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Bias-Corrected Size Trends in Chum Salmon in the Central Bering Sea and North Pacific Ocean

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Abstract: We estimated bias-corrected mean fork lengths of gillnet-caught chum salmon using a size selectivity estimate of the gillnet to test how the bias correction affects the estimated temporal pattern of chum salmon body size, during 1971–1994 and 1994–2007. Results showed bias-corrected mean fork lengths were smaller than uncorrected means. Therefore, when examining ontogenetic changes in fish size (e.g. the growth trajectory) using data collected by research gillnets, the uncorrected mean fork length can overestimate the true value. Comparison of temporal trends in bias-corrected mean fish lengths to uncorrected means showed similar results because both illustrated a decrease in chum salmon fork length in 1971–1994, and a stable fish size after 1994. Uncorrected mean values of chum salmon fork length for fish caught using research gillnets can be used as a proxy for fish size to examine temporal trends. We conclude that interpreting temporal trends using either uncorrected or bias-corrected data will support the same general conclusions regarding long-term changes in chum salmon body size.

Keywords: chum salmon, ocean survey, fish size, temporal trend, gillnet selectivity, sampling bias

INTRODUCTION

The Bering-Aleutian Salmon International Survey (BASIS) of the North Pacific Anadromous Fish Commission (NPAFC), begun in 2002, established the trawl as the standard fishing gear to collect salmon (NPAFC 2001). One of the scientific issues stated in the BASIS plan was to investigate the key biological, climatic, and oceanographic factors affecting long-term changes in Bering Sea food production and salmon growth rates. However, information on long-term changes in salmon growth is difficult to obtain from BASIS surveys because the research began only a short number of years ago. Since 1972, Japanese research vessels have monitored salmon stock condition in the Bering Sea and North Pacific by catching fish using a research gillnet consisting of ten different mesh sizes (Takagi 1975, 1996). These Japanese monitoring surveys provide valuable information on long-term changes in salmon growth because their standardized methods and data series were established several decades ago and have not changed.

Analysis of the temporal trend in chum salmon fork lengths from Japanese research gillnet surveys showed a decrease in fish size from the 1970s to the 1990s, and not much change in fish size through the middle of the next decade (Fukuwaka et al. 2007). The temporal trend in fish size from high seas research surveys correlated with age and size at maturation of Ishikari River chum salmon (Fukuwaka et al. 2007). Fish size at maturation of other populations of chum salmon and other species of Pacific salmon has shown similar trends, with a decrease in size into the 1990s and an increase in size in recent years (e.g. Helle and Hoffman 1998; Eggers and Irvine 2007; Helle et al. 2007; Shaul et al. 2007).

Recent studies have shown that estimates of fish size are biased in catches from multi-mesh research gillnets due to the size selectivity of this fishing gear (Finstad et al. 2000; Finstad and Berg 2004; Fukuwaka et al. 2008). The data series on immature and maturing chum salmon body size collected at sea by Japanese research monitoring programs are based on catches in a multi-mesh research gillnet. As long-term changes in salmon body size are of primary interest to the BASIS program, the objective of our study was to test how the temporal pattern of uncorrected values of chum salmon fish length compares to bias-corrected values using data collected in Japanese salmon research gillnet surveys from 1971 to 1994 and 1994 to 2007. We estimated bias-corrected mean fork lengths of gillnet-caught chum salmon using a size selectivity estimate based on comparison of the research gillnet catches of the R/V *Wakatake maru* moni-

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toring surveys and the mid-water trawl catches of the R/V *Kaiyo maru* BASIS surveys reported in Fukuwaka et al. (2008).

MATERIALS AND METHODS

Chum salmon fork length and ocean age from scale collections were determined for each mesh size in catches of a standard salmon research gillnet from Japanese monitoring surveys conducted in the central Bering Sea and North Pacific between 170°E and 170°W from June 11 to July 20, 1971–2007. High-seas salmon monitoring surveys using this standardized research gillnet began in 1972, however, measurements of chum salmon fork length caught by the same gear were available from surveys in 1971, and therefore were included in this study. The gillnet configuration comprised variable-meshes representing a geometric series of factor 1.14 (identical number of 50-m by ca. 7-m panels of 48-, 55-, 63-, 72-, 82-, 93-, 106-, 121-, 138-, and 157-mm meshes composed of nylon monofilament line; Takagi 1975). To maintain the gillnet's stretch while fishing, additional panels of 115- or 121-mm mesh were attached at both ends, however, catches in these meshes were not included in our analysis. In recent years, three 50-m panels of each research mesh size were used in gillnet operations. However, before 1993 sometimes four to six 50-m panels of each mesh size were used. Because the same number of panels of each mesh size was used in each fishing operation, the change in the number of panels over the time period does not affect the relative catch efficiency of each mesh size. We set the maximum catch efficiency of the 157-mm mesh to 1.0 and estimated the efficiencies of each mesh size relative to catches in that mesh size.

To correct for the bias in fish size caused by gillnet sampling, we weighted fork length by the reciprocal of the catch efficiency. Catch efficiency of the research gillnet was estimated by inter-calibrating research gillnet catches with trawl catches conducted during the 2002–2004 BASIS cruises (Fukuwaka et al. 2008). Annual mean fork length was estimated using the following equation:

$$\bar{l}_{corr} = \sum l \frac{n_{l,m}}{E_m(l)} \Big/ \sum \frac{n_{l,m}}{E_m(l)}$$

where l was the mid point of length class, $n_{l,m}$ was the number of fish at length class l caught in gillnet mesh m, and $E_m(l)$ was the catch efficiency of gillnet mesh m for length class l. Although the number of fish caught, $n_{l,m}$, was assumed to have a Poisson error (Fukuwaka et al. 2008), we did not evaluate the bias caused by the sampling error in this study. Because sample size was large for all age groups except age-0.5 (age-0.1 n = 67-1338, age-0.2 n = 139-1585, age-0.3 n = 178-1719, age-0.4 n = 27-573, and age-0.5 n = 0-28; Table 1), we assumed the bias caused by sampling error in mean fork length was much smaller than the bias caused by gillnet selectivity. The average % difference between uncorrected and bias-corrected values was estimated for each age group:

$$\%\ \text{difference} = 100 \times \frac{\bar{l}_{uncorr} - \bar{l}_{corr}}{\bar{l}_{corr}}$$

To compare the temporal trends in the annual mean fork length of uncorrected and bias-corrected values, we estimated the correlation coefficient between year and the uncorrected and bias-corrected sizes for two time periods,

Table 1. Correlation coefficient (*r*) and significance (*P*) between year and uncorrected and bias-corrected mean fork lengths of chum salmon caught in the central Bering Sea and North Pacific in summer. The symbol N indicates the range of the number of fish used for estimation of annual mean fork lengths in each time period. Values are presented for two time periods (1971–1994 and 1994–2007) and chum salmon age groups (0.1–0.5).

Period	Age	Uncorrected		Bias-corrected		N
		r	*P*	*r*	*P*	
1971–1994	0.1	0.068	0.753	-0.073	0.736	144–1338
	0.2	-0.800	< 0.001	-0.752	< 0.001	192–1585
	0.3	-0.831	< 0.001	-0.792	< 0.001	274–1719
	0.4	-0.869	< 0.001	-0.836	< 0.001	27–573
	0.5	-0.539	0.001	-0.517	0.011	0–28
1994–2007	0.1	0.443	0.112	0.276	0.340	67–883
	0.2	-0.113	0.700	-0.191	0.513	139–1018
	0.3	0.319	0.267	0.187	0.522	178–883
	0.4	0.391	0.167	0.133	0.649	37–324
	0.5	0.117	0.689	0.346	0.226	2–25

1971–1994 and 1994–2007. The significance of the correlation coefficient was tested using a *t*-test. The data were separated into the two time periods because a previous study showed the correlation coefficient of uncorrected annual mean fork length was significantly negative in 1972–1994 and not significant in 1994–2004 (Fukuwaka et al. 2007).

RESULTS

Bias-corrected mean fork lengths of chum salmon were smaller than means calculated from raw data (Fig. 1). However, the difference was less in the oldest age group. Average % difference was 3.2% for age-0.1 fish, 3.4% for age-0.2 fish, 5.2% for age-0.3 fish, 2.9% for age-0.4 fish, and 1.4% for age-0.5 fish. For age-0.5 fish some bias-corrected means were larger than uncorrected means (Fig. 1E). The difference between corrected and uncorrected fork lengths was statistically significant (*t*-test, $\alpha = 0.05$) in 32 of 37 years for age-0.1 fish, 33 of 37 years for age-0.2 fish, 37 of 37 years for age-0.3 fish, 25 of 37 years for age-0.4 fish, and 3 of 27 years for age 0.5 fish. The difference between mean fork lengths and less difference in the oldest age group were caused by a heavier weight (i.e. the reciprocal of catch efficiency) applied to estimate for smaller fish.

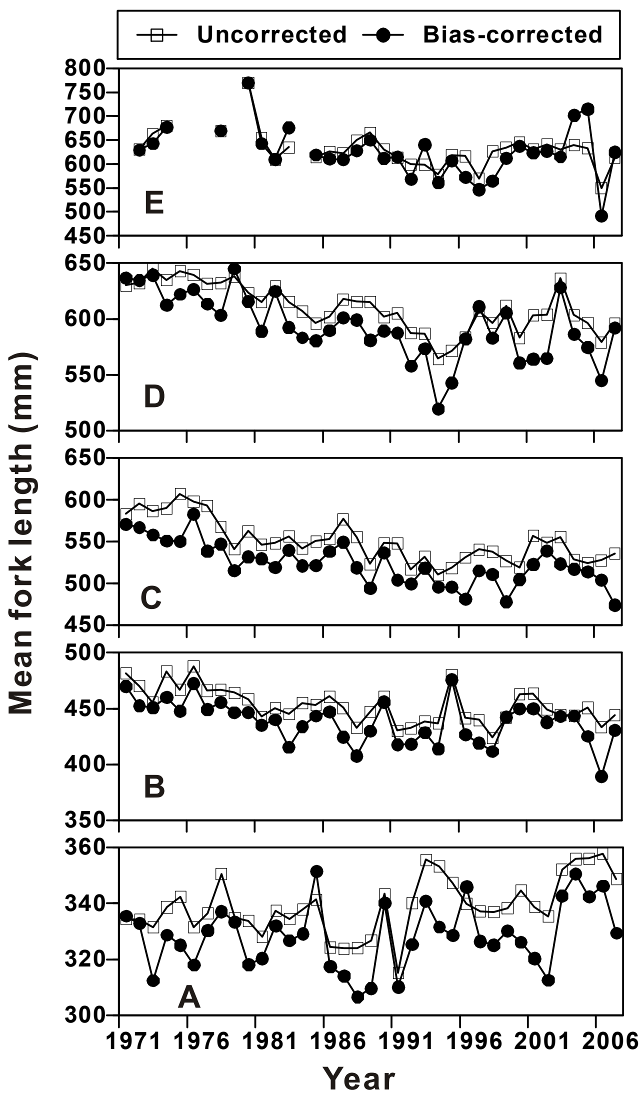

Fig. 1. Annual change in mean fork length of chum salmon of age-0.1 (A), age-0.2 (B), age-0.3 (C), age-0.4 (D), and age-0.5 (E) caught in the central Bering Sea and North Pacific in summer, 1971–2007. The data series shows values for uncorrected fish size calculated from mean fish length of gillnet catches (open squares) and bias-corrected mean fish lengths (solid circles).

The temporal trend of bias-corrected mean chum salmon fork length was similar to that calculated from uncorrected data (Fig. 1). Correlation coefficients (r) between corrected and uncorrected means were 0.771 ($P < 0.001$) for age-0.1 fish, 0.886 ($P < 0.001$) for age-0.2 fish, 0.853 ($P < 0.001$) for age-0.3 fish, 0.915 ($P < 0.001$) for age-0.4 fish, and 0.829 ($P < 0.001$) for age-0.5 fish. Over the time period 1971-1994, both time series of mean fork lengths of age-0.2, -0.3, -0.4, and -0.5 fish decreased significantly, but the correlation coefficients between year and bias-corrected means were smaller than those from uncorrected data (Table 1). Mean fork length of age-0.1 fish showed no significant temporal trend in 1971–1994. After 1994, mean fork lengths of all age groups were relatively stable and showed no significant trend.

DISCUSSION

The temporal trend of bias-corrected mean fork length was similar to that of uncorrected mean fork length of chum salmon caught using a salmon research gillnet. Although some authors have not considered the bias in fish size caused by gillnet sampling (e.g. Ishida et al. 1993; Azumaya and Ishida 2000; Fukuwaka et al. 2007), temporal trends of uncorrected values follow the same trends as unbiased values. The temporal correspondence between uncorrected mean sizes from research gillnet catches and sizes of mature fish caught in weirs in fresh water, which may be less size selective (Ishida et al. 1993; Fukuwaka et al. 2007), further supports the usefulness of uncorrected data as a proxy for unbiased values. However, for studies of ontogenetic changes in chum salmon size (e.g. the growth trajectory), researchers should account for the overestimation of true mean fork length when using uncorrected data from research gillnet catches.

The salmon research gillnet was designed to be nonselective with regard to fish size (Takagi 1975). This design was based on the assumptions that (1) gillnet panels of a geometric mesh size series offset the individual selectivity of each single mesh panel and (2) each mesh size had a common maximum efficiency, or fishing intensity. These assumptions have a theoretical basis in Balanov's principle of geometric similarity, which states that the selectivity curves for different mesh sizes must be similar because all meshes and all fish of the same species are geometrically similar (Hamley 1975). However, the second assumption is not valid when gillnet efficiency increases with mesh size (reviewed by Hamley 1975). Fukuwaka et al. (2008) recently determined that the catch efficiencies of the salmon research gillnet increases with mesh size and fish size, which suggests that the second assumption is not necessarily true. The unidirectional bias toward larger size we observed in this study was caused by the higher catch efficiency for large fish than for small fish in research gillnet catches. When the bias is not unidirectional in the research gillnet catch the reason may be a large sampling error caused by small sample size. In addition, lower correlation coefficients for temporal trends in bias-corrected mean fork length might be the result of small sample sizes being caught in small mesh sizes. Because variance in numbers and sizes of fish caught in small mesh sizes can increase with heavier weights (reciprocals of catch efficiency) in the bias-correction, bias-corrected mean fork length may be unreliable if small numbers of fish are caught in small mesh sizes.

Although studies of ontogenetic changes in chum salmon size from research gillnet data should correct for the overestimation of true mean fork length, we conclude that interpreting temporal trends using uncorrected or bias-corrected data will support the same general conclusions regarding long-term changes in chum salmon body size.

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