**Growth and Harvest Forecast Models for Southeast Alaska Pink Salmon**

**James M. Murphy1, Emily A. Fergusson1, Andrew Piston2, Andrew Gray1, and Edward Farley1**

*1 NOAA Fisheries, Alaska Fisheries Science Center, Auke Bay Laboratories, 17109 Point Lena Loop Road, Juneau, Alaska, 99801, USA*

*21Alaska Department of Fish and Game, Division of Commercial Fisheries, 2030 Sea Level Drive, Ketchikan, AK 99901*

Keywords: pink salmon, *Oncorhynchus gorbuscha,* Southeast Alaska, juvenile abundance, juvenile growth

Growth and harvest forecast models are used to provide insight into the role of temperature in the early marine ecology of Southeast Alaska (SEAK) pink salmon (*Oncorhynchus gorbuscha)*. The onset of the Gulf of Alaska marine heatwaves in 2014-2015 (Bond et al. 2015) has highlighted the importance of understanding the resilience of salmon to warming climate as the frequency and magnitude of marine heatwaves are expected to increase with warming Arctic conditions (DiLorenzo and Mantua 2016). Pre-season harvest forecasts using adult pink salmon data have been a persistent challenge due to the presence of a single adult age and high variation in spawner-recruit relationships. Juvenile models have been developed to assist harvest forecasts for SEAK pink salmon (Orsi et al. 2016, Wertheimer et al. 2018, Murphy et al. 2019) using data collected during Southeast Coastal Monitoring (SECM) surveys (Murphy et al. 1999, Orsi et al. 2016, Fergusson et al. 2019) and have become the primary tool used for pre-season harvest guidance in SEAK pink salmon fisheries. Temperature is an important environmental covariate in the harvest forecast model, but it is unclear how it contributes to the forecast performance (Murphy et al. 2019). Although environmental conditions are often used to account for changes in survival, they also play an important role in the distribution and migration of salmon. These two ecological processes are confounded within the harvest model as juvenile abundance is measured with catch-per-unit-effort (CPUE) data. Growth models are developed to provide ecological insight into the role of temperature in their growth and survival. Otolith thermal mark recoveries of hatchery chum salmon are included to give insight into the general migratory pattern of SEAK juvenile salmon. Finally, northern Bering Sea juvenile abundance models are included to add insight into critical periods in the marine survival of Alaskan pink salmon.

Data on juvenile salmon associated oceanographic and ecosystem indicators have been collected during SECM surveys since 1997 within the northern region of SEAK (Fergusson et al. 2019). Data from eight station along two transects in Icy Strait (Fig. 1) are used in harvest and growth models of SEAK pink salmon. Oceanographic data collected at these stations consist of a conductivity-temperature-depth (CTD) profiles of temperature (°C) and salinity (PSU), a water sample for chlorophyll-a (ug/L), and a 60-cm bongo net tow for zooplankton. The overall average 20-m integrated water column temperature was used to estimate the Icy Strait Temperature Index (ISTI) (May-Aug and May-Jul). Fish were sampled at each station with a NETS Nordic 264 rope trawl fished for 20 min at each station at least one time during June-August with tow speeds of approximately 1.5 m/sec resulting in a typical fishing dimensions of 18 m wide by 24 m deep.

Peak monthly (June and July) juvenile catch-per-unit-effort (CPUE) and associated environmental variables were used in a multiple linear regression model to forecast harvest based on the approach described in Wertheimer et al. (2006). CPUE was standardized to 20 minute trawl set and calibrated to the NOAA Ship John N. Cobb, based on fishing power experiments (Wertheimer et al. 2010). The model was defined as:

,

where *γ* is the coefficient for environmental covariates X (e.g., water temperatures, climate indices, fish size and condition) and *ε* is the normally distributed error term. A backward/forward stepwise regression model selection procedure identified candidate models via Akaike Information Criterion (AIC) and small sample AIC (AICc). Mean and Median Absolute Percentage Error (MAPE, MEAPE) statistics from jackknife cross validations were used to define forecast accuracy of candidate models, and the harvest forecast was based on the 80% bootstrap confidence interval of the model with the highest forecast accuracy. A two-parameter model, including CPUE and the Icy Strait Temperature Index (ISTI), has been the most consistently selected model over time and accounts for 78% (*R2*) of the variability in harvest data (Fig. 2, Table 1). Temperature is a significant negative covariate in the model and partial residuals identify a simple linear relationship between temperature and harvest across the range of observed temperatures (Fig. 2). A linear relationship is more consistent with a simple ecological process such as temperature effects on juvenile distribution and migration; a threshold or non-linear relationship may be more likely if temperature is altering ecological rate processes.

A similar stepwise model selection approach was used to identify environmental variables important to juvenile pink salmon growth. Year-to-year variation in juvenile pink salmon growth was approximated by their length (fork length) standardized to July 24th based on their apparent growth rate between the June and July SECM surveys. A two-parameter model including May chlorophyll (ug/L) and the May-July ISTI index was identified as the best fitting model to average annual size of juvenile pink salmon. The model accounted for 71% (Adjusted *R2*) of the variability in the year-to-year variation in the average size of juvenile pink salmon, 1997-2018, and 82% of the variability from 1997-2015 (Fig. 3 Table 2). May chlorophyll data were not available in 2016 and 2017. The poor fit of the model in 2018 is likely due to the late outmigration timing of juvenile pink salmon (Scott Vulstek, personal communication), which highlights complications of modeling juvenile growth with size data. The essential point of this growth model is that temperature is a significant positive covariate, the opposite effect in the harvest model. Reconciling the effect of temperature in the growth and harvest models leads to the inference that growth and survival of pink salmon are not linked, or that ecological processes other than survival are contributing to the significance of temperature in the harvest model. The temperature effect in the harvest model may simply reflect changes in juvenile migration.

Otolith thermal marks of juvenile chum salmon recovered during SECM surveys provide some insight into the migratory pattern expected for SEAK pink salmon (Table 3). Hatchery chum salmon origins vary by month with the stocks closest to Icy Strait (DIPAC) accounting for the largest proportion in June, hatchery stocks from the middle region of SEAK (NSRAA) reach their peak in July, and stocks furthest away from Icy Strait (SSRAA) reach their highest proportion in August. This highlights that at least some proportion of juvenile salmon from all regions of SEAK migrate through Icy Strait, and changes in the overall migration of juveniles can alter the relationship between juvenile CPUE and their abundance. The combination of trawl CPUE and temperature may be a more accurate measure of juvenile abundance than trawl CPUE data alone if the proportion of SEAK juveniles that migrate through Icy Strait (the northern migration corridor) increases in warm years. If true, this significantly increases the importance of the initial or early marine life-history stage to the overall marine survival of SEAK pink salmon.

Juvenile abundance models from the northern Bering Sea provide insight into the importance of the early marine life-history stage of pink salmon to their marine survival. Surface trawl catch rates from the northern Bering Sea trawl surveys (Fig. 4) were used to construct an index of juvenile pink salmon abundance as:

,

where *CPUEi* is the catch-per-unit-effort at station *i*, *θ* is the mixed-layer-depth (MLD) adjustment, and *I* is the total number of stations sampled by year. Effort is the area swept by the trawl in km2, and the MLD adjustment, θ, is:

where *Ci* is catch of juvenile pink at station, *i*, *M*i, is the ratio of MLD to trawl depth when trawl depth is shallower than mixed layer depth, and 1.0 when trawl depth is below the mixed-layer depth, and *I* is the total number of stations sampled in that year (Murphy et al. 2017). This juvenile abundance index explains 73% (R2=73%) of the year-to-year variability in adult returns to Norton Sound and the Yukon River (Fig. 5, Table 4), highlighting the importance of the early or initial marine life-history period to the marine survival of pink salmon in the northern Bering Sea.

Critical periods in the natural mortality schedule of salmon are important to our understanding of their underlying production dynamics and the scientific advice provided to fisheries management. The initial or early marine period of juvenile pink salmon has largely been believed to be the primary determinant of year-class strength (Parker 1968; Mortensen et al. 2000; Willette et al. 2001; Wertheimer and Thrower 2007) due to the high and variable mortality that occurs during this stage. The importance of the initial marine period to the survival of SEAK pink salmon increases and the negative influence of temperature on survival decreases if trawl CPUE and temperature are used together as an index of juvenile abundance. The inability to identify the origin of juvenile pink salmon limits attempts to test the role of temperature within the harvest forecast model; however, the data included here provide ecological support for interpreting temperature as a measure of juvenile migration and that CPUE and temperature should be used as an index of juvenile abundance.

**REFERENCES**

Bond, N. A., M. F. Cronin, H. Freeland, and N. Mantua. 2015. Causes and impacts of the 2014 anomaly in the NE Pacific. Geophysical Research Letters 42: 3414–3420.

Di Lorenzo, E. and N. Mantua. 2016. Multi-year persistence of the 2014/15 North Pacific marine heatwave. Nature Climate Change 6:1042.

Fergusson, E.A., J. Watson, A. Gray, and J. Murphy. 2019. Annual survey of juvenile salmon, ecologically-related species, and biophysical factors in the marine waters of southeastern Alaska, May–August 2017. NPAFC Doc. 1847. 43 pp. National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center, Auke Bay Laboratories, Ted Stevens Marine Research Institute (Available at <https://npafc.org>).

Mortensen, D. G., A. C. Wertheimer, S. G. Taylor, and J. H. Landingham. 2000. The relation between early marine growth of pink salmon, *Oncorhynchus gorbuscha*, and marine water temperature, secondary production, and survival to adulthood. Fishery Bulletin 98:319–335.

Murphy, J. M., A. L. Brase, and J. A. Orsi. 1999. Survey of juvenile Pacific salmon in the northern region of southeastern Alaska, May–October 1997. U. S. Dept. of Commer. NOAA Tech. Memo NMFS-AFSC-105, 40p.

Murphy, J., K. G. Howard, J. C. Gann, K. C. Cieciel, W.D. Templin, and C.M. Guthrie. 2017. Juvenile Chinook salmon abundance in the northern Bering Sea: implications for future returns and fisheries in the Yukon River. Deep-Sea Res. II. 135:156–167.

Murphy, J.M., A.C. Wertheimer, E. Fergusson, A. Piston, S. Heinl, C. Waters, J. Watson, and A. Gray. 2019. 2018 pink salmon harvest forecast models from Southeast Alaska coastal monitoring surveys. NPAFC Doc. 1848. 19 pp. Alaska Fisheries Science Center and Alaska Department of Fish and Game (Available at https://npafc.org).

Orsi, J.A., E.A. Fergusson, A.C. Wertheimer, E.V. Farley, and P.R. Mundy. 2016. Forecasting pink salmon production in Southeast Alaska using ecosystem indicators in times of climate change N. Pac. Anadr. Fish Comm. Bull. 6:483–499.

Parker, R. R. 1968. Marine mortality schedules of pink salmon of the Bella Coola River, central British Columbia. Journal Fisheries Research Board Canada 25:757–794.

Wertheimer A. C., J. A. Orsi, M. V. Sturdevant, and E. A. Fergusson. 2006. Forecasting pink salmon harvest in Southeast Alaska from juvenile salmon abundance and associated environmental parameters. Pp. 65-72 In: H. Geiger (Rapporteur) (ed.), Proceedings of the 22nd Northeast Pacific Pink and Chum Workshop. Pacific Salmon Commission, Vancouver, British Columbia.

Wertheimer, A. C., J. A. Orsi, E. A. Fergusson, and M. V. Sturdevant. 2010. Calibration of Juvenile Salmon Catches using Paired Comparisons between Two Research Vessels Fishing Nordic 264 Surface Trawls in Southeast Alaska, July 2009. (NPAFC Doc. 1277). Auke Bay Laboratories, Alaska Fish. Sci. Cen., Nat. Mar. Fish. Serv., NOAA, 17109 Point Lena Loop Road, Juneau, 99801, USA, 19 pp. (Available at <https://npafc.org)>.

Wertheimer, A. C., and F. P. Thrower. 2007. Mortality rates of chum salmon during their initial marine residency. American Fisheries Society Symposium Series 57:233-247.

Wertheimer, A. C., J. A. Orsi, and E. A. Fergusson. 2018. Forecasting pink salmon harvest in southeast Alaska from juvenile salmon abundance and associated biophysical parameters: 2016 returns and 2017 forecast. Auke Bay Laboratory Manuscript, Alaska Fisheries Science Center, NOAA, NMFS. 25 pp. (Available at http://www.npafc.org).

Willette, T. M., R. T. Cooney, V. Patrick, D. M. Mason, G. L. Thomas, and D. Scheel. 2001. Ecological processes influencing mortality of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. Fisheries Oceanography 10(1):14–41.