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Interannual variability in stock abundance and body size of Pacific salmon in the central Bering Sea

Yukimasa Ishida, Tomonori Azumaya, Masa-aki Fukuwaka
Hokkaido National Fisheries Research Institute, Fisheries Research Agency
116 Katsurakoi, Kushiro 085-0802, Japan

and

Nancy Davis
School of Aquatic and Fishery Sciences, University of Washington
Seattle, WA 98195-5020, USA

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Abstract

Variability in catch-per-unit-effort (CPUE) and mean body size was examined for pink, chum and sockeye salmon collected with research gillnets in the central Bering Sea in July from 1972 to 2000. CPUEs of three species showed significant increasing trends with large interannual variability. CPUE of pink salmon was higher in odd years than in even years, and abruptly increased in odd years from 1989. CPUEs of chum and sockeye salmon were higher during 1979-1984 and 1992-1998, but lower during 1985-1991. Chum salmon also showed odd/even year fluctuations, which was out of phase with pink salmon, but sockeye salmon did not show such fluctuations. In body size, pink salmon showed a significant decreasing trend, and chum and sockeye salmon also showed significant decreasing trends at ocean age 3 and older ages, but not at ocean age 2. Significant negative relationships between CPUE and body size were found within species. No correlation was found between an Aleutian Low Pressure index (ALPI) and CPUE or body size, but the increases in CPUE around the late 1970s and early 1990s may relate to the regime shift in 1977 and 1989 identified by the ALPI.

Introduction

Production of Pacific salmon increased due to reduced high-seas catches of salmon, the large releases of hatchery fish, and favorable ocean conditions after the mid 1970s (Pearcy, 1992), and there was evidence that the average body size at maturity decreased in some salmon stocks as ocean abundance increased (Ishida et al., 1993; Kaeriyama, 1996; Bigler et al., 1996). These results suggest that density dependent effects may be one of causes for the growth reduction in body size of Pacific salmon in the North Pacific Ocean. Among Pacific salmon, pink, chum and sockeye salmon represent approximately 90% of the commercial catches taken each year and the long-term pattern of the Aleutian Low pressure index (ALPI) corresponded to the trends in salmon catch, indicating that climate and the marine environment may play an important role in salmon production (Beamish and Bouillon 1993). Besides, body size at maturity and population abundance increased since the mid 1990s for some salmon stocks, possibly indicating another climate change in the North Pacific Ocean (Helle and Hoffman, 1998). The purpose of this paper is to examine variability in fish density and body size for pink, chum and sockeye salmon in the central Bering Sea, and to clarify the relationships between fish density and body size, and the effect of ALPI and sea surface temperature (SST) on these biological characters of Pacific salmon.

Materials and Methods

To examine interannual variability in fish density of pink, chum and sockeye salmon, the data collected in the central Bering Sea (175°E-175°W, 55°N-59°N) in July from 1972 to 2000 were used in this study (Fig. 1). We analyzed the data obtained by non-selective research-type gillnets consisting of 10 different mesh size ranging from 48 to 157 mm (Takagi, 1975). The density index (catch-per-unit effort, CPUE) was calculated as number of fish caught by 30 tans of gillnet.

Fish were processed by recording fork length, body weight, sex, and gonad weight. A scale for age determination was collected from the standard International North Pacific Fisheries Commission (INPFC) preferred area of the body of each fish, if scales were present. Age was determined in the laboratory by visual examination of scale samples. Maturity was determined from gonad weights (Takagi, 1961).

Aleutian Low Pressure index measures the relative intensity of the Aleutian Low pressure system of the North Pacific from December through March. It is calculated as the mean area (km^2) with sea level pressure <= 100.5 kPa and expressed as an anomaly from the 1950-1997 mean. A positive index value reflects a relatively strong, or intense Aleutian Low (Beamish et al. 1997). Data were cited from http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/english/clm_indx1.htm. Average sea surface temperature (SST) in the central Bering Sea in July was determined using mean monthly SST data in 2° x2° grids from 1972 to 2000 provided by the Japan Meteorological Agency.

Results

CPUEs of three species showed significant increasing trends with large interannual variability. CPUE of pink salmon was higher in odd years than in even years, and abruptly increased in odd years from 1989. CPUEs of chum and sockeye salmon were higher during 1979-1984 and 1992-1998, but lower during 1985-1991. Chum salmon also showed odd/even year fluctuations, which was out of phase with pink salmon, but sockeye salmon did not show such fluctuations. Higher CPUE of chum salmon in even years gradually decreased from 1992 to 2000. Sockeye salmon also showed lower CPUE from 1998 to 2000(Fig. 2). A negative relationship between pink and chum, and positive relationships between sockeye and chum or pink salmon were found in CPUE, but all three relationships were not significant. The proportion of age 2 chum and sockeye salmon increased when CPUE increased (Fig. 3). The effect of ALPI and SST on CPUE was examined for each species, but no correlation was found.

Body size of pink salmon showed a significant decreasing trend, and chum and sockeye salmon also showed significant decreasing trends at ocean age 3 and older ages, but not at ocean age 2 (Fig. 4). Significant negative relationships were found between CPUE and body size for three species. But pink salmon in even years did not show a significant negative relationship, maybe due to very low CPUE (Fig. 5). Age 2 chum salmon showed a negative relationship, but not significant. Body size of age 2 sockeye salmon had a significant positive relationship with CPUE. We also examined a CPUE and body size relationship between different species. There were only three significant negative relationships between CPUE of chum and body size of age 4 sockeye, and between CPUE of sockeye and body size of age 3 or age 4 chum salmon. The effect of ALPI and SST on body size was examined, but no correlation was found, except a negative relationship between SST and body size of age 4 chum salmon. Multiple regression analysis also confirmed that body sizes were associated with fish density intra-specifically, but not with the ALPI and SST (Table 1).

Discussion

One of the most interesting facts found in this study is the abrupt increase in CPUE of pink salmon in 1989 and the coherent changes in CPUE of sockeye and chum salmon around the late 1970s and early 1990s. Beamish and Bouillon (1993) reported that the long-term pattern of the Aleutian Low pressure system corresponded to the trends in salmon catch, to copepod production, and to other climate indices, indicating that climate and the marine environment may play an important role in salmon production. So we assumed that the ALPI may effect on salmon abundance and growth in the Bering Sea, but we could not find a clear relationship between them. Beamish et al. (1999) also reported that the trends or regimes can be characterized by stable means in physical data series or multiyear periods of linked recruitment patterns in fish populations and found that both the 1977 and the 1989 changes in the ALPI anomaly time series were significant. There was not a significant correlation between ALPI and CPUE for each species as mentioned above, but the increases in CPUE of three species around the late 1970s and early 1990s may relate to the regime shift in 1977 and 1989 identified by Beamish et al. (1999).

Significant intraspecific relationships between CPUE and body size were found for three species in the Bering Sea. Tadokoro et al. (1996) reported that chum salmon changed their dominant diet from gelatinous zooplankton (pteropods, appendicularians, jellyfishes, chaetognaths, polychaetes, and unidentified materials) in 1991, when pink salmon were abundant, to a diet of crustaceans (euphausiids, copepods, amphipods, ostracods, mysids, and decapods) in 1992, when pink salmon were less abundant. Davis et al. (2000) indicated that sockeye, pink, and chum salmon stomach contents contained fish during the day, and increased their feeding on euphausiids and copepods during the night. They speculated that a daytime switch to feeding on fish by sockeye, pink, and chum salmon may be a mechanism to decrease competition for food. Azumaya and Ishida (2000) also found that the distribution patterns of chum salmon differed between odd and even years, and chum salmon distribution were more concentrated to the west in even years of low pink salmon abundance and shifted southeastward in odd years of high pink salmon abundance. These results suggest that there is a limit in food and space for Pacific salmon in the central Bering Sea, and the shift of distribution and food works as a mechanism to decrease the competition between different species. Bugaev et al. (2001) indicated that the body size of Russian sockeye returning to the Ozernaya River was substantially reduced in years when the ocean abundances of Kamchatkan pink and sockeye salmon were high. However, we could not find a negative relationship between body size of sockeye and CPUE of pink salmon in the central Bering Sea. The competition between pink and sockeye salmon may possibly occur in the ocean during the homeward migration, but not in the central Bering Sea, because fish may be more concentrated at that time and be actively feeding like Bristol Bay sockeye salmon (Rogers and Ruggerone 1993).

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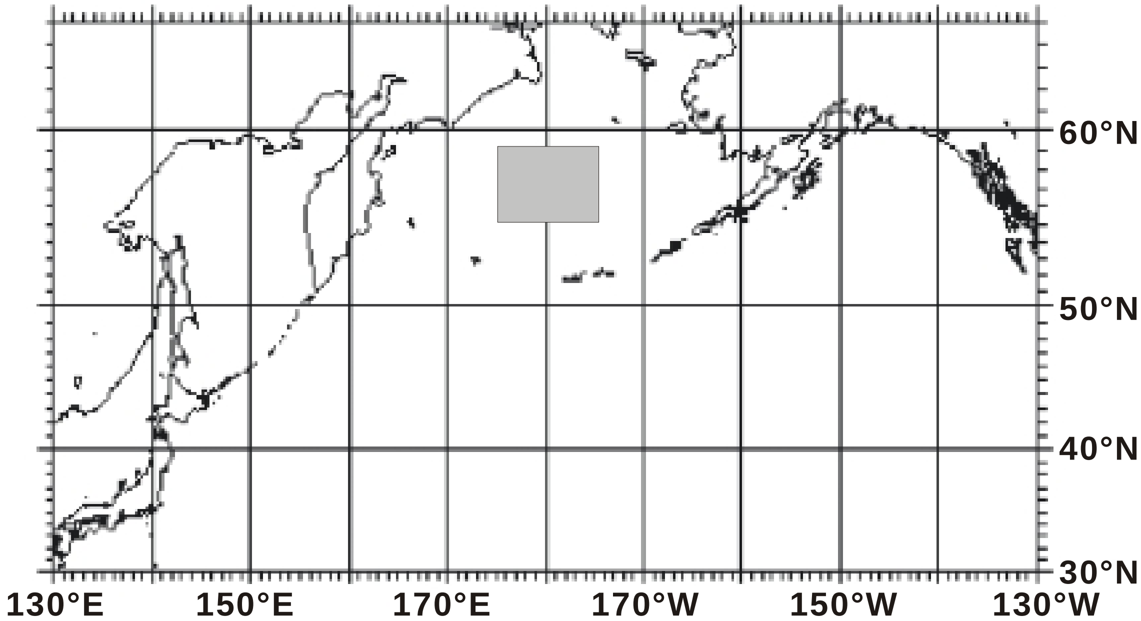

Figure 1. Survey area in the central Bering Sea in July from 1972 to 2000.

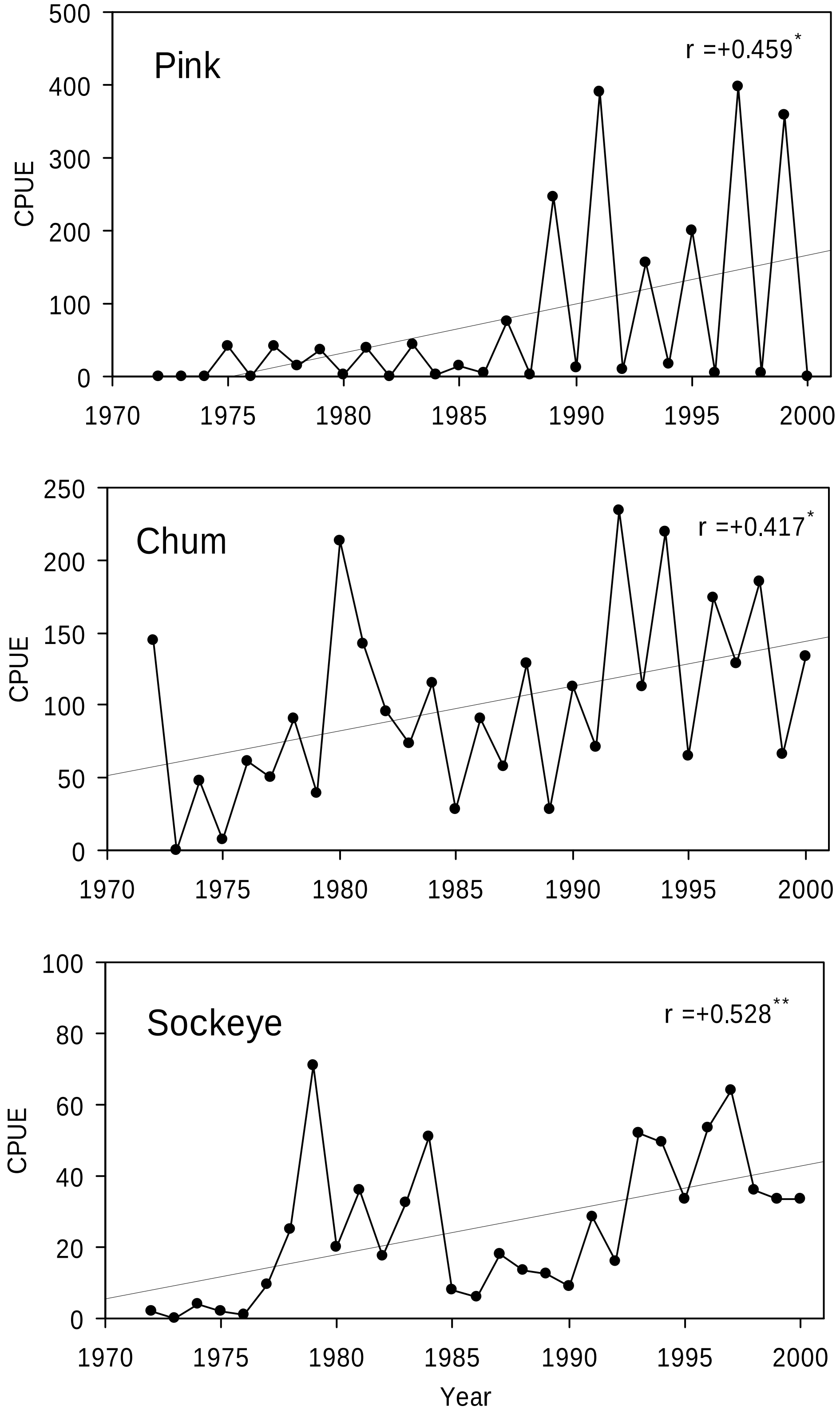

Fig. 2. CPUE of pink, chum, and sockeye salmon in the central Bering Sea in July from 1972 to 2000.

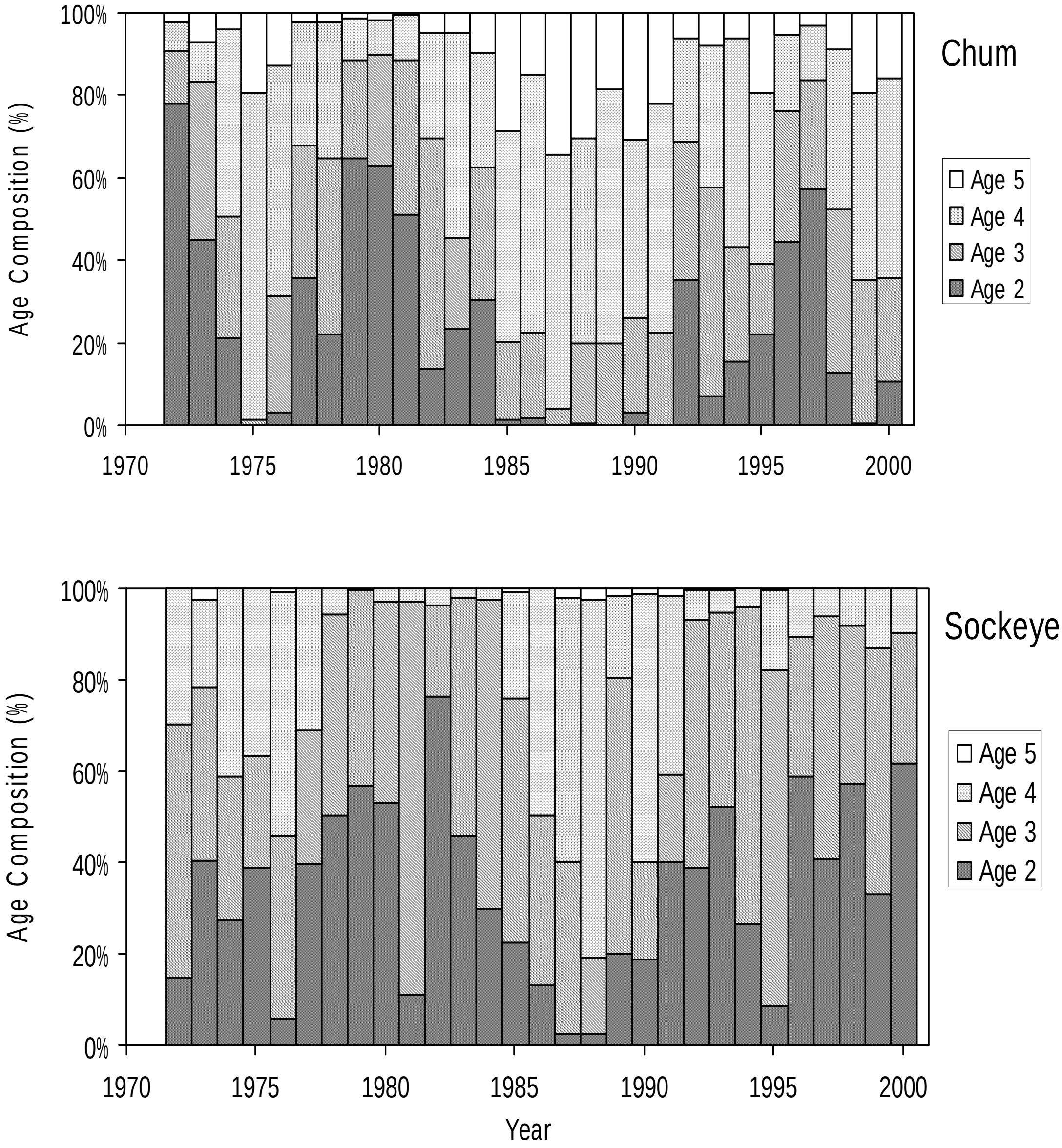

Fig. 3. Ocean age composition of chum and sockeye salmon in the central Bering Sea in July from 1972 to 2000.

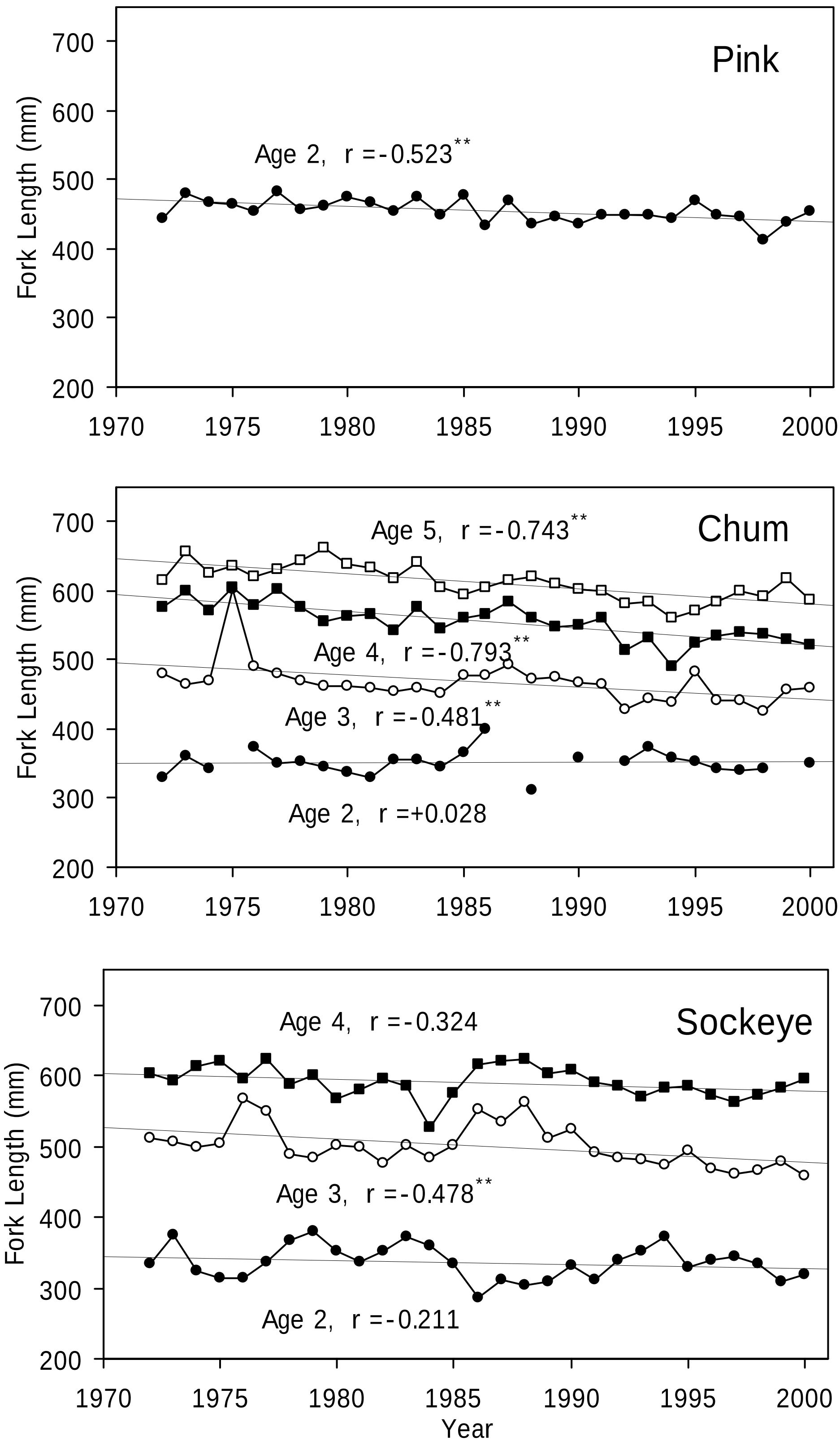

Fig.4. Fork length (mm) of pink, chum, and sockeye salmon in the central Bering Sea in July from 1972 to 2000.

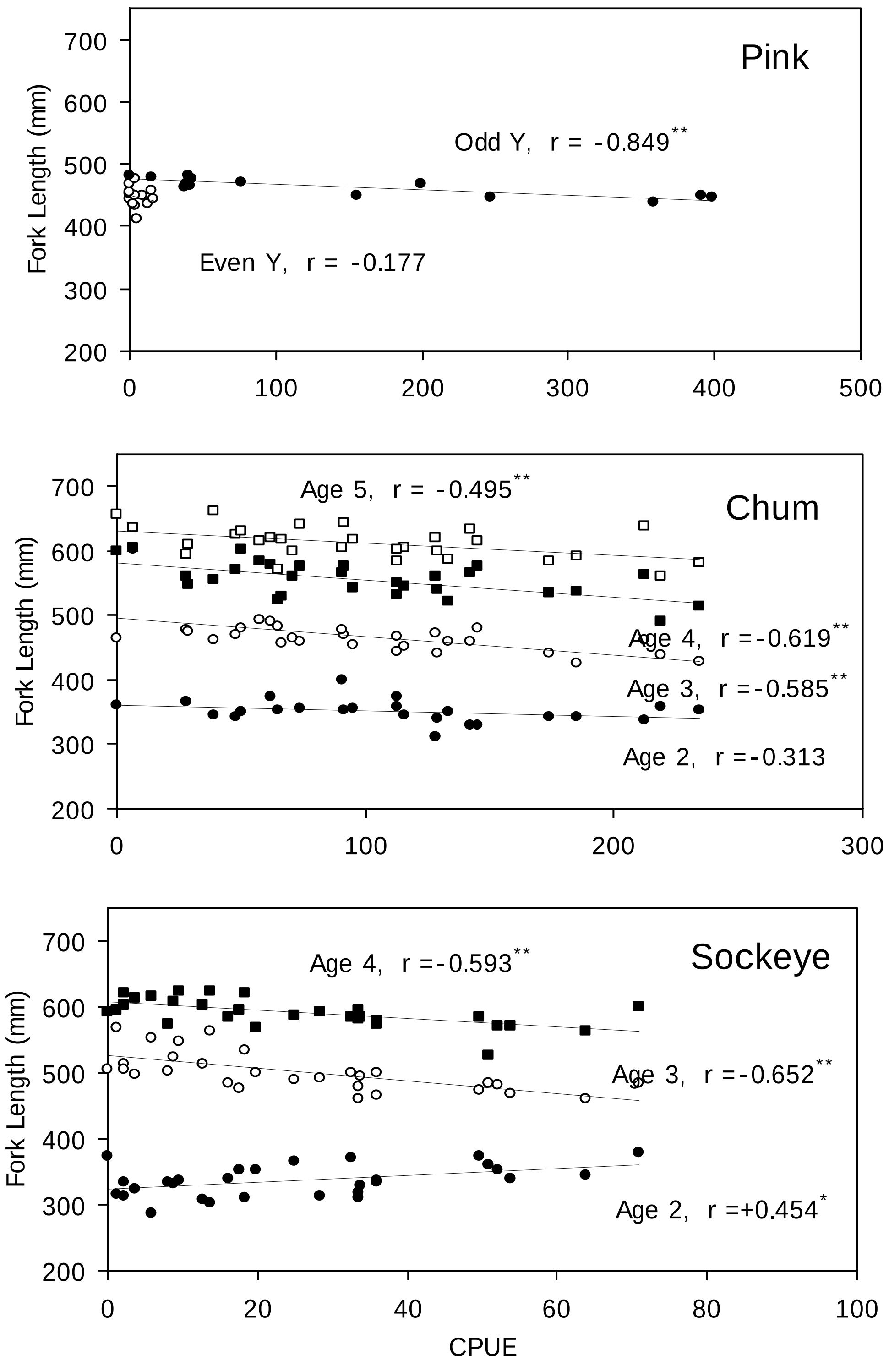

Fig. 5. Relationship between CPUE and fork length of pink, chum, and sockeye salmon in the central Bering Sea in July from 1972 to 2000.

Table 1. Summary of standardized regression coefficients of Aleutian Low Pressure Index (ALPI), SST, CPUEs of pink, sockeye and chum on average fork length of each species by age or year group.

Species	Age group	ALPI	SST	CPUE			R^2	p
				Pink	Sockeye	Chum		
Pink	2	0.093	0.076	-0.285	0.035	-0.549*	0.27	0.17
	odd year	0.284	0.148	-0.720**	-0.184	-0.239	0.83	<0.01
	even year	-0.295	0.192	-0.120	-0.048	-0.038	0.12	0.93
Sockeye	2	-0.136	-0.125	-0.457*	0.703**	-0.089	0.43	0.02
	3	0.227	0.016	-0.090	-0.595**	-0.216	0.50	<0.01
	4	0.003	0.161	-0.095	-0.540**	-0.277	0.42	0.02
Chum	2	0.124	-0.063	0.032	-0.104	-0.287	0.12	0.78
	3	-0.023	-0.132	-0.034	-0.270	-0.465*	0.46	<0.01
	4	0.217	0.038	-0.207	-0.358*	-0.600**	0.62	<0.01
	5	0.179	-0.096	-0.258	0.026	-0.569**	0.35	0.06