Size-Selective Mortality of Bristol Bay Sockeye Smolts in Relation to Smolt Characteristics, Ocean Conditions, and Sockeye Salmon Productivity

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Mortality of salmon in the ocean is generally believed to be size-selective in which smaller, slower growing fish are less likely to survive (e.g., Moss et al. 2005); however, relatively little is known about the degree to which size-selective mortality varies over decades and is related to ocean conditions, climate shifts, and salmon smolt characteristics. We are currently investigating size-selective mortality of Bristol Bay sockeye salmon, and here we present preliminary findings on Kvichak sockeye salmon. Kvichak River sockeye salmon is the most abundant sockeye stock in the North Pacific (producing annual runs up to 48 million fish), and in some peak-cycle years the Kvichak watershed produced more than 50% of the North Pacific's sockeye salmon (Eggers and Rogers 1987; Ruggerone and Link 2006). Beginning with the 1991 brood year and the adult return in 1995, however, productivity of the Kvichak stock averaged less than one return per spawner (R/S), leading the State of Alaska to classify Kvichak sockeye salmon as a Stock of Concern, even though the habitat was relatively pristine and managers eliminated direct harvests and reduced incidental harvests. The stock has begun to recover in recent years (Morstad and Brazil 2012).

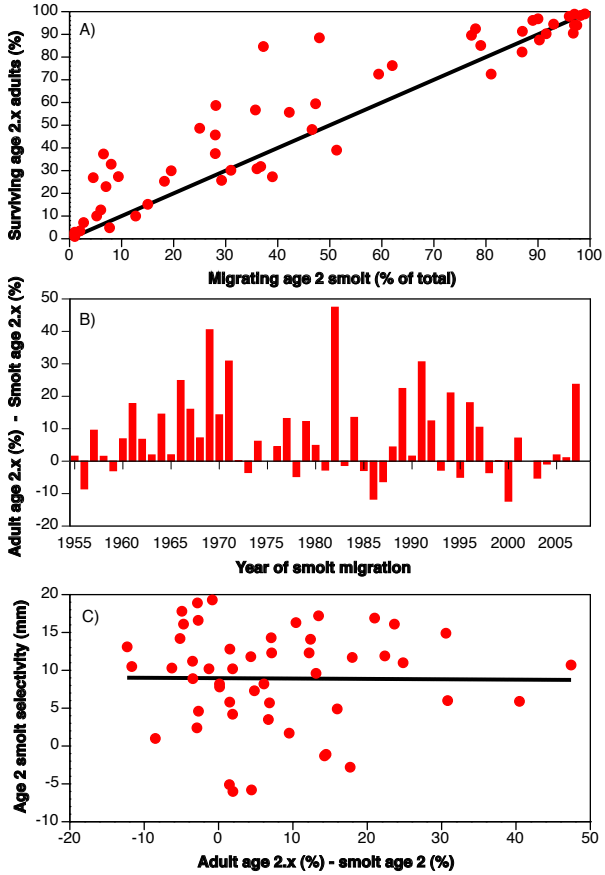

Fig. 1. Tests to examine whether there was significant avoidance of the fyke net by larger age-2 sockeye salmon smolts in the Kvichak River, Bristol Bay, Alaska. All values are aligned by year of smolt migration. For panel C, a positive slope is expected if selectivity of age-2 smolts was significantly affected by avoidance of the net by large smolts. Tests show that age-2 smolts have higher survival than age-1 smolts, as expected, but there was no evidence of significant net avoidance.

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We estimated the degree of size-selective mortality of age-1 and age-2 smolts as follows:

(1) Selectivity (mm) = Length of surviving smolts (mm) - Length of migrating smolts (mm).

Mean lengths of age-1 and age-2 sockeye salmon smolts migrating in the Kvichak River from 1955 to 2008 were obtained from annual smolt reports produced by the Alaska Department of Fish and Game and other agencies (e.g., Kerns 1961; Paulus and Parker 1974; Wade et al. 2013). Smolt sampling methods using a fyke net in the Kvichak River have remained largely unchanged over the years (Crawford and Tilly 1995). Net avoidance studies were conducted in the 1960s to minimize net avoidance by larger smolts (e.g., age-2 fish; Kerns 1961). Field crews consistently placed the net in the fastest water possible without losing the net (> 0.9 m/s). We re-examined potential net avoidance by larger age-2 smolts during the past five decades but found little evidence that avoidance might bias the patterns of size-selective mortality (Fig. 1).

To estimate the size of Kvichak sockeye salmon smolts that survived two or three years at sea, we developed a smolt length/scale radius regression and back-calculated size of age-1 and age-2 smolts from adult sockeye scales collected from 1957 to 2010. Smolt scales were collected using scrapes from the preferred scale area (versus single scales from the preferred area among adults); therefore, a small correction (3%) was made to the smolt scale measurements based on analysis of scrape versus individual scale data provided by Clutter and Whitesel (1956). Analysis of covariance and visual plots did not indicate different relationships with respect to sockeye salmon stock (five stocks) or year of smolt migration (five years). Length-at-age of surviving sockeye salmon smolts was calculated from the weighted mean of 50 freshwater scale measurements from each major adult age group per year (up to 200 scales per year).

Mean length of emigrating age-1 and age-2 sockeye salmon smolts averaged 87 mm and 107 mm, respectively, during smolt years 1955-2008. Mean length of migrating smolts were smaller and less variable after the mid-1970s. Mean length of surviving age-1 and age-2 smolts (back-calculated from adult scales) after two or three years at sea was 101 mm and 116 mm, respectively. Length of survivors was variable from year to year, but we observed no clear trend over time. Length of surviving smolts increased with length of the migrating smolts, but the slope was less than one indicating less benefit of greater size at the higher end of both smolt age groups.

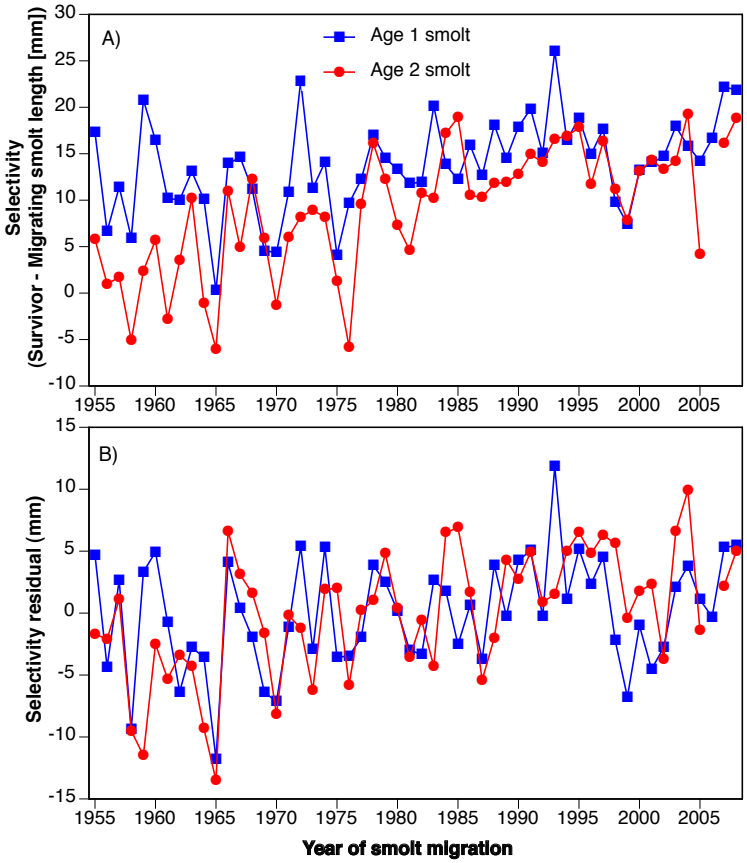

Fig. 2. Selectivity (A) and selectivity standardized for length of emigrating Kvichak River sockeye salmon smolts (B), 1955-2008. Panel (B) values are the residuals of the regressions shown in Fig. 3.

Selectivity of the sockeye salmon smolt age groups was correlated over the 54-year period, and it was consistently higher for age-1 smolts (average 14 mm) versus age-2 smolts (9 mm), as expected, because younger smaller fish are likely to experience greater size-selective mortality. Selectivity tended to be somewhat low and highly variable during the 1950s to early 1970s, then increased after the mid-1970s and became somewhat less variable (Fig. 2A). The high variability in the early period reflects, in part, the high variability in parent spawning escapement, juvenile abundance in the lakes, and length-at-age.

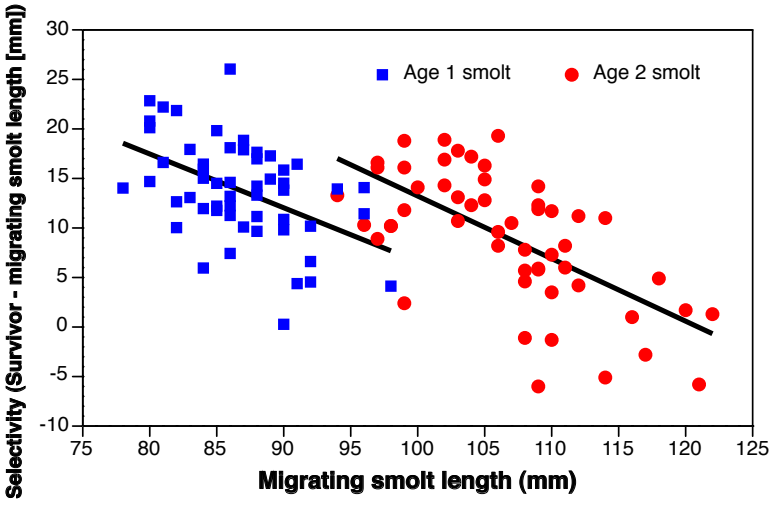

Fig. 3. Selectivity of age-1 and age-2 Kvichak River sockeye salmon smolts in relation to length of migrating smolts.

Selectivity of age-1 and age-2 sockeye salmon smolts declined with mean length of emigrating smolts, as expected (Fig. 3). However, when mean length of age-1 and age-2 migrating smolts overlapped, selectivity was less for age-1 versus age-2 smolts, perhaps reflecting the greater fitness of rapidly growing age-1 smolts versus slower growing age-2 smolts of the same body size. Using the regressions in Fig. 3, we standardized selectivity for length of migrating smolts (i.e., residual of the regressions). Standardized selectivity tended to be low and variable during the early period followed by somewhat higher selectivity after the mid-1970s and lower selectivity during 1998 to 2002, i.e., the years immediately following the strong 1997/1998 El Niño (Fig. 2B).

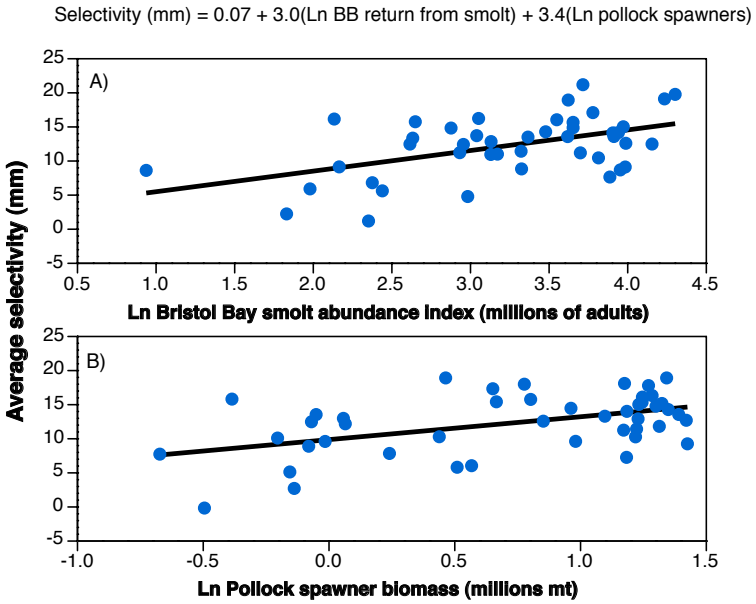

Fig. 4. Multi-variate relationship between average selectivity of age-1 and age-2 Kvichak River sockeye salmon smolts in relation to (A) an index of total sockeye salmon smolts entering the southeastern Bering Sea (based on adult returns from each smolt year) and to (B) an index of age-0 pollock (sockeye prey) during the year of smolt migration, 1964-2008. Both independent variables were significant ($p < 0.05$); overall variability explained by smolt abundance and pollock was 45% (adjusted R^2). Serial autocorrelation of model residuals (0.12) was non-significant.

We plan to conduct additional tests to further examine factors affecting selectivity and how the selectivity index may be related to sockeye salmon productivity. Initial preliminary analyses indicated selectivity of Kvichak sockeye was higher during years of high total sockeye smolt abundance entering the southeastern Bering Sea (Fig. 4A), perhaps reflecting early marine density-dependent growth and survival of sockeye salmon, as indicated by a recent study in the Bering Sea (Farley et al. 2011). Selectivity was also correlated with an index of age-0 pollock abundance in the southeastern Bering Sea in a multivariate regression that included abundance of Bristol Bay sockeye salmon smolts as an independent variable (Fig. 4B). This relationship might reflect an advantage for larger sockeye smolts when juvenile pollock are abundant because larger sockeye salmon eat larger, more energetic juvenile pollock which can be a highly important prey in warm water years (Farley et al. 2004; Farley and Trudel 2009; Farley et al. 2009, 2011).

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