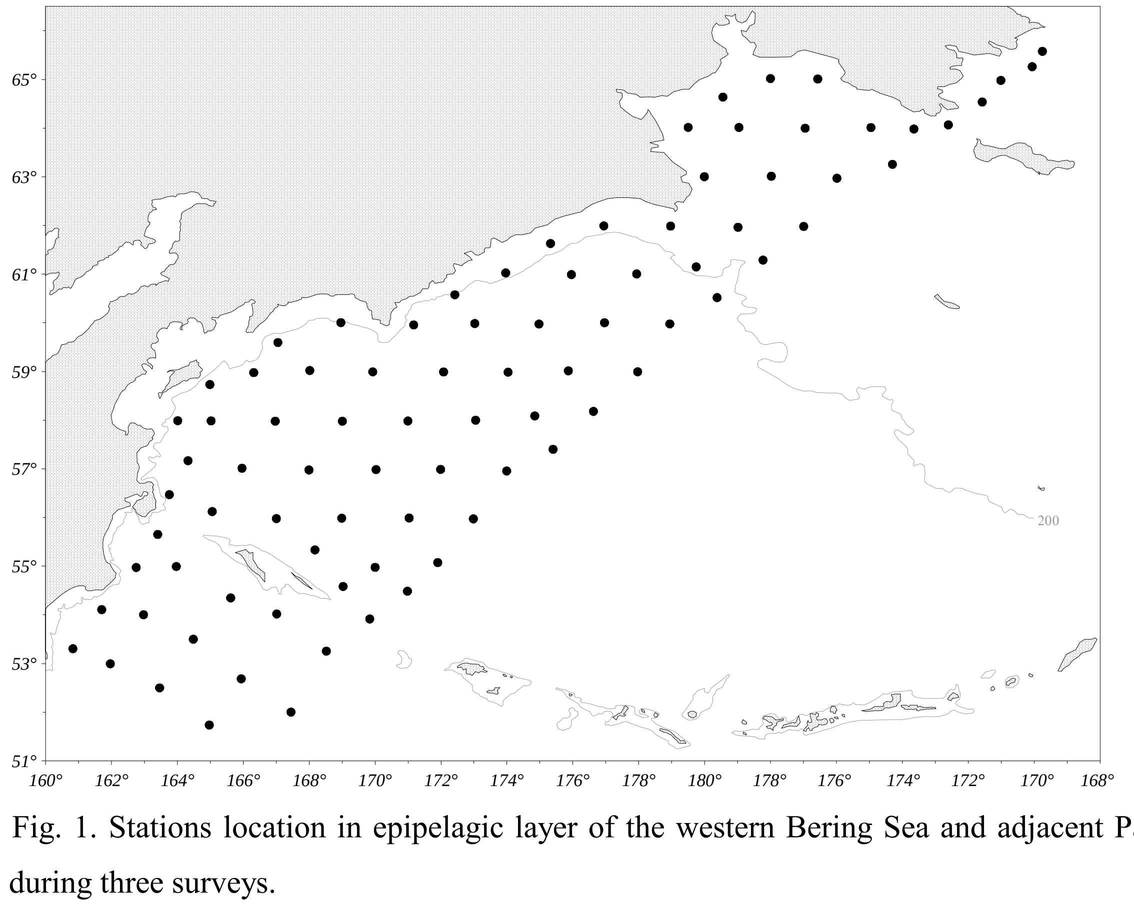


Fig. 1. Stations location in epipelagic layer of the western Bering Sea and adjacent Pacific waters during three surveys.

Preliminary analysis of frequency distributions of relative abundance estimates showed that it differed significantly from normal distribution. In accordance with recommendations from Volvenko (1998), the initial CPUE values were log-transformed: y=lg(x+1), where x – initial values, y – log-transformed values, lg – decimal logarithm. In most cases, the log-transformed

CPUEs were well approximated by normal distribution. The log-transformed values were subsequently used for regression analysis. The relationship between different characteristics was approximated using the following linear equation: y = const1*x+const2, where const1 - slope, const2 – intercept and x – independent variable.

We separated catches into three groups: juvenile (individuals at the ocean age of zero), immature (immature individuals at the ocean age of one year and older) and mature individuals. Approximate ocean age of immature chum, sockeye and chinook salmon was determined on the basis of length-at-age estimates from previously published results (Shuntov, 1989; Shuntov et al., 1993; Radchenko, 1994; Sobolevsky, Radchenko and Startsev, 1994; Glebov, 1998; Glebov, 2000; Starovoytov, 2002). The age-length keys, which we used for chum salmon, can be summarized as follows: summer 2002 – 29-41 (ocean age - .1), 42-52 (ocean age - .2), 53-80 cm (ocean age - .3 and older), autumn 2002 - 29-42, 43-51, 52-81 cm, autumn 2003 - 31-44, 45-54, 55-72 cm, respectively. As to sockeye salmon, age-length keys can be summarized as follows: summer 2003 - 25-38 (ocean age - .1), 39-48 (.2), 49-59 cm (.3 and older), autumn 2002 - 30-43, 44-52, 53-65 cm, autumn 2003 - 30-43, 44-52, 53-65 cm, respectively. Age-length keys for chinook salmon were as follows: summer 2003 - 25-51 (ocean age -.1), 52-70 (.2), 71-80 cm (.3 and older), autumn 2002 - 32-52, 53-73, 74-88 cm, autumn 2003 - 32-52, 53-73, 74-88 cm, respectively.

## Results and discussion

Our results testify for significant age- and season-specificity of chum salmon distribution. Table 1 and other tables that follow contain correlation coefficients for linear equations describing relationships between log-transformed values of various characteristics. Statistically significant correlation coefficients indicate presence of relationship between a certain pair of characteristics. Similarity in distribution of .1 and .2 age groups of immature chum salmon is evident from highly significant positive correlation between their CPUEs during all surveys (Table 1, Fig. 2).

Table 1.

Values of correlation coefficients for relationships between log-transformed values of different characteristics of chum salmon.

| | | | depth (m) | percentage of individuals at the age of .1 | percentage of individuals at the age of .2 | percentage of individuals at the age of .3 and older | average length (cm) (immature) | average length (cm) (juvenile) | average length (cm) (mature) | CPUE (inds./hour) (immature) | CPUE (inds./hour) (juvenile) | CPUE (inds./hour) (mature) | CPUE (inds./hour) of individuals at the age of .1 | CPUE (inds./hour) of individuals at the age of .2 | CPUE (inds./hour) of individuals at the age of .3 and older |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Number of characteristic | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| percentage of individuals at the age of .1 | 2 | summer 2003 | **0,35** | | | | | | | | | | | | |
| | | autumn 2002 | **0,55** | | | | | | | | | | | | |
| | | autumn 2003 | 0,16 | | | | | | | | | | | | |
| percentage of individuals at the age of .2 | 3 | summer 2003 | 0,12 | 0,16 | | | | | | | | | | | |
| | | autumn 2002 | **0,43** | -0,03 | | | | | | | | | | | |
| | | autumn 2003 | **0,35** | **-0,40** | | | | | | | | | | | |
| percentage of individuals at the age of .3 and older | 4 | summer 2003 | **-0,29** | **-0,61** | -0,19 | | | | | | | | | | |
| | | autumn 2002 | **-0,48** | **-0,70** | 0,06 | | | | | | | | | | |
| | | autumn 2003 | -0,15 | **-0,55** | **0,29** | | | | | | | | | | |
| average length (cm) (immature) | 5 | summer 2003 | **-0,47** | **-0,87** | -0,17 | **0,84** | | | | | | | | | |
| | | autumn 2002 | **-0,59** | **-0,87** | 0,04 | **0,84** | | | | | | | | | |
| | | autumn 2003 | -0,22 | **-0,82** | **0,47** | **0,74** | | | | | | | | | |
| average length (cm) (juvenile) | 6 | summer 2003 | 0,96 | 0,83 | 0,99 | -0,30 | -0,59 | | | | | | | | |
| | | autumn 2002 | -0,40 | -0,08 | -0,44 | 0,10 | 0,08 | | | | | | | | |
| | | autumn 2003 | -0,32 | -0,06 | -0,20 | 0,16 | 0,07 | | | | | | | | |
| average length (cm) (mature) | 7 | summer 2003 | **-0,53** | -0,16 | -0,04 | **0,24** | **0,26** | | | | | | | | |
| | | autumn 2002 | -0,21 | -0,04 | -0,23 | -0,06 | -0,22 | | | | | | | | |
| | | autumn 2003 | -0,07 | **0,45** | -0,01 | -0,03 | -0,27 | 0,29 | | | | | | | |
| CPUE (inds./hour) (immature) | 8 | summer 2003 | **0,34** | **0,51** | **0,39** | **-0,34** | **-0,49** | 0,71 | **-0,26** | | | | | | |
| | | autumn 2002 | **0,75** | **0,72** | 0,09 | **-0,60** | **-0,74** | -0,04 | -0,02 | | | | | | |
| | | autumn 2003 | **0,62** | **0,40** | 0,09 | -0,22 | **-0,51** | 0,15 | **0,58** | | | | | | |
| CPUE (inds./hour) (juvenile) | 9 | summer 2003 | **-0,28** | -0,14 | 0,11 | 0,03 | 0,13 | -0,93 | 0,11 | -0,13 | | | | | |
| | | autumn 2002 | -0,17 | 0,12 | **-0,29** | -0,06 | -0,03 | -0,15 | -0,12 | -0,12 | | | | | |
| | | autumn 2003 | 0,04 | 0,13 | -0,05 | -0,10 | -0,08 | -0,02 | -0,24 | 0,08 | | | | | |
| CPUE (inds./hour) (mature) | 10 | summer 2003 | -0,12 | **-0,30** | -0,04 | **0,56** | **0,48** | -0,23 | 0,18 | -0,04 | 0,02 | | | | |
| | | autumn 2002 | **0,42** | -0,21 | **0,47** | 0,19 | 0,17 | -0,13 | -0,15 | 0,16 | **-0,29** | | | | |
| | | autumn 2003 | **0,41** | -0,17 | **0,34** | **0,30** | **0,29** | -0,23 | 0,12 | 0,17 | -0,12 | | | | |
| CPUE (inds./hour) of individuals at the age of .1 | 11 | summer 2003 | 0,18 | **0,72** | **0,26** | **-0,56** | **-0,72** | 0,99 | -0,08 | **0,92** | -0,19 | **-0,31** | | | |
| | | autumn 2002 | **0,51** | **0,80** | -0,14 | **-0,73** | **-0,83** | 0,17 | 0,05 | **0,94** | -0,11 | -0,18 | | | |
| | | autumn 2003 | **0,26** | **0,55** | -0,09 | **-0,35** | **-0,67** | 0,01 | **0,55** | **0,97** | -0,03 | -0,11 | | | |
| CPUE (inds./hour) of individuals at the age of .2 | 12 | summer 2003 | 0,10 | **0,43** | **0,61** | **-0,35** | **-0,45** | 0,78 | 0,02 | **0,93** | -0,15 | -0,16 | **0,82** | | |
| | | autumn 2002 | **0,62** | **0,37** | **0,63** | -0,23 | **-0,33** | -0,21 | -0,14 | **0,71** | **-0,41** | **0,35** | **0,49** | | |
| | | autumn 2003 | **0,32** | 0,08 | **0,58** | 0,00 | -0,05 | -0,19 | 0,40 | **0,76** | 0,00 | 0,22 | **0,63** | | |
| CPUE (inds./hour) of individuals at the age of .3 and older | 13 | summer 2003 | **-0,35** | -0,10 | **0,23** | **0,53** | **0,34** | 0,32 | **0,32** | **0,49** | -0,09 | **0,46** | 0,22 | **0,47** | |
| | | autumn 2002 | 0,11 | -0,15 | **0,42** | **0,55** | **0,30** | -0,19 | -0,16 | 0,17 | **-0,30** | **0,30** | -0,08 | **0,54** | |
| | | autumn 2003 | 0,06 | -0,19 | **0,36** | **0,74** | **0,40** | 0,01 | 0,24 | 0,21 | -0,03 | **0,40** | 0,08 | **0,41** | |

Note. Here and in other tables that follow statistically significant correlation coefficients (probability of null-hypothesis is less than 5% ($P<0.05$)) are marked bold. Numbers of characteristics in the first vertical column of table match those in the fi

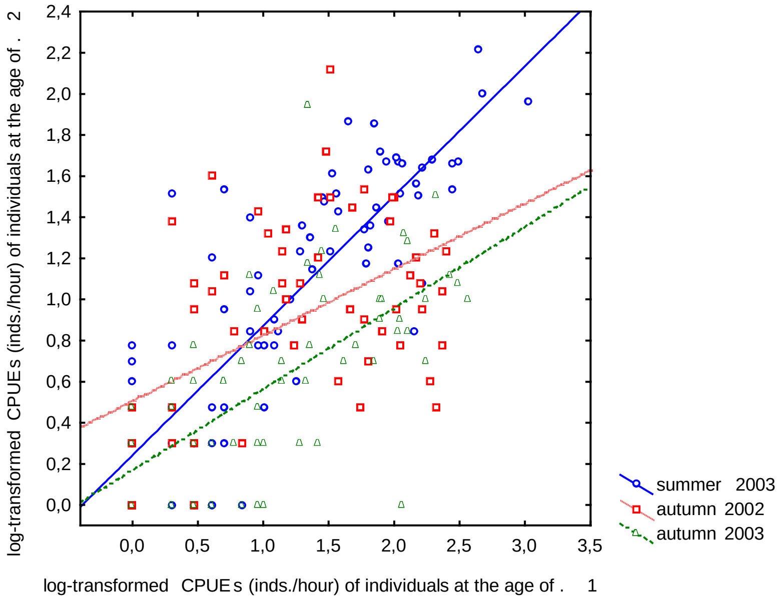


Fig. 2. Correlation between log-transformed CPUEs (inds./h) of immature .1 and .2 chum salmon. Summer of 2003 - r=**0,82**, autumn of 2002. - r=**0,49**, autumn of 2003 - r=**0,63**. Here and below statistically significant (P<0,05) correlation coefficients (r) are marked bold; solid lines – trend lines.

On the contrary, for all three surveys no correlation between CPUEs of .3 and older and .1 age groups of immature chum salmon was observed (Table 1, Fig. 3). This fact indicates small spatial association of these age groups during the entire summer-autumn period. The correlation coefficients indicate that distribution of .2 chum salmon was similar to that of both .3 and older and .1 age groups (Table 1, Fig. 4).

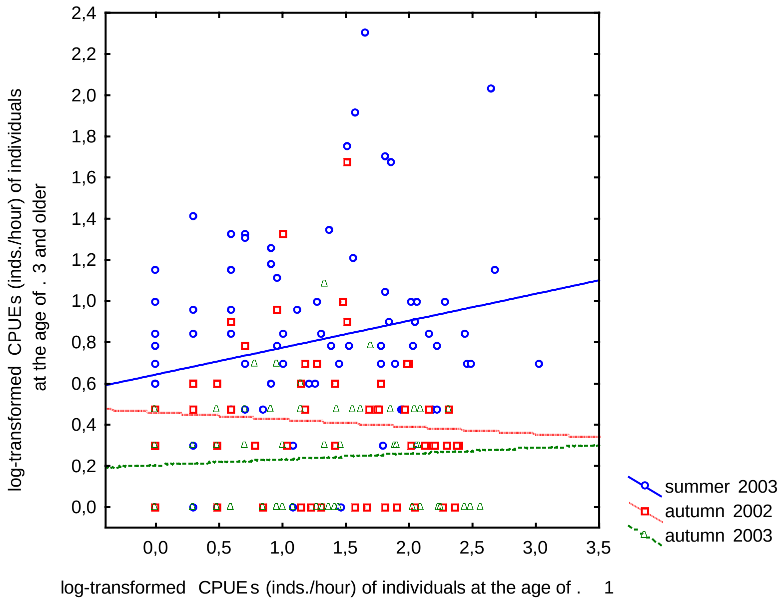


Fig. 3. Correlation between CPUEs (inds./h) of immature .1 and .3 and older chum salmon. Summer of 2003 - r=0,22, autumn of 2002. - r=-0,08, autumn of 2003 - r=0,08.

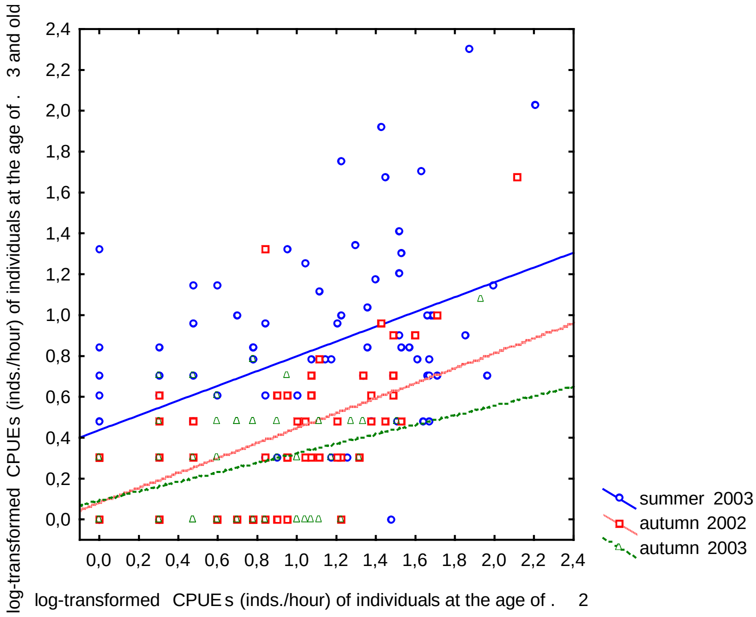


Fig. 4. Correlation between CPUEs (inds./h) of immature .2 and .3 and older chum salmon. Summer of 2003 - r=**0,47**, autumn of 2002. - r=**0,54**, autumn of 2003 - r=**0,41**.

Statistically significant negative correlation between average length of immature chum salmon in catch and relevant CPUE of immature chum salmon indicates prevalence of younger age groups during all surveys (Table 1, Fig. 5). Therefore, during the whole time period of surveys, highest catches of immature chum salmon were formed mainly by relatively small (fork length - 29-41 cm) individuals of younger age group (age - .1). Statistically significant positive correlation between the share of .1 age individuals (in % of the total catch of immature chum salmon) and total catch of immature chum salmon was observed for the entire summer-autumn period (Table 1, Fig. 6).

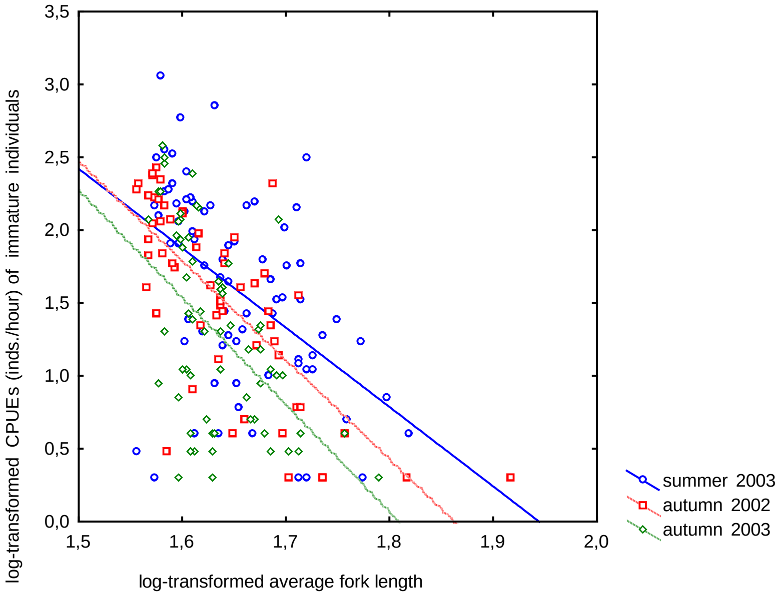


Fig. 5. Correlation between average fork length and CPUEs (inds./h) of immature chum salmon. Summer of 2003 - r=**-0,49**, autumn of 2002. - r=**-0,74**, autumn of 2003 - r=**-0,51**.

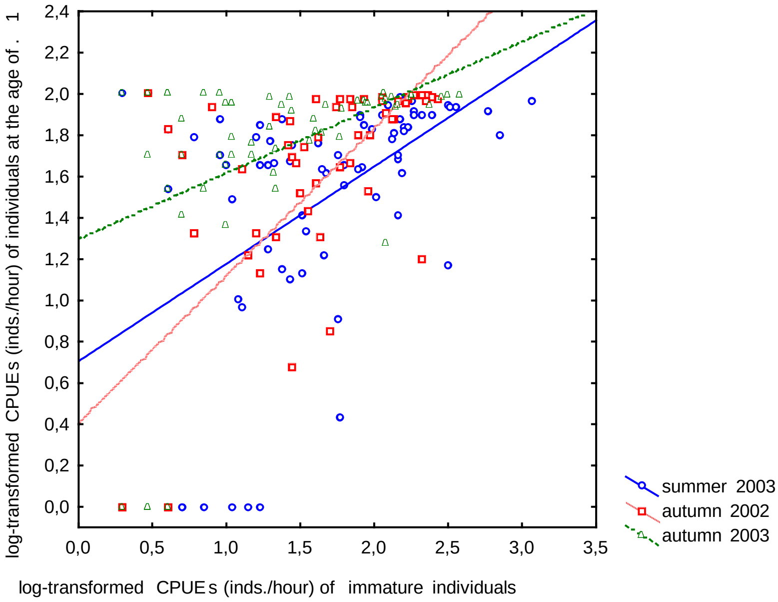


Fig. 6. Correlation between CPUEs (inds./h) of immature chum salmon and ratio (% from the total immature chum salmon catch) of .1 chum salmon. Summer of 2003 - r=**0,51**, autumn of 2002. - r=**0,72**, autumn of 2003 - r=**0,40**.

Age-specificity of immature chum salmon distribution expressed itself in greater abundance of small-size individuals in deep-water areas of the Bering Sea. Larger individuals preferred shallower shelf zone and shelf break area. As the result of this, strong negative correlation between average length of immature chum salmon in catch and depth at the location of trawling was observed for summer and early autumn surveys (Table 1, Fig. 7). This fact corresponds quite well with substantial concentration of large-size individuals (mainly at the age of .3 and older) in shallow areas of Anadyr and Koryak shelf during summer survey. In late autumn survey immature chum salmon of older age groups (.3 and older) left the shelf zone during winter its migration and became almost evenly distributed throughout entire western Bering Sea. As the result of this, we observed no correlation between average length of immature chum salmon in catch and depth at the location of trawling. It is well known, that older age groups of immature chum salmon leave the Russian economic zone of the Bering Sea earlier than age .1 individuals (Sobolevsky, 1994).

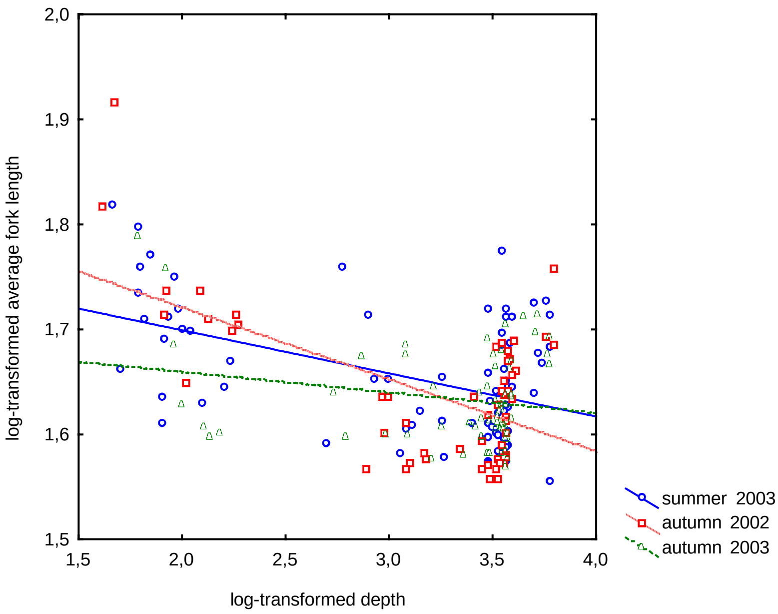


Fig. 7. Correlation between depth at the location of trawling and average fork length of immature chum salmon. Summer of 2003 - r=**-0,47**, autumn of 2002. - r=**-0,59**, autumn of 2003 - r=-0,22.

Significant correlations between share of different age groups (in % of the total catch of immature chum salmon) and depth at the location of trawling also indicate spatial separation of major concentrations of different age groups. In most cases, such correlations were positive age groups .1 and .2 and negative for oldest age group of immature chum salmon (.3 and older).

Larger individuals of mature chum salmon preferred shallower shelf zone and shelf break area as compared with deep-water areas (Table 1, Fig. 8). As the result of this, strong negative correlation between average length of mature chum salmon in catch and depth at the location of trawling was observed for summer survey. Similar but statistically insignificant trends could be also observed for two autumn surveys when the abundance of mature chum salmon in the area investigated was quite low. As we see, there is a similarity between immature and mature chum salmon in the concentration of large-size individuals of older age groups in the shelf zone and shelf break area. It should be noted that mature and large-size immature chum salmon migrate into the Bering Sea from the Pacific Ocean earlier than small-size chum salmon (Shuntov et al., 1993).

Significant positive correlation between CPUEs of .3 and older immature chum salmon and CPUEs of mature chum salmon was observed during all surveys (Table 1, Fig. 9). This fact indicates that these groups of chum salmon prefer the same foraging conditions. Sobolevsky, Radchenko and Startsev (1994) also noted significant spatial overlap in areas of major concentration of mature and large-size immature chum salmon.

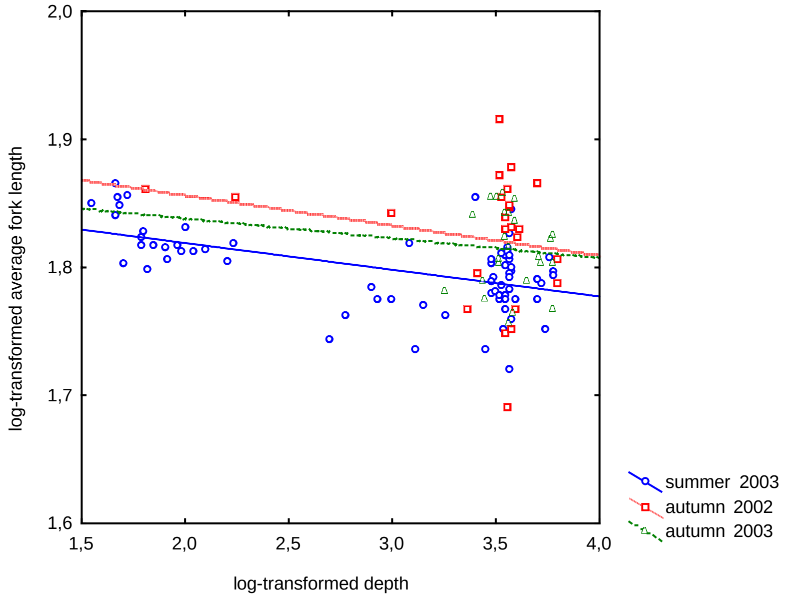


Fig. 8. Correlation between depth at the location of trawling and average fork length of mature chum salmon. Summer of 2003 - r=**-0,53**, autumn of 2002. - r=-0,21, autumn of 2003 - r=-0,07.

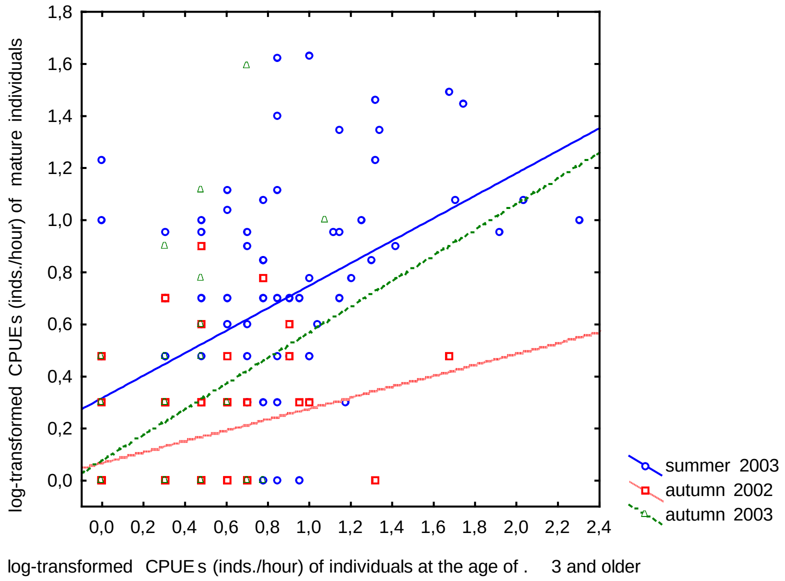


Fig. 9. Correlation between CPUEs (inds./h) of immature .3 and older chum salmon and mature chum salmon. Summer of 2003 - r=**0,46**, autumn of 2002. - r=**0,30**, autumn of 2003 - r=**0,40**.

Negative correlation between CPUEs of .1 immature chum salmon and CPUEs of mature chum salmon was observed during summer surveys (Table 1, Fig. 10). This indicates spatial separation of these groups from each other during summer period.

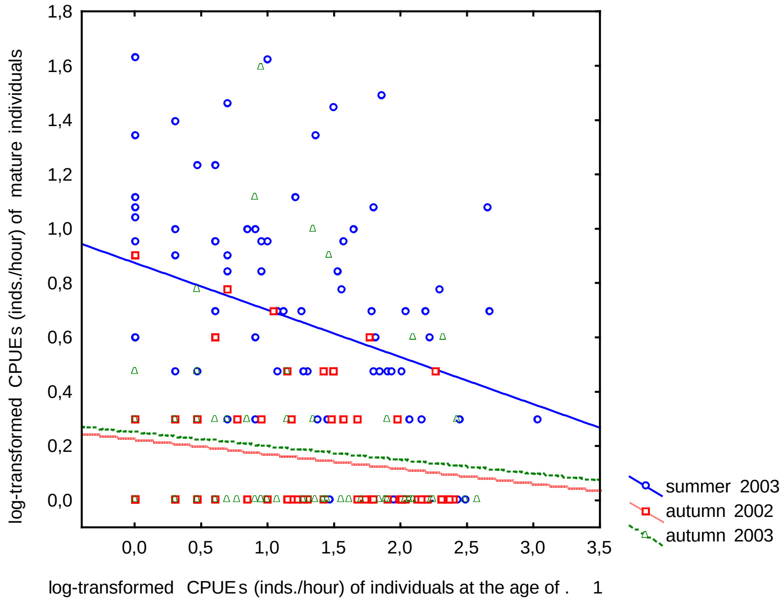


Fig. 10. Correlation between CPUEs (inds./h) of immature .1 chum salmon and mature chum salmon. Summer of 2003 - r=**-0,31**, autumn of 2002. - r=-0,18, autumn of 2003 - r=-0,11.

Our results on distribution of different age groups of immature sockeye salmon differ considerably from those for immature chum salmon. CPUEs for all age groups of chum salmon (.1, .2 и .3 and older) were positively correlated with each other. This indicates similarity in their distribution (Table 2).

Table 2.

Values of correlation coefficients for relationships between log-transformed values of different characteristics of sockeye salmon.

| | | depth (m) | percentage of individuals at the age of .1 | percentage of individuals at the age of .2 | percentage of individuals at the age of .3 and older | average length (cm) (immature) | average length (cm) (juvenile) | CPUE (inds./hour) (immature) | CPUE (inds./hour) (juvenile) | CPUE (inds./hour) of individuals at the age of .1 | CPUE (inds./hour) of individuals at the age of .2 | CPUE (inds./hour) of individuals at the age of .3 and older |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of characteristic | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 2 | summer 2003 | -0.01 | | | | | | | | | | |
| | autumn 2002 | 0.04 | | | | | | | | | | |
| | autumn 2003 | -0.23 | | | | | | | | | | |
| 3 | summer 2003 | **0.29** | -0.09 | | | | | | | | | |
| | autumn 2002 | **0.40** | -0.17 | | | | | | | | | |
| | autumn 2003 | **0.37** | **-0.47** | | | | | | | | | |
| 4 | summer 2003 | 0.18 | -0.17 | **-0.37** | | | | | | | | |
| | autumn 2002 | -0.14 | **-0.30** | -0.17 | | | | | | | | |
| | autumn 2003 | 0.08 | -0.24 | -0.14 | | | | | | | | |
| 5 | summer 2003 | 0.13 | **-0.80** | 0.04 | **0.54** | | | | | | | |
| | autumn 2002 | -0.07 | **-0.78** | 0.17 | **0.67** | | | | | | | |
| | autumn 2003 | 0.19 | **-0.78** | **0.39** | **0.43** | | | | | | | |
| 6 | summer 2003 | 0.49 | -0.32 | -0.42 | 0.54 | 0.32 | | | | | | |
| | autumn 2002 | **0.44** | -0.08 | -0.34 | 0.18 | 0.05 | | | | | | |
| | autumn 2003 | 0.04 | 0.27 | 0.10 | 0.14 | -0.24 | | | | | | |
| 7 | summer 2003 | **0.30** | **0.59** | 0.09 | 0.11 | **-0.44** | -0.29 | | | | | |
| | autumn 2002 | **0.78** | **0.30** | **0.43** | 0.04 | -0.16 | **0.50** | | | | | |
| | autumn 2003 | **0.68** | **0.33** | 0.22 | -0.04 | **-0.42** | 0.18 | | | | | |
| 8 | summer 2003 | **-0.29** | 0.09 | -0.02 | -0.05 | -0.11 | -0.46 | 0.17 | | | | |
| | autumn 2002 | -0.14 | 0.25 | -0.01 | -0.14 | **-0.31** | -0.22 | 0.06 | | | | |
| | autumn 2003 | 0.00 | 0.20 | -0.03 | 0.04 | **-0.35** | -0.33 | **0.28** | | | | |
| 9 | summer 2003 | -0.01 | **0.74** | -0.06 | -0.04 | **-0.64** | 0.07 | **0.94** | 0.23 | | | |
| | autumn 2002 | 0.16 | **0.67** | 0.10 | -0.10 | **-0.51** | 0.13 | **0.85** | **0.35** | | | |
| | autumn 2003 | -0.01 | **0.57** | -0.01 | -0.10 | **-0.64** | 0.41 | **0.94** | **0.35** | | | |
| 10 | summer 2003 | 0.09 | **0.37** | **0.42** | -0.02 | **-0.26** | 0.03 | **0.88** | 0.23 | **0.74** | | |
| | autumn 2002 | **0.38** | 0.01 | **0.69** | 0.04 | 0.13 | -0.09 | **0.89** | 0.08 | **0.57** | | |
| | autumn 2003 | **0.26** | 0.02 | **0.55** | -0.17 | -0.10 | 0.19 | **0.86** | 0.15 | **0.69** | | |
| 11 | summer 2003 | **0.27** | 0.14 | -0.09 | **0.74** | 0.20 | 0.53 | **0.62** | 0.02 | **0.45** | **0.50** | |
| | autumn 2002 | 0.10 | 0.01 | 0.21 | **0.61** | **0.32** | 0.06 | **0.71** | 0.08 | **0.48** | **0.69** | |
| | autumn 2003 | 0.08 | 0.03 | -0.04 | **0.69** | 0.07 | 0.12 | **0.53** | 0.24 | **0.46** | **0.38** | |

Statistically significant negative correlation between average length of sockeye salmon in catch and relevant CPUE of sockeye salmon indicates prevalence of younger age groups during all surveys. Therefore, highest catches of immature sockeye salmon were formed mainly by relatively small individuals of younger age groups. However, early autumn survey of 2002 was an exception. Statistically significant positive correlation between the share of .1 age individuals (in % of the total catch of immature chum salmon) and total catch of immature sockeye salmon was observed for the entire summer-autumn period.

On the contrary, to the chum salmon, age-specificity of immature sockeye salmon distribution was not evident. No correlation between average length of sockeye salmon in catch and depth at the location of trawling was observed for any of the surveys. The absence of significant correlations between share of .1 age group (in % of the total catch of immature chum salmon) and depth at the location of trawling also indicates similarity in distribution of different age groups

(Table 2). Therefore, all age groups of sockeye salmon had no significant differences in distribution.

Just like for chum salmon, our results for different age groups of immature chinook salmon showed that most significant distinctions in distribution were observed between age group of .1 and age group of .3 and older (Table 3). For chinook salmon, as opposed to chum and sockeye salmon, no correlation between average length of chinook salmon in catch and relevant CPUE was observed. No difference in share of different age groups was observed between low and high catches. To be more specific, relationships between CPUEs of chinook salmon and share of certain age group were characterized by low and statistically insignificant correlation coefficients (P>0.05).

Table 3.

Values of correlation coefficients for relationships between log-transformed values of different characteristics of chinook salmon.

| | | depth (m) | percentage of individuals at the age of .1 | percentage of individuals at the age of .2 | percentage of individuals at the age of .3 and older | average length (cm) (immature) | average length (cm) (juvenile) | CPUE (inds./hour) (immature) | CPUE (inds./hour) (juvenile) | CPUE (inds./hour) of individuals at the age of .1 | CPUE (inds./hour) of individuals at the age of .2 | CPUE (inds./hour) of individuals at the age of .3 and older |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of characteristic | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| 2 | summer 2003 | 0.16 | | | | | | | | | | |
| | autumn 2002 | **0.57** | | | | | | | | | | |
| | autumn 2003 | 0.18 | | | | | | | | | | |
| 3 | summer 2003 | 0.09 | **-0.39** | | | | | | | | | |
| | autumn 2002 | -0.24 | **-0.51** | | | | | | | | | |
| | autumn 2003 | -0.10 | **-0.71** | | | | | | | | | |
| 4 | summer 2003 | -0.29 | **-0.40** | -0.04 | | | | | | | | |
| | autumn 2002 | **-0.45** | **-0.63** | -0.08 | | | | | | | | |
| | autumn 2003 | **-0.44** | **-0.42** | 0.11 | | | | | | | | |
| 5 | summer 2003 | -0.18 | **-0.73** | **0.60** | **0.44** | | | | | | | |
| | autumn 2002 | **-0.49** | **-0.89** | **0.49** | **0.70** | | | | | | | |
| | autumn 2003 | **-0.30** | **-0.81** | **0.53** | **0.74** | | | | | | | |
| 6 | summer 2003 | | | | | | | | | | | |
| | autumn 2002 | 0.16 | 0.38 | -0.38 | | -0.44 | | | | | | |
| | autumn 2003 | -0.20 | 0.23 | 0.19 | -0.26 | -0.16 | | | | | | |
| 7 | summer 2003 | -0.19 | 0.22 | **0.34** | -0.03 | 0.03 | | | | | | |
| | autumn 2002 | **0.23** | 0.29 | 0.09 | -0.17 | -0.19 | 0.08 | | | | | |
| | autumn 2003 | 0.02 | 0.17 | 0.27 | 0.00 | -0.05 | 0.40 | | | | | |
| 8 | summer 2003 | | | | | | | | | | | |
| | autumn 2002 | 0.13 | 0.16 | 0.03 | -0.21 | -0.17 | -0.34 | -0.16 | | | | |
| | autumn 2003 | **0.26** | 0.27 | **-0.35** | -0.03 | -0.13 | **-0.51** | -0.05 | | | | |
| 9 | summer 2003 | -0.02 | **0.45** | 0.08 | -0.09 | -0.22 | | **0.94** | | | | |
| | autumn 2002 | **0.49** | **0.71** | -0.30 | **-0.43** | **-0.60** | 0.25 | **0.86** | 0.10 | | | |
| | autumn 2003 | 0.25 | **0.60** | -0.12 | **-0.31** | **-0.47** | 0.33 | **0.87** | 0.02 | | | |
| 10 | summer 2003 | 0.11 | -0.18 | **0.81** | -0.02 | **0.44** | | **0.67** | | **0.43** | | |
| | autumn 2002 | -0.12 | **-0.46** | **0.97** | -0.10 | **0.45** | -0.39 | 0.22 | 0.06 | -0.18 | | |
| | autumn 2003 | -0.05 | **-0.46** | **0.89** | 0.05 | **0.37** | 0.19 | **0.61** | **-0.33** | 0.26 | | |
| 11 | summer 2003 | **-0.31** | -0.24 | 0.04 | **0.92** | **0.32** | | 0.09 | | 0.04 | 0.07 | |
| | autumn 2002 | **-0.43** | **-0.61** | -0.06 | **0.99** | **0.68** | | -0.14 | -0.21 | **-0.40** | -0.08 | |
| | autumn 2003 | **-0.45** | **-0.43** | 0.10 | **0.99** | **0.75** | -0.26 | 0.01 | -0.05 | **-0.30** | 0.04 | |

Significant negative correlation between CPUEs of .3 and older individuals of chinook salmon and depth at the location of trawling was observed. A concentration of large-size chinook salmon in the shelf areas of the Bering Sea has been observed previously (Shuntov, 1989; Glebov, 2000). Chinook salmon occupies deep-water areas of Aleutian and Kommandor basins during initial stage of its spring migrations into the Bering Sea (Glebov, 2000). Later on large-size chinook salmon of older age groups migrate to the shelf areas. This fact explains negative correlation between average length of chinook salmon and depth at the location of trawling (Table 3). Summer survey of 2003 was an exception, as all age groups concentrated in shallow areas of northwestern Bering Sea. This may be a result of year-specific oceanological conditions in summer of 2003. During the period of autumn surveys of 2002 and 2003, large-size (58.6-84.0 cm) individuals dominated in the shallow northern part of survey area, while small-size individuals of younger age groups (39.6-54.6 cm) occupied the deep-water part of survey area.

As we analyze relationships between CPUEs of different salmon species, it becomes evident that maximum differences in distribution are found between immature sockeye and chinook salmon (Table 4). Immature chum salmon occupies an intermediate position between these two species in its distribution pattern. For example, in the majority of surveys CPUEs of .1 age chum salmon were positively correlated with that of .1 age sockeye and chinook salmon. No such correlations were found between sockeye and chinook salmon of .1 age group. For CPUEs of .3 and older individuals no any significant interspecific correlations were observed.

Table 4.

Values of correlation coefficients for relationships between log-transformed values of different characteristics of immature chum, sockeye and chinook salmon.

| | | average length (cm) (immature chum salmon) | average length (cm) (immature sockeye salmon) | average length (cm) (immature chinook salmon) | CPUE (inds./hour) of individuals at the age of .1 (immature chum salmon) | CPUE (inds./hour) of individuals at the age of .1 (immature sockeye salmon) | CPUE (inds./hour) of individuals at the age of .1 (immature chinook salmon) | CPUE (inds./hour) of individuals at the age of .2 (immature chum salmon) | CPUE (inds./hour) of individuals at the age of .2 (immature sockeye salmon) | CPUE (inds./hour) of individuals at the age of .2 (immature chinook salmon) | CPUE (inds./hour) of individuals at the age of .3 and older (immature chum salmon) | CPUE (inds./hour) of individuals at the age of .3 and older (immature sockeye salmon) | CPUE (inds./hour) of individuals at the age of .3 and older (immature chinook salmon) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of characteristic | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| 2 | summer 2003 | 0.21 | | | | | | | | | | | |
| | autumn 2002 | **0.31** | | | | | | | | | | | |
| | autumn 2003 | **0.39** | | | | | | | | | | | |
| 3 | summer 2003 | **0.31** | **0.37** | | | | | | | | | | |
| | autumn 2002 | 0.29 | -0.06 | | | | | | | | | | |
| | autumn 2003 | **0.46** | 0.19 | | | | | | | | | | |
| 4 | summer 2003 | **-0.72** | **-0.24** | -0.05 | | | | | | | | | |
| | autumn 2002 | **-0.83** | -0.07 | -0.26 | | | | | | | | | |
| | autumn 2003 | **-0.67** | -0.25 | -0.32 | | | | | | | | | |
| 5 | summer 2003 | **-0.41** | **-0.64** | -0.13 | **0.57** | | | | | | | | |
| | autumn 2002 | **-0.57** | **-0.51** | -0.06 | **0.53** | | | | | | | | |
| | autumn 2003 | **-0.33** | **-0.64** | -0.13 | 0.24 | | | | | | | | |
| 6 | summer 2003 | -0.21 | -0.20 | -0.22 | **0.31** | 0.27 | | | | | | | |
| | autumn 2002 | **-0.52** | 0.03 | **-0.60** | **0.49** | 0.10 | | | | | | | |
| | autumn 2003 | -0.31 | **-0.40** | **-0.47** | 0.12 | 0.25 | | | | | | | |
| 7 | summer 2003 | **-0.45** | -0.15 | 0.04 | **0.82** | **0.46** | 0.25 | | | | | | |
| | autumn 2002 | **-0.33** | **0.39** | -0.18 | **0.49** | 0.02 | 0.19 | | | | | | |
| | autumn 2003 | -0.05 | 0.12 | -0.05 | **0.63** | 0.07 | -0.25 | | | | | | |
| 8 | summer 2003 | **-0.35** | **-0.26** | -0.04 | **0.56** | **0.74** | **0.31** | **0.49** | | | | | |
| | autumn 2002 | -0.11 | 0.13 | -0.14 | **0.32** | **0.57** | 0.06 | **0.45** | | | | | |
| | autumn 2003 | -0.16 | -0.10 | 0.11 | 0.11 | **0.69** | -0.15 | 0.08 | | | | | |
| 9 | summer 2003 | -0.06 | 0.22 | **0.44** | 0.19 | 0.02 | **0.43** | 0.16 | 0.03 | | | | |
| | autumn 2002 | 0.13 | 0.09 | **0.45** | -0.20 | -0.23 | -0.18 | -0.10 | -0.29 | | | | |
| | autumn 2003 | 0.20 | 0.05 | **0.37** | -0.21 | -0.20 | 0.26 | -0.10 | -0.10 | | | | |
| 10 | summer 2003 | **0.34** | 0.06 | **0.38** | 0.22 | 0.11 | -0.05 | **0.47** | 0.22 | 0.13 | | | |
| | autumn 2002 | **0.30** | **0.60** | -0.02 | -0.08 | **-0.36** | -0.13 | **0.54** | 0.21 | -0.14 | | | |
| | autumn 2003 | **0.40** | 0.21 | 0.26 | 0.08 | -0.24 | -0.12 | **0.41** | -0.16 | 0.19 | | | |
| 11 | summer 2003 | **-0.38** | 0.20 | 0.25 | **0.41** | **0.45** | 0.21 | **0.37** | **0.50** | **0.34** | -0.01 | | |
| | autumn 2002 | -0.21 | **0.32** | -0.28 | **0.41** | **0.48** | 0.23 | **0.37** | **0.69** | -0.33 | 0.23 | | |
| | autumn 2003 | 0.15 | 0.07 | -0.06 | -0.12 | **0.46** | 0.02 | 0.16 | **0.38** | -0.19 | 0.03 | | |
| 12 | summer 2003 | 0.15 | -0.07 | **0.32** | -0.06 | 0.18 | 0.04 | -0.06 | -0.04 | 0.07 | 0.10 | 0.24 | |
| | autumn 2002 | 0.33 | -0.14 | **0.68** | -0.26 | 0.03 | **-0.40** | -0.22 | -0.04 | -0.08 | -0.04 | -0.03 | |
| | autumn 2003 | **0.50** | -0.23 | **0.75** | -0.33 | **0.40** | **-0.30** | -0.29 | 0.32 | 0.04 | -0.03 | 0.16 | |

Highly significant positive correlations between CPUEs of juvenile individuals of all Pacific salmon species during both autumn surveys testify for similarity in their distribution patterns during autumn period (Table 5).

Table 5.

Values of correlation coefficients for relationships between log-transformed values of different characteristics of juvenile chum, sockeye and chinook salmon.

| | | CPUE (inds./hour) (juvenile pink salmon) | CPUE (inds./hour) (juvenile chum salmon) | CPUE (inds./hour) (juvenile coho salmon) | CPUE (inds./hour) (juvenile sockeye salmon) | CPUE (inds./hour) (juvenile chinook salmon) |
|---|---|---|---|---|---|---|
| Number of characteristic | | 1 | 2 | 3 | 4 | 5 |
| 2 | autumn 2002 | **0.39** | | | | |
| | autumn 2003 | **0.41** | | | | |
| 3 | autumn 2002 | **0.30** | **0.28** | | | |
| | autumn 2003 | **0.41** | **0.25** | | | |
| 4 | autumn 2002 | **0.51** | **0.54** | 0.09 | | |
| | autumn 2003 | **0.28** | **0.78** | 0.20 | | |
| 5 | autumn 2002 | **0.42** | **0.43** | **0.55** | **0.32** | |
| | autumn 2003 | **0.61** | **0.63** | **0.47** | **0.51** | |

Our results allow us to conclude that maximum catches of chum and sockeye salmon, as opposed to chinook salmon, were obtained in the areas of concentration of younger age groups (.1). The fact of dominance of .1 age groups of sockeye salmon in major catches of this species in the southwestern Bering Sea was reported previously (Radchenko, 1994). Both for chum and chinook salmon we observed similarity in distribution between .1 and .2 individuals, as well as between .2 and .3 and older individuals. It has been reported previously that large-size immature (.3 and older) and mature chum salmon concentrate primarily in the coastal areas of the western Bering Sea during summer (Shuntov, 1989; Starovoytov, 2002). Immature individuals of .2 age group tend to concentrate somewhat further from coastal areas, whereas fishes of .1 were observed primarily in deep-water areas of Aleutian and Kommador basins. Similar age-specific distribution pattern was noted previously for chinook salmon in the western Bering Sea (Shuntov, 1989; Glebov, 2000). Unlike for chum and chinook salmon, our data did not show age-specificity in distribution of sockeye salmon in the western Bering Sea.

We can conclude that spatial distribution patterns of Pacific salmon are species-, age- and season-specific in their nature. The greatest species-specific differences in distribution were observed between sockeye and chinook salmon. The greatest age-specific differences in distribution were observed between oldest age group (.3 and older individuals) and the youngest one (.1). However, such age-specificity in distribution was observed only for chum and chinook salmon. Interspecific differences in distribution were more evident for the oldest age group, as compared with the youngest one. Species-, age- and season-specificity of Pacific salmon's distribution patterns seems to be the result of adaptive strategy, which is directed toward reduction of intra- and interspecific competition through the maximum spatial separation of different age groups from each other.

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