Do Asian Pink Salmon Affect the Survival of Bristol Bay Sockeye Salmon?

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The abundance of pink salmon and chum salmon in the subarctic North Pacific Ocean are at historically high levels (Eggers 2009; Irvine et al. 2009; Ruggerone et al. 2010a). This increased abundance has raised concerns that density dependent interactions in the ocean may reduce growth and survival of conspecifics and associated salmon species (Ruggerone and Neilson 2004; Helle et al. 2007; Ruggerone et al. 2010a). Ruggerone et al. (2003) found that competition between Asian pink salmon and Bristol Bay sockeye salmon reduced the growth of sockeye salmon. They suggested average sockeye smolt-to-adult survival rates for three large stocks (Kvichak, Egegik, and Ugashik) outmigrating in 1977-1997 were significantly lower for smolts entering the ocean during even-numbered years and interacting with abundant odd-year Asian pink salmon than for smolts entering the ocean during odd-numbered years (Fig. 1). However, their analysis did not link smolt survival directly to the highly variable annual abundance of Asian pink salmon. If the large variation in average odd- and even-year smolt survival was caused by the differences in average odd- and even-year pink salmon abundances, we would expect the actual annual abundance of pink salmon to have a significant and measurable impact on annual variation in smolt survival.

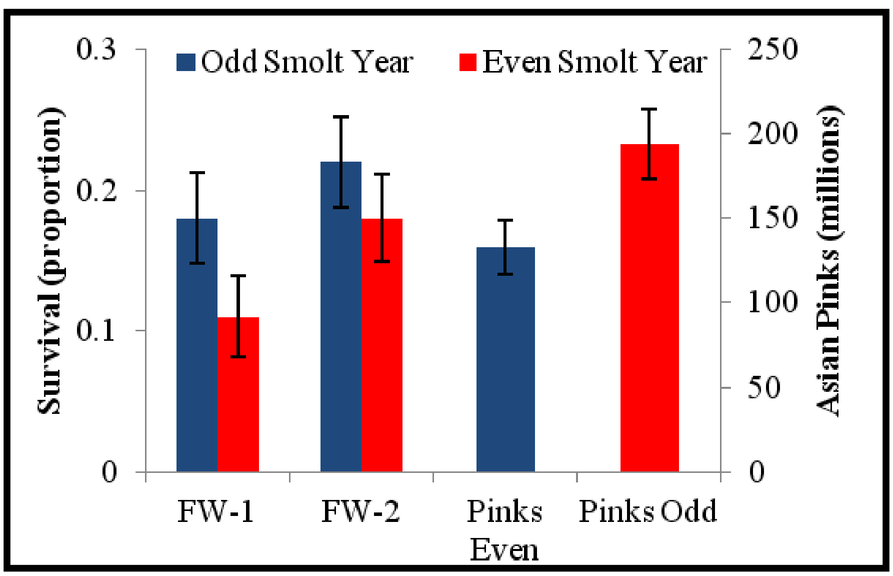

Fig. 1. Average smolt-to-adult survival for three Bristol Bay sockeye salmon stocks (Kvichak, Egegik, and Ugashik) for the smolt years 1977-1997 and corresponding adult Asian pink salmon abundance. Error bars are SE of means.

The objectives of this paper were to (1) revisit the 1977-1997 smolt data to evaluate the effect of Asian pink salmon abundance on Bristol Bay sockeye salmon smolt survival and (2) use juvenile salmon data from the Bering-Aleutian Salmon International Survey (BASIS) and corresponding adult returns to examine the effects of Asian pink salmon abundance on survival and returns of Bristol Bay sockeye salmon for the smolt years 2002-2007 (the smolt year is when smolts out-migrate to the ocean).

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Sockeye Salmon Smolt Years 1977-1997

To evaluate 1977-1997 sockeye salmon smolt survival, we used the same data sets as Ruggerone et al. (2003). Sockeye salmon smolt numbers and corresponding adult returns were provided by the Alaska Department of Fish and Game (ADFG; personal communication, Lowell Fair, 333 Raspberry Road, Anchorage, AK 99518) for the Kvichak River (smolt years 1977-1997); Egegik River (smolt years 1982-1997); and Ugashik River (smolt years 1983-1997). Asian pink salmon abundance data were from Rogers (2001). We compared four models to examine if pink abundance affects sockeye salmon survival by stock and smolt age and for the three stock average: simple regression (no temporal trend in survival); autoregressive 1 (AR(1) annual trend in survival); autoregressive 2 (AR(2) biennial trend in survival); and autoregressive 1,2 (AR(1,2), accounting for both annual and biennial trends in survival). We transformed survival data for the analysis using the arcsine square root and used the corrected Akiake Information Criterion (AIC_c; Shono 2000) to compare alternate models.

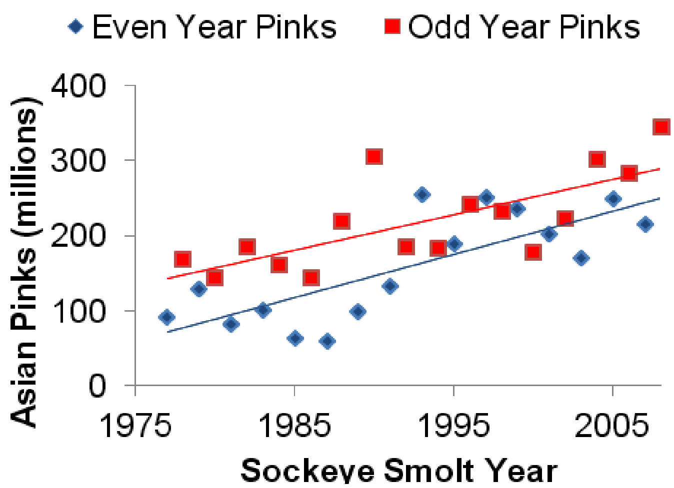

Fig. 2. Abundance of odd- and even-year Asian pink salmon compared with abundance of sockeye salmon for the smolt years 1997-2008.

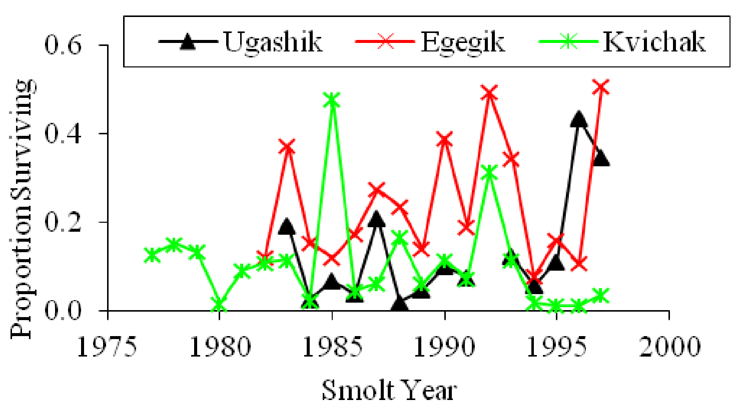

Fig. 3. Smolt-to-adult survival for three Bristol Bay sockeye salmon stocks for the smolt years 1977-1997.

During the smolt years 1977-1997, Asian pink salmon increased in abundance over time for both the odd and even lines (Fig. 2), but there was no consistent trend in the survival of the three sockeye salmon stocks (Fig. 3). Survival was not significantly ($p > 0.1$) correlated between stocks; survival was positively correlated with time for the Egegik and Ugashik stocks and negatively correlated with time for the Kvichak stock (Table 1). Temporal correlations were significant only for Ugashik sockeye survival ($p = 0.06$) and pink salmon abundance ($p < 0.01$). The AIC_c comparisons indicated that the AR models fit survival data better than the simple regression model and that the AR(1,2) model did not improve the fit (Table 2).

The AR(1) and AR(2) models had virtually identical AIC_c values for all stock/age combinations (differences < 0.5), except for Egegik age-1 smolts for which the AIC_c value of the AR(1) was more than 3 points lower (Table 2). For both the AR(1) and AR(2) models, the coefficients for pink salmon abundance (indicating effect of pinks) were negative for the Kvichak stock, positive for the Egegik and Ugashik stocks, and positive for the three stock average; significance levels are shown in Fig. 4.

Table 1. Cross-correlation matrix of correlation coefficients (r) for Bristol Bay sockeye smolt survival, Asian pink abundance, and time for the smolt years 1977-1997.

	Year	Kvichak	Egegik	Ugashik
Kvichak	-0.19			
Egegik	0.22	0.17		
Ugashik	0.51[1]	-0.25	0.34	
Pinks	0.57[2]	-0.23	0.34	0.27

[1]$p = 0.06$ [2]$p < 0.01$

Table 2. Akiake information criterion (AIC_c) values (corrected for small sample sizes) for simple regression (Regr) and autoregressive models (AR(1), AR(2), and AR(1,2)) of sockeye smolt-to-adult survival as a function of Asian pink abundance. Sockeye salmon survival stratified by stock and smolt age and the three-stock average. Lowest values within 0.5 of each other are shown in the grey area for each stock/age group.

Stock/Age	Regr.	AR(1)	AR(2)	AR(1,2)
Kvichak-1	-10.4	-32.5	-32.1	-29.1
Kvichak-2	-11.3	-32.3	-32.3	-32.3
Egegik-1	-1.2	-26.1	-29.5	-27.8
Egegik-2	-0.7	-35.1	-35.3	-32.9
Ugashik-1	-8.0	-27.1	-27.0	-23.6
Ugashik-2	-4.7	-27.6	-26.8	-24.3
3-stock average	-32.6	-45.0	-44.6	-44.5

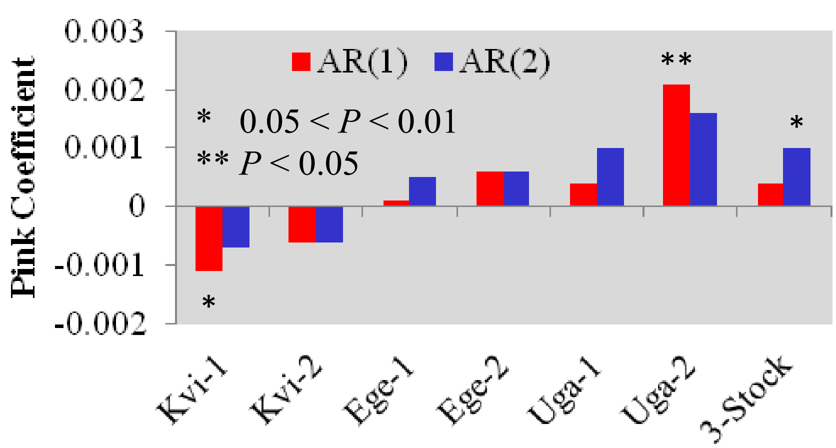

Fig. 4. Coefficients for the effect of Asian pink salmon abundance on survival of sockeye salmon by stock and smolt age for AR(1) and AR(2) time-series models.

In all cases, the autoregressive coefficients for the models were not significant ($p > 0.1$), which suggests the regression (no trends) model may be more appropriate even with higher AIC_c values. The results for the pink salmon coefficient were the same for the regression model as for the autoregressive models (for both smolt ages, Kvichak negative, Egegik and Ugashik positive; positive for the three-stock average), but none of the coefficients for pink abundance were significant ($p > 0.1$).

Our results show no consistent response of smolt survival among the three Bristol Bay sockeye stocks in relation to Asian pink salmon abundance. This could be caused by actual stock-specific differences in response to Asian pink salmon. Seeb et al. (2010) have shown differences in ocean distributions of Bristol Bay sockeye salmon, so the stocks could have differential overlap with, and response to, Asian pink salmon. The negative response of the Kvichak stock could be driven by density-dependent growth consistent with Ruggerone et al. (2003). The positive response of the other stocks could be a compensatory effect of predator sheltering by the more abundant pink salmon that results in increased survival of Egegik and Ugashik sockeye salmon. A more simplistic explanation is that the relationships between sockeye survival and pink abundance are artifacts of increasing pink numbers and stock-specific survival patterns driven by other factors. Regardless of the mechanism, our results for the smolt years 1977-1997 show no net reduction in sockeye smolt survival due to Asian pink salmon abundance.

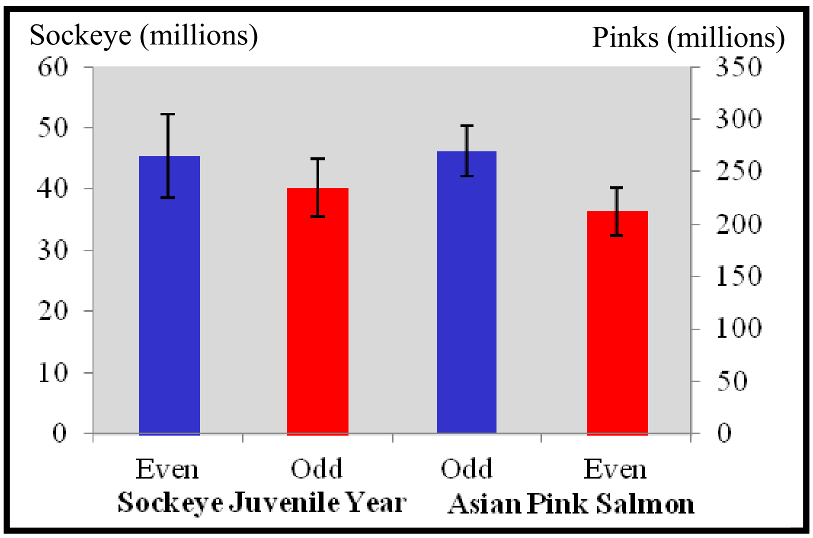

Fig. 5. Average Bristol Bay adult sockeye returns and Asian adult pink salmon abundances in odd and even years for the smolt years 2002-2007. Error bars are SE of means.

Sockeye Salmon Smolt Years 2002-2007

Estimates of juvenile Bristol Bay sockeye salmon abundance in the Bering Sea were available for the smolt years 2002-2007 (Farley et al. 2009). Corresponding adult return data were provided by ADFG. An index of sockeye salmon marine survival from juvenile-to-adult was calculated by dividing the estimate of juvenile abundance by the number of adults returning. Asian pink salmon data were extended to this time period using the data and methods of Ruggerone et al. (2010b).

Average Bristol Bay sockeye salmon adult returns for this time period were higher for even-year smolts, even though the odd-year pink salmon they encountered in the first ocean winter were also more abundant (Fig. 5). The index of juvenile sockeye salmon survival was higher for even-year juveniles during 2002-2007, and the survival index was positively correlated with pink salmon abundance (Fig. 6). These results are contradictory to the hypothesis that even-year sockeye smolts encountering more abundant odd-year pink salmon will have reduced survival due to density-dependent interactions.

We conclude, based on our results from both time periods, there is no discernable negative impact of Asian pink salmon on smolt-to-adult survival of Bristol Bay sockeye salmon.

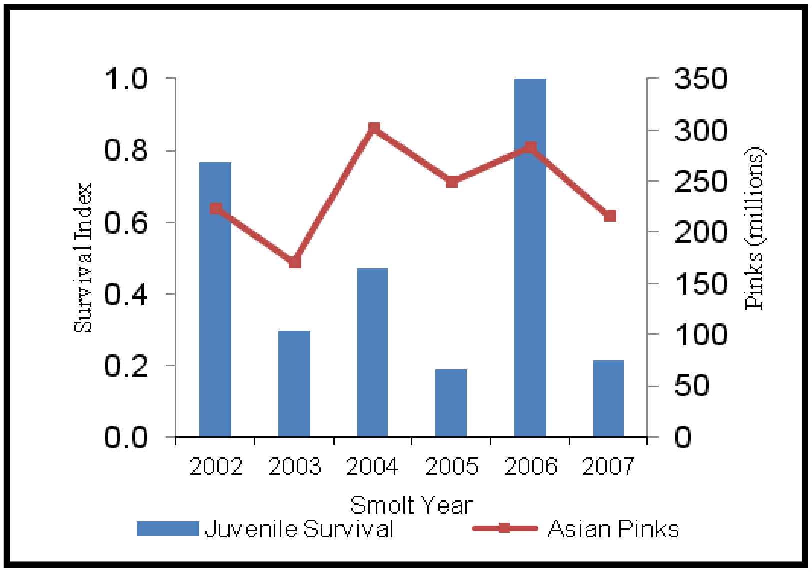

Fig. 6. Comparison of the Bristol Bay juvenile sockeye survival index and Asian pink salmon abundance for the smolt years 2002-2007.

The conclusion that there is no discernable negative impact of Asian pink salmon on ocean survival of Bristol Bay sockeye salmon is challenged by Ruggerone et al. (this report) by their questioning the validity of our correlation analyses (and by extension, our regression and time-series analyses) and asserting that comparison of odd- and even- year smolt survival of Bristol Bay sockeye salmon (Ruggerone et al. 2003) is a more robust approach to analyzing these data. We disagree that our use of data is inappropriate or that our analytical approach is less robust than odd-/even-year averaging of smolt survival.

Ruggerone et al. (this report) state that our correlation analyses are confounded because environmental conditions influence the degree to which Asian pink salmon interact or affect Bristol Bay sockeye salmon and because of measurement error in the time series of Asian pink salmon abundance and Bristol Bay sockeye salmon. Concerns for environmental noise and measurement error affecting the power of correlation analyses are certainly valid. However, Ruggerone et al. (2003) used correlation analysis to establish a statistical connection between Bristol Bay sockeye salmon scale growth and Asian pink salmon abundance. The use of correlation analysis for similar time series with unknown measurement errors is ubiquitous in Ruggerone et al. (this report) to support the concept of density-dependence. Ruggerone et al. (2003) also used the Bristol Bay smolt data in an analysis of variance to statistically evaluate the average survival of odd- and even- year smolts, without concern for measurement error. Our application of statistical analyses to these data is consistent with and as credible as those of Ruggerone et al.

Our time series approach is a much better approach for determining if the abundance of Asian pink salmon affects Bristol Bay sockeye salmon smolt survival than the odd-/even-year averaging approach used by Ruggerone et al. (2003). Both pink salmon abundance and sockeye smolt survival have varied considerably over time (Figs. 2 and 3). Our time series analysis examines both for trends in survival and the effect of abundance on survival, with the explicit hypothesis that abundance in a given year has some effect on survival in that year. Environmental factors can certainly influence the relationship, but over time, if the large effects of pink salmon abundance asserted by Ruggerone et al. (2003) are occurring, we should be able to detect the abundance effect. The odd-/even-year averaging approach, in contrast, unlinks the actual abundance of pink salmon from the response variable, smolt survival. The same criticism, that environmental factors can influence the degree to which pink salmon abundance affects survival, applies to this approach. But in this case, very high or very low survival rates have a large weighting affect on the analysis, regardless of the magnitude of pink salmon abundance in the year in which survival anomalies occur.

In closing, we stand by our analyses, results, and conclusions. Our use of the data series is consistent with what has been established in the scientific literature by Ruggerone et al. (2003), and our analytical approach is an improvement in evaluating the impact of Asian pink salmon on Bristol Bay sockeye salmon smolt-to-adult survival.

REFERENCES

Eggers, D.M. 2009. Historical biomass of pink, chum, and sockeye salmon in the North Pacific Ocean. Am. Fish. Soc. Symp. 70: 267-305.

Farley, E.V., J. Murphy, J. Moss, A. Feldmann, and L. Eisner. 2009. Marine ecology of western Alaska juvenile salmon. Am. Fish. Soc. Symp. 70: 307-329.

Helle, J.H., E.C. Martinson, D.M. Eggers, and O. Gritsenko. 2007. Influence of salmon abundance and ocean conditions on body size of Pacific salmon. N. Pac. Anadr. Fish Comm. Bull. 4: 289-298. (Available at www.npafc.org).

Irvine, J.R., M. Fukuwaka, T. Kaga, J.H. Park, K.B. Seong, S. Kang, V. Karpenko, N. Klovach, H. Bartlett, and E. Volk. 2009. Pacific salmon status and abundance trends. N. Pac. Anadr. Fish Comm. Doc. 1199, Rev. 1. 153 pp. (Available at www.npafc.org).

Rogers, D.E. 2001. Estimates of annual salmon runs from the North Pacific, 1951-2001. Univ. Washington, School of Aquatic Sciences, SAFS-UW-0115, Seattle. 11 pp. (Available at https://digital.lib.washington.edu/researchworks/handle/1773/3783).

Ruggerone, G.T., and J.L. Nielsen. 2004. Evidence for competitive dominance of pink salmon (*Oncorhynchus gorbuscha*) over other salmonids in the North Pacific Ocean. Rev. Fish Biol. Fish. 14: 371–390.

Ruggerone, G.T., M. Zimmermann, K.W. Myers, J.L. Nielsen, and D.E. Rogers. 2003. Competition between Asian pink salmon and Alaskan sockeye salmon in the North Pacific Ocean. Fish. Oceanogr. 3: 209–219.

Ruggerone, G.T., R.M. Peterman, B. Dorner, and K.W. Myers. 2010a. Magnitude and trends in abundance of hatchery and wild pink salmon, chum salmon, and sockeye salmon in the North Pacific Ocean. Mar. Coast. Fish. Dynam. Manage. Ecosys. Sci. 2: 306–328.

Ruggerone, G.T., R.M. Peterman, B. Dorner, K.W. Myers, and N.J. Mantua. 2010b. Abundance of adult hatchery and wild salmon by region of the North Pacific. Univ. Washington, School of Aquatic and Fishery Sciences, SAFS-UW 1001, Seattle. (Available at https://digital.lib.washington.edu/researchworks/handle/1773/3783).

Seeb, L.W., J.E. Seeb, C. Habicht, E.V. Farley, and F.M. Utter. 2010. Single-nucleotide polymorphic genotypes reveal patterns of early juvenile migration of sockeye salmon in the eastern Bering Sea. Trans. Am. Fish. Soc. 140(3): 734-738.

Shono, H. 2000. Efficiency of the finite correction of Akaike's information criteria. Fish. Sci. 66: 608-610.