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Implications of a Warming Bering Sea for Bristol Bay Sockeye Salmon

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The eastern Bering Sea shelf is an important nursery ground for juvenile Bristol Bay sockeye salmon (*Oncorhynchus nerka*; Farley et al. 2009) and the mechanism regulating size and condition of juvenile salmon is believed to be bottom-up control of the trophic structure (Farley et al. 2007b). A leading hypothesis for ocean productivity on the eastern Bering Sea shelf suggests that the southern extent and duration of sea ice in spring affects whether the benthic or pelagic communities benefit from spring and summer production (Hunt et al. 2002). Warmer winters with less sea ice are believed to favor pelagic productivity, potentially benefitting salmon growth and early marine survival. Changes in size, survival, distribution, diet, and growth rate potential for western Alaska salmon in response to changing spring and summer sea surface temperatures have been noted (Farley et al. 2005; Farley et al. 2007b; Farley and Moss 2009; Farley and Trudel 2009). While there is evidence that reduced size of juvenile pink (*O. gorbuscha*) and coho (*O. kisutch*) salmon leads to higher over-winter mortality (Beamish et al. 2004; Moss et al. 2005), direct evidence that the first winter at sea is the critical period for Pacific salmon that spend more than one year in the ocean has not been fully documented (i.e. sockeye salmon; Farley et al. 2007a).

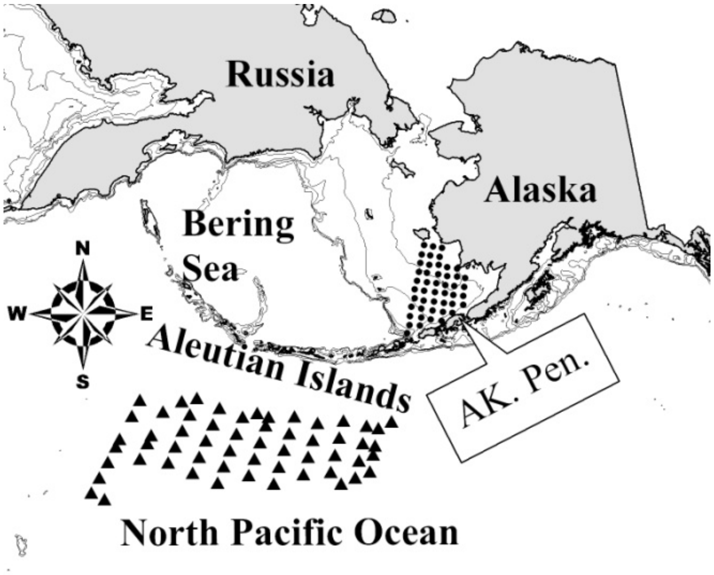

Fig. 1. Map providing examples of stations sampled by scientists with the Alaska Fisheries Science Center, Bering Aleutian Salmon International Survey project during mid August-September, 2002 to 2008 (black dots) and stations sampled by scientists with the TINRO-Center during February-March 2009 (black triangles).

Over-winter survival of Pacific salmon is believed to be a function of size and energetic status they gain during their first summer at sea. We tested this notion for Bristol Bay sockeye salmon utilizing data from large-scale fisheries and oceanographic surveys conducted during mid-August to September 2002 to 2008 by scientists with the Alaska Fisheries Science Center and during February to March 2009 by scientists with TINRO Center (Fig. 1). Genetic analysis indicated

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Table 1. Bootstrap estimates of relative abundance ($\widehat{RA}$, millions) and marine survival index ($\widehat{MSI}$) with upper and lower confindence bounds (95% confidence intervals, LCI and UCI) for juvenile sockeye salmon collected during Fall 2002 to 2007 in the eastern Bering Sea and subsequent number of adult sockeye salmon returns to Bristol Bay (millions) 2 and 3 years later. The dash (-) indicates that the LCI was below 0%.

		$\widehat{RA}$				$\widehat{MSI}$	
Year	LCI	Est	UCI	Adult Returns	LCI	Est	UCI
2002	64.2	136.9	209.6	59.2	21.1%	46.4%	71.7%
2003	98.4	181.6	264.7	33.0	8.9%	19.3%	29.6%
2004	36.3	65.8	95.4	98.4	31.6%	61.5%	91.4%
2005	160.8	338.3	515.8	49.2	7.5%	15.5%	23.6%
2006	27.2	83.4	139.5	38.6	9.6%	52.7%	95.9%
2007	46.3	359.4	672.6	41.0	-%	14.8%	36.2%

that roughly 60% of the ocean age-1 salmon captured in the North Pacific Ocean during February to March 2009 were from Bristol Bay (Table 1). The size frequency data for juvenile and ocean age-1 sockeye salmon indicates that size-selective mortality occurs for Bristol Bay sockeye salmon between fall and their first winter at sea (Fig. 2). Differences in the seasonal energetic signatures for lipid and protein suggest that these fish are not starving but instead the larger fish captured during winter appear to be utilizing energy stores to minimize predation (Fig. 3). Energetic status of juvenile sockeye salmon was also strongly related to marine survival indices (Fig. 4), and years with lower energetic status appear to be a function of density-dependent processes associated with high juvenile sockeye salmon abundance.

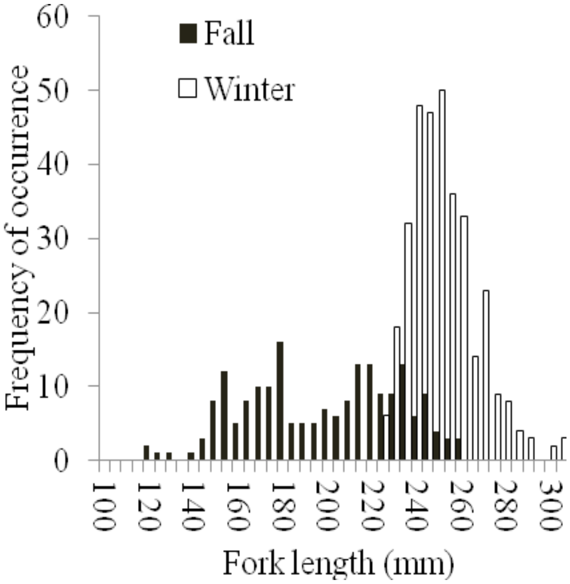

Fig. 2. Fork length frequency for juvenile sockeye salmon captured during fall 2008 (dark bar) in the eastern Bering Sea and ocean age-1 sockeye salmon captured during winter 2009 (clear bar) in the North Pacific Ocean.

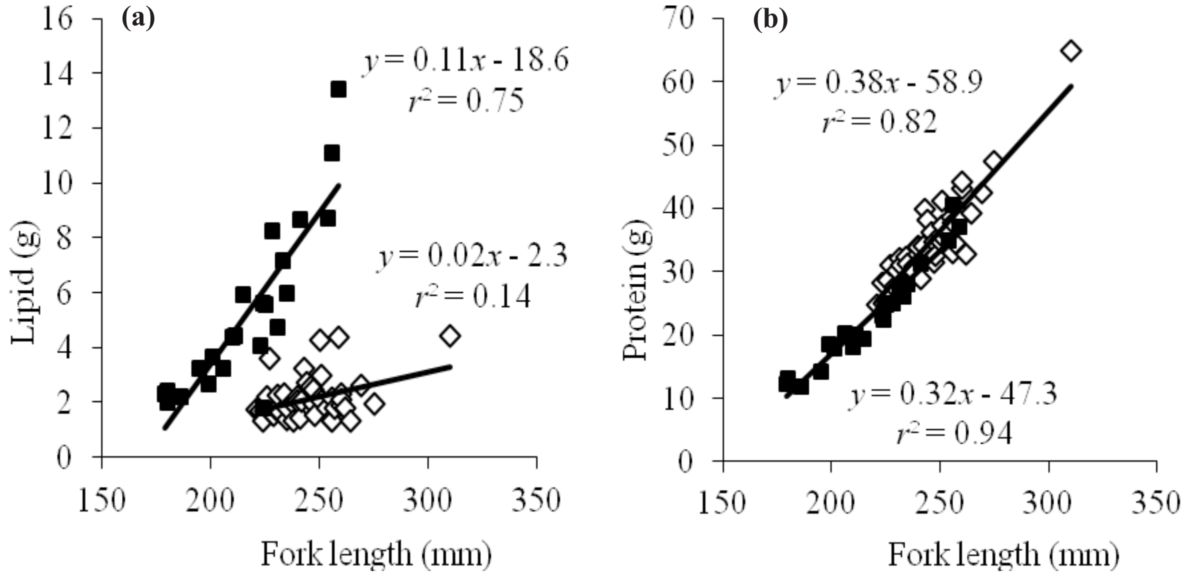

Fig. 3. The relationship between fork length (mm) and (a) lipid (g) and (b) protein (g) for juvenile (squares) and ocean age-1 (triangles) sockeye salmon collected during fall 2008 in the eastern Bering Sea and winter 2009 in the North Pacific Ocean, respectively.

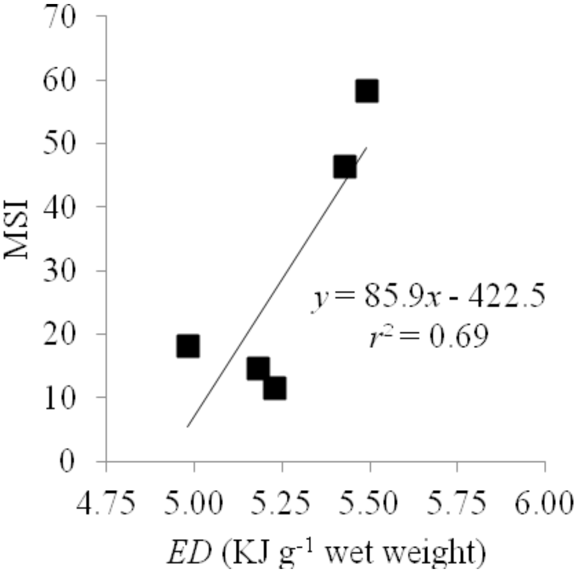

Fig. 4. The relationship between marine survival index (*MSI*) and energy density (*ED*; KJ g^{-1} wet weight) for juvenile salmon captured during fall 2003 to 2007 in the eastern Bering Sea.

It is generally agreed that the Bering Sea will continue to warm up (Christensen et al. 2007), thus there is an expectation for continued healthy returns of sockeye salmon to Bristol Bay watersheds (e.g. Farley et al. 2007b; Farley et al. 2007c). Many juvenile salmon and, in particular, juvenile sockeye salmon relied heavily on age-0 walleye pollock for prey during years with anomalously warm sea temperatures (Farley et al. 2009). However, there is new evidence that extended periods of warming may reduce the availability of lipid-rich crustacean zooplankton, negatively impacting walleye pollock recruitment (Hunt et al. 2011). This result suggests that continued high sea temperatures could reduce the availability of age-0 pollock, causing juvenile sockeye salmon to seek other, potentially lipid-poor prey items. In addition, a previous analysis suggested that if summer sea temperatures were increased by 5°C, the largest decrease in growth rate potential for juvenile Bristol Bay sockeye salmon would occur during years where observed sea temperatures (2000 to 2006) were already anomalously warm (Farley and Trudel 2009). Thus, under a climate warming scenario, we hypothesize that sustained increases in sea temperatures above those observed during 2002 to 2005 may impact the energetic status and growth rate potential for juvenile Bristol Bay sockeye salmon, potentially leading to increased overwinter mortality.

Note—The full article for this extended abstract was published in ICES Journal of Marine Science–Farley et al. 2011 doi:10.1093/fsr021.

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