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RC 63

February 16, 2019

To: Alaska Board of Fisheries

RE: Status of Rearing and Spawning Capacity of Chignik Lakes Watershed for Sockeye Salmon

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This memo is intended to provide a brief summary of our assessment of changes in the quality of rearing habitat for sockeye salmon in the Chignik Lakes watershed. The University of Washington, Alaska Salmon Program (UW-FRI) is in a unique position to comment on this matter as we have been studying the ecology of sockeye salmon and their habitat in this ecosystem since around 1950. The data used to generate the summary outlined in this memo have been collected since 1961, thereby providing a unique long-term perspective on the ecological status of this watershed.

The Chignik Lakes as a Habitat Network

To understand how sockeye salmon use the Chignik watershed, it is important to recognize that it is a complex *network* of different habitats, each of which provides unique spawning and rearing conditions for sockeye salmon. Sockeye salmon move between the discrete habitats that compose this network to complete the juvenile freshwater rearing phase before migrating to the Gulf of Alaska.

The principal habitats in the Chignik system are the shallow and warm upper lake (Black Lake) which is connected downstream via the Black River to colder and less productive Chignik Lake. Chignik Lake discharges to the Chignik Lagoon, a shallow but extremely productive tidal lagoon, via the short Chignik River. The Chignik Lagoon is connected to the Gulf of Alaska where Chignik sockeye complete the marine phase of their life-cycle.

The Chignik watershed supports several genetically distinct stocks of sockeye salmon (Creelman et al. 2011) including one that migrates to the watershed in June and July to spawn primarily in the tributaries of Black Lake in the upper watershed. A later-running stock migrates to the watershed in July and August, and spawns on the beaches of Chignik Lake and in its tributary streams. Another stock returns to the watershed in late August and early September to spawn in the Chignik River just upstream of tidal influence.

Most of the fish in the Black Lake stock spend a single year rearing in freshwater (primarily in productive and warm Black Lake) before migrating to the ocean to spend another 3 years growing there before they return to spawn as '1.3' fish. Because Chignik Lake is considerably colder and less productive than Black Lake, fish in the Chignik Lake stock typically spend 2 years growing in freshwater before migrating to the ocean to spend 3 years growing; thus, they primarily return to freshwater as '2.3' age fish. Despite these generalities in the dominant age classes in each of the principal stocks, there is also considerable variation in both 1) the life-history strategies observed in each of the stocks (i.e., both major stocks have some contributions of 1.2, 1.3, 2.2, 2.3, etc., fish) and 2) the rearing strategies used by individual fish as they migrate through the habitat network.

submitted by: Chuck McCallum

The different rearing strategies that juvenile sockeye use in the Chignik watershed appear to reflect adaptations to exploit the complementary growth conditions represented throughout the habitat network. For example, Simmons et al. (2013) showed that when smolts are large during their spring outmigration, they tend to migrate rapidly through the Chignik Lagoon and to the Gulf of Alaska. In contrast, when smolts are small, they tend to reside in the Chignik Lagoon for several additional weeks to accumulate additional growth before migrating to the Gulf of Alaska.

Similar to how smolts appear to use the lagoon as a way to make up for reduced growth in the lakes, juvenile salmon from the Black Lake stock use Chignik Lake as a stopover site to make up growth in years that are not particularly hospitable in Black Lake. Wesley et al. (2008) documented that there is a mid-summer downstream migration of juvenile salmon out of Black Lake during particularly warm summers; these fish move to downstream Chignik Lake that is deep enough that it never becomes inhospitably warm to sockeye salmon. Interestingly, warm climate conditions enhance the growing conditions for juvenile sockeye salmon in Chignik Lake, while degrade conditions in shallow Black Lake. The opposite pattern is observed in years with cold climate where Chignik remains cold enough to constrain growth of sockeye fry while Black Lake is closer to optimal. Thus, the complementary habitat conditions offered by Black Lake, Chignik Lake, and Chignik Lagoon provide a range of opportunities for juvenile sockeye salmon to achieve the necessary growth for successful survival as smolts.

With hot summers becoming increasingly common with climate warming, there has been concern that the early migration of juvenile sockeye from Black Lake to Chignik Lake will intensify competition between these two stocks, thereby reducing smolt production from the system. Our long-term monitoring data of juvenile sockeye growth do not support this concern. A detailed genetics analysis by Griffiths et al. (2013) identified the stock of origin of juvenile fish caught in Chignik Lake and assessed their physiological condition relative to fish that had moved downstream from Black Lake. This analysis showed that Chignik-fish caught in Chignik Lake were in as good or better condition than Black-fish caught in the same samples. This result corroborates the findings of Westley et al. (2008) who documented that the fish that migrated out of Black Lake during warm summers were in compromised condition compared to the individuals that remained in Black Lake for the summer. Further, Griffiths et al. (2014) analyzed juvenile growth as inferred from scales collected from 1950-2010 and correlated stock-specific growth rates of the Black and Chignik Lake stocks with various climate indicators. This analysis demonstrated that growth of the two stocks showed opposite responses to the same climate forcing, further emphasizing the importance of variation in habitat conditions throughout the watershed habitat network for maintaining growth opportunity for sockeye salmon. Thus, the complexity of habitat and its associated stock structure of sockeye salmon in the Chignik watershed make the overall system highly resilient to changes in the prevailing environmental conditions, as has become appreciated for Alaska sockeye salmon in general (Hilborn et al. 2003, Schindler et al. 2010).

<u>Long-term Trends in Growth of Juvenile Sockeye Salmon</u>

As part of our long-term research that has monitored the ecology of sockeye salmon juveniles and their habitat in the Chignik watershed, we perform an annual fall survey to assess growth performance of juvenile sockeye salmon following their first summer of lake residency. Figure 1 shows the annual deviations from the long-term average of the fork length of juvenile sockeye salmon caught in Black and Chignik lakes between 1961 and 2018. Positive values indicate that fish were larger than average in a given year. Negative values indicate that fish were smaller than average in a given year. The data in Figure 1 show a pronounced trend towards faster growth of juvenile sockeye salmon in both lakes between 1961 and 2018, in the Chignik watershed. Enhanced growth rates of juvenile sockeye salmon has been observed throughout the last decade, indicating the maintenance of high quality rearing habitat in this ecosystem.

The failed run in 2018 at Chignik resulted from a nearly complete collapse of the cohort of 3-ocean fish returning that year. These fish would have been sampled as juveniles in our townet surveys in September 2014. As can be seen for sampling in both Chignik and Black lakes, juvenile sockeye were substantially larger than average in 2014, demonstrating they had experienced above average growth conditions during their freshwater nursery period. In 2015, the year when fish that will return after three years in the ocean in 2019, juvenile sockeye were also larger than the long-term average in Chignik Lake. Unfortunately, inclement weather and low water prevented us from obtaining a sampling from Black Lake during that year.

Overall, our long-term data show that growth conditions during the last 10 years have generally been better than the long-term average observed since 1961. This increase in observed growth occurred primarily after the regime shift of the Pacific Decadal Oscillation in 1977 that resulted in warmer ocean and air temperatures throughout Alaska. Juvenile sockeye salmon growth in Bristol Bay show the same response to warming climate conditions (Schindler et al. 2005).

Thus, freshwater habitat in the Chignik watershed has become progressively more productive for juvenile sockeye salmon over the last 60 years, and has been consistently above average since 2000.

Effects of Climate Warming and Geomorphic Change in the Watershed

Sockeye salmon spawning and nursery habitat in the Chignik watershed is responding to both ongoing climate warming and to geomorphic evolution of the rivers and their tributary streams. Western Alaska has been one of the fastest warming regions globally over the last century, a trend that has generally translated into improved growing conditions for juvenile sockeye salmon in Bristol Bay (Schindler et al. 2005) and at Chignik (Griffiths et al. 2014, Figure 1). We should expect that this warming trend should continue for the next several decades which will further impact rearing conditions for sockeye in the future (Griffiths et al. 2011).

Black Lake has been undergoing rapid geomorphic change that has resulted in reduced volume of rearing habitat there, that has been visibly apparent over the last 50 years. However, there has been no associated decline in the production of the Black Lake sockeye salmon over this time frame (Figure 2). While there is considerable year-to-year variation in the size of the return to each of the Chignik stocks, production from the watershed increased substantially in the late 1970s in response to the shift to a warmer mode of the Pacific Decadal Oscillation, a large-scale climate oscillation that affects the productivity of western Alaska sockeye salmon. Both the Black Lake and the Chignik Lake stocks continue to demonstrate this improved productivity observed since the late 1970s, despite geomorphic changes in the watershed. Thus, we can conclude that there have been no detectable negative effects of changing habitat conditions on sockeye salmon at Chignik over the past several decades.

Looking to the future, there is concern that continued climate warming and further reductions in the volume of Black Lake and connectivity to its tributaries may reduce the habitat capacity of this part of the watershed. Modeling analyses considering a range of scenarios that encompass possible future combinations of geomorphic and climate conditions suggest that Black Lake rearing capacity may be limited during the summer in the future, though most of this effect will be a response to warming climate (Griffiths et al. 2011). However, the warming that may reduce the summer habitat quality of Black Lake is very likely to continue improving growth conditions in Chignik Lake which are presently constrained by cold water temperatures. Given the expectation that climate warming will continue for decades, and that rapid geomorphic evolution will continue as well, it is critically important that habitat conditions and the biological status of the Chignik sockeye salmon stocks are monitored carefully, and that management reference points are assessed routinely. While there is no evidence to suggest that habitat quality has degraded in the last 50 years (in fact, it appears to have improved for sockeye salmon), future conditions could change markedly in ways that necessitate changes to management goals and reference points to sustain the fisheries this ecosystem supports.

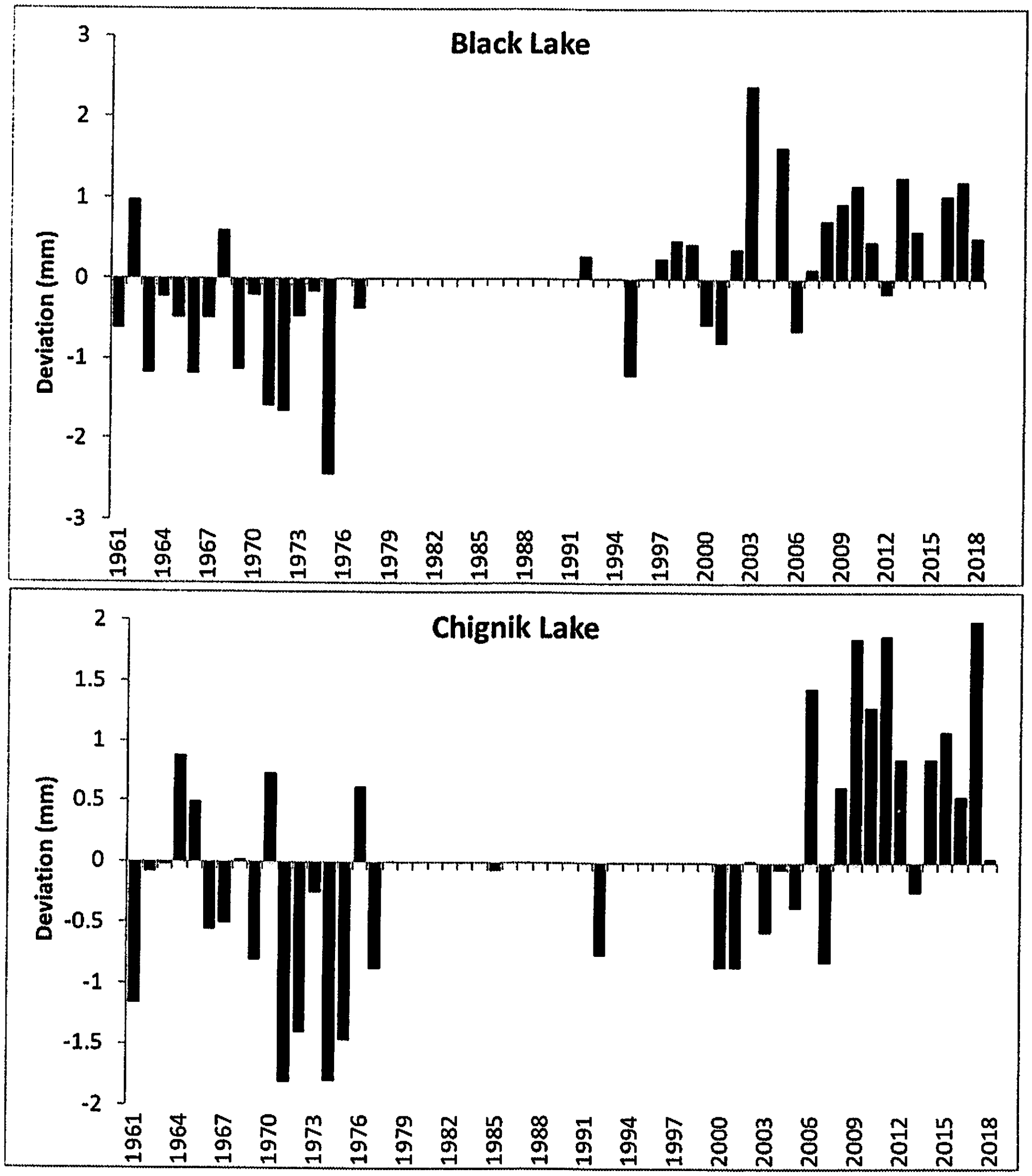

Figure 1. Average body sizes (fork length) of juvenile sockeye salmon caught in townetting surveys on September 1 in Chignik and Black lakes from 1961 – 2018, expressed as deviations from the long-term average (63.3mm Black Lake, 61.5mm Chignik Lake). Positive values denote better-than-average growth in that year; negative values denote worse-than-average growth in that year. Note that several years of data are missing during the 1980s and early 1990s. UW-FRI unpublished data.

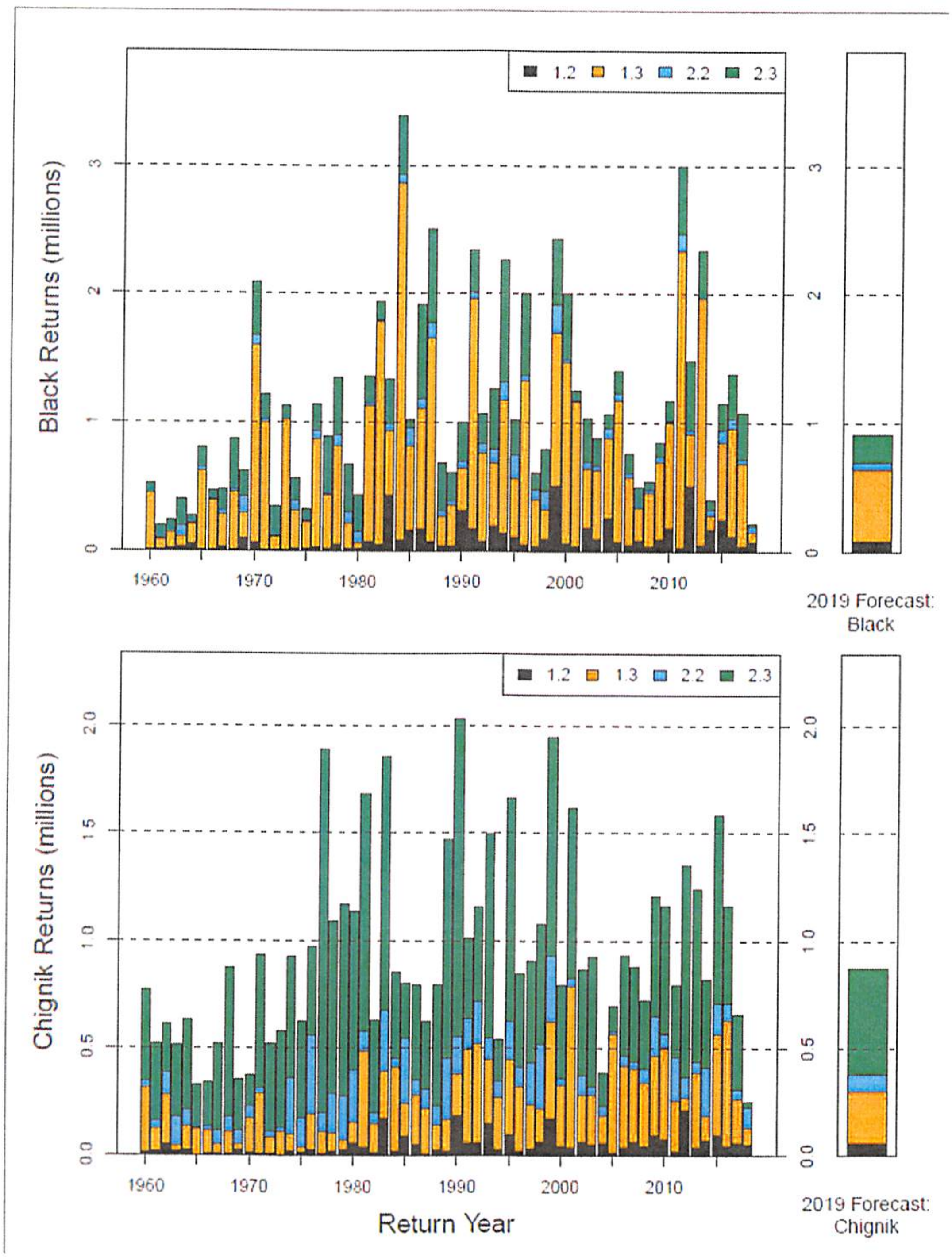

Figure 2. Observed changes in the sockeye returns to Black Lake (top panel) and Chignik Lake (bottom panel) from 1960 to 2018. Shown for each year is the contribution of the dominant age classes observed in the return for each year (i.e., age 1.2, 2.2, 1.3, and 2.3 fish). Data are from the ADF&G. Also shown is the UW-FRI forecast for the expected return in 2019, based on the return observed in 2018 (Cunningham and Schindler 2019).

References

Creelman, E.K., L. Hauser, R.K. Simmons, W.D. Templin, L.W. Seeb. 2011. Temporal and geographic genetic divergence: characterizing sockeye salmon populations in the Chignik Watershed, Alaska, using single-nucleotide polymorphisms. Transactions of the American Fisheries Society 140: 749-762.

Cunningham, C., and D. Schindler. 2019. Chignik Lakes sockeye salmon preseason forecast for 2019. University of Washington (FRI) report to Chignik Regional Aquaculture Association.

Griffiths, J.R., D.E. Schindler, L.S. Balistrieri, and G.T. Ruggerone. 2011. Effects of simultaneous climate change and geomorphic evolution on thermal characteristics of a shallow Alaskan lake. Limnology and Oceanography 56: 193-205.

Griffiths, J.R., D.E. Schindler, and L.W. Seeb. 2013. How stock of origin affects performance of individuals across a meta-ecosystem: an example from sockeye salmon. PLoS ONE 8: e58584. Doi:10.1371/journal.pone.0058584

Griffiths, J.R., D.E. Schindler, G.T. Ruggerone, and J.D. Bumgarner. 2014. Climate variation is filtered differently among lakes to influence growth of juvenile sockeye salmon in an Alaskan watershed. Oikos 123: 687-698.

Hilborn, R., T.P. Quinn, D.E. Schindler, and D.E. Rogers. 2003. Biocomplexity and fisheries sustainability. Proceedings of the National Academy of Sciences, USA 100: 6564-6568.

Schindler, D.E., D.E. Rogers, M.D. Scheuerell, C.A. Abrey. 2005. Effects of changing climate on zooplankton and juvenile sockeye salmon growth in southwestern Alaska. Ecology 86:198-209.

Schindler, D.E., R. Hilborn, B. Chasco, C.P. Boatright, T.P. Quinn, L.A. Rogers, M.S. Webster. 2010. Population diversity and the portfolio effect in an exploited species. Nature 465: 609-612.

Simmons, R.K., T.P. Quinn, L.W. Seeb, D.E. Schindler, R. Hilborn. 2013. Role of estuarine rearing for sockeye salmon in Alaska (USA). Marine Ecology Progress Series 481: 211-223.

Westley, P.A.H., R. Hilborn, T.P. Quinn, G.T. Ruggerone, and D.E. Schindler 2008. Long-term changes in rearing habitat and downstream movement by juvenile sockeye salmon (Oncorhynchus nerka) in an interconnected Alaska lake system. Ecology of Freshwater Fish 17: 443-454.