Long-term Trends in Annual Bristol Bay Sockeye Salmon Scale Growth at Sea in Relation to Sockeye Abundance and Environmental Trends, 1955–2000

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Pacific salmon populations rearing in the North Pacific Ocean and Bering Sea increased substantially after the marine climate shift during the mid-1970s. Density-dependent growth has been observed among many stocks of Pacific salmon and it raises questions about the relationship between salmon growth at sea and salmon survival and production. For example, after the mid-1970s, did salmon growth decline during each stage of ocean life in response to greater salmon abundance, or did growth increase during certain periods of ocean life most critical to survival, followed by reduced growth during other periods when growth may be less important to survival?

We measured annual marine scale growth of Bristol Bay and central Alaska sockeye salmon, 1955 to 2000, in order to test whether annual salmon growth at sea was positively or negatively associated with the large increase in salmon abundance that began in the mid-1970s (see Hagen et al. 2001; Davis et al. 1990 for scale methods). Bristol Bay and central Alaska sockeye salmon runs more than doubled after the mid-1970s, a trend that was common to many stocks.

After the mid-1970s, sockeye salmon scale growth tended to be above average during the first two years at sea. This pattern was generally consistent among Kvichak age-2.2 and age-2.3 sockeye salmon (Figs. 1 and 2), but was especially pronounced among Chignik sockeye salmon (Fig. 3). During the first year at sea, Kvichak sockeye rear in the Bering Sea whereas Chignik sockeye rear in the North Pacific Ocean, indicating early marine growth was generally favorable in both regions after the mid-1970s. One exception to the trend was the somewhat above average growth of Kvichak age-2.2 sockeye salmon during the second year at sea beginning in the mid-1960s.

After the mid-1970s, scale growth of ocean age-3 Kvichak sockeye salmon tended to be below average during the third year at sea (Fig. 2), especially during odd-numbered years. Chignik scale growth during the third year at sea was variable due to the odd/even year pattern but somewhat below average after the mid-1970s (Fig. 3). Chignik salmon scale growth during the homeward migration was below average after the mid-1970s. These growth trends were opposite of that during the first two years at sea.

Scale growth during the second and third years at sea show an odd/even-year pattern that is inversely related to Asian pink salmon abundance (Ruggerone et al. unpublished analysis). For example, multivariate time series analysis indicated scale growth during the second year at sea (SW2) was negatively related to harvest of Eastern Kamchatka pink salmon (1,000 mt) and positively related to winter sea-surface temperature in the North Pacific Ocean (Fig. 4).

Previous analyses indicated adult length of Bristol Bay sockeye salmon was inversely related to adult sockeye salmon run size (Rogers and Ruggerone 1993). A new analysis of this relationship indicates Bristol Bay sockeye length also decreased in years of large Asian pink salmon runs during the previous year. However, salmon size was greater at a given salmon abundance during 1977–2000 compared with 1958–1976. These effects on length of female age-1.3 sockeye salmon are shown in the following multivariate time series equation (Fig. 5; Ruggerone et al. unpublished analysis):

$$\text{Length} = 571.7 - 0.339(\textit{sockeye run}) + 8.76(\textit{period};\ 0 \text{ or } 1) - 0.067(\textit{pink run},\ \text{y-}1) + \varepsilon$$

Bristol Bay sockeye salmon runs tended to be relatively low when scale growth during the first and second years at sea was below average. Sockeye runs increased when marine scale growth increased beyond average scale growth (Fig. 6), suggesting that greater growth during both the first and second years at sea were associated with greater salmon survival.

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This analysis suggests sockeye salmon growth during the first two years at sea was an important factor leading to the large abundance of western and central Alaska sockeye salmon since the mid-1970s. Although density-dependent growth may occur during early marine life, density-dependent growth is most apparent in the later stages of life when reduced growth likely has less effect on survival.

Fig. 1. Age-2.3 Kvichak sockeye salmon growth during first, second and third years at sea.

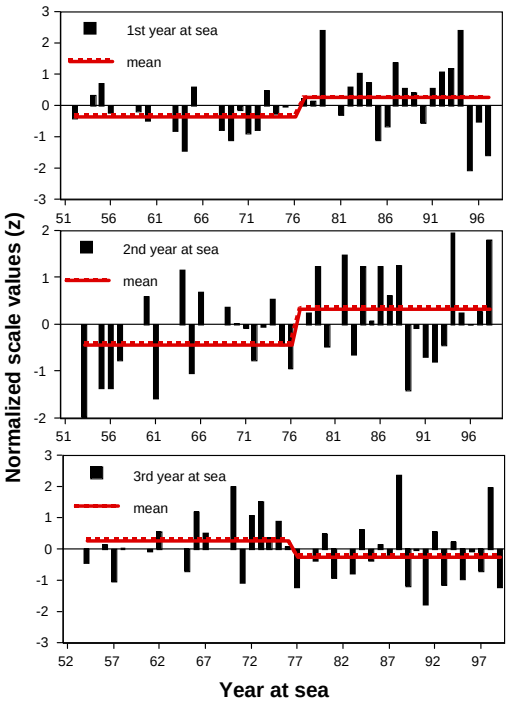


Fig. 2. Age-2.2 Kvichak sockeye salmon growth during first and second years at sea.

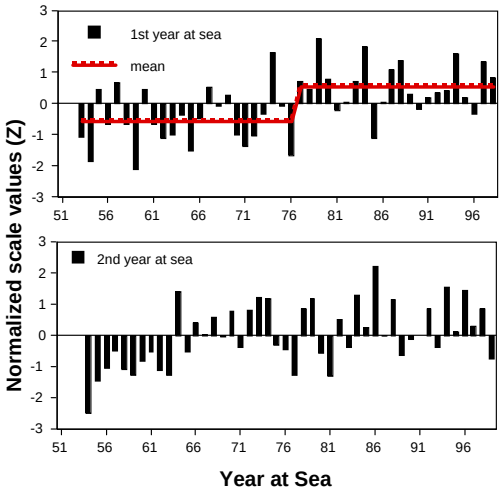


Fig. 3. Chignik sockeye salmon growth during first, second, third years at sea and during homeward migration.

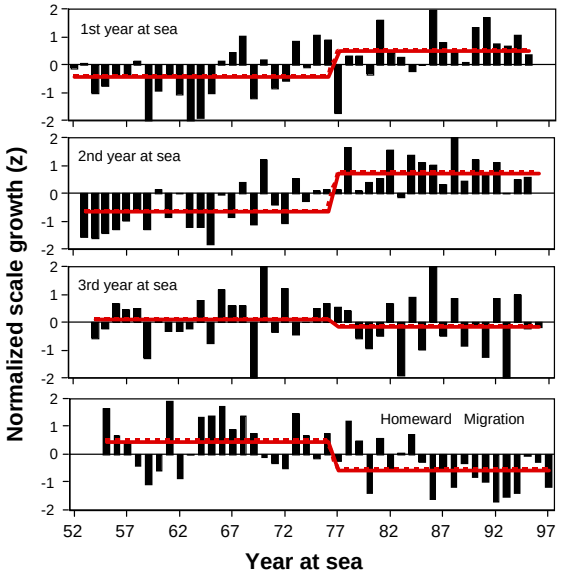


Fig. 4. Multivariate time series corrected plots showing the relationship between female age-1.3 sockeye length and Bristol Bay sockeye run, Asian pink salmon run (y-1), and time period.

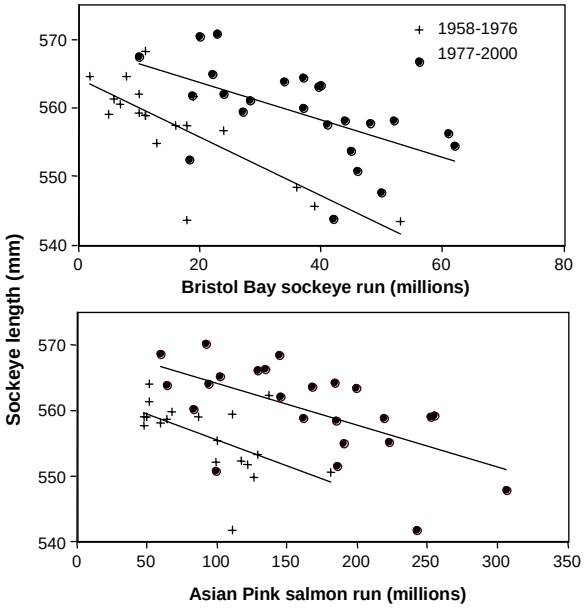


Fig. 5. Adult returns of sockeye salmon to Bristol Bay in relation to scale growth of age-2.2 Kvichak sockeye salmon during first two years at sea (lowess curve fit).

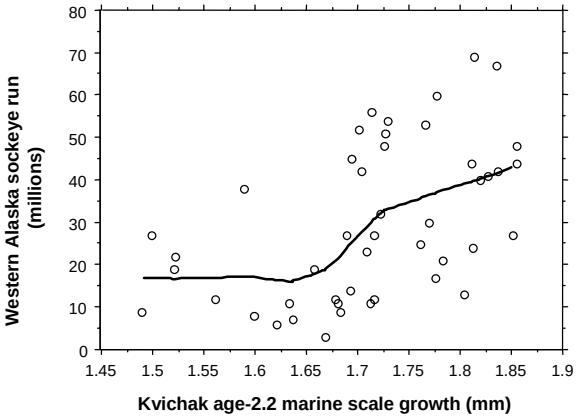
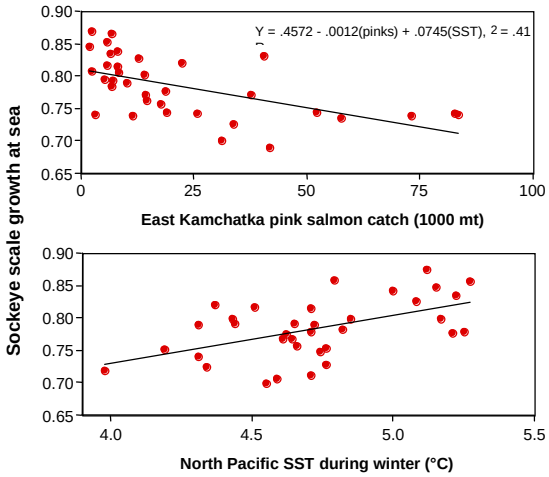


Fig. 6. Partial residual plots showing the effect of eastern Kamchatka pink salmon and North Pacific Ocean winter sea-surface temperature (°C) on Kvichak sockeye salmon scale growth during second year at sea.



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