EXECUTIVE SUMMARY:

Project 10: Fraser River Sockeye Production Dynamics

Our main objective in this report is to present data and analyses that will contribute to the understanding of possible causes of reduced abundance and productivity of Fraser River sockeye salmon. We hope that our data, as well as analyses by other scientists who use them, will help to gain a better understanding of the causes of the dramatic changes in Fraser River sockeye salmon and thereby aid in developing appropriate management responses. Here, "productivity" is the number of adult returns produced per spawner, where "spawners" are the fish that reproduce for a given sockeye population in a given year, and "adult returns" (or “recruits”) refer to the number of mature adult salmon resulting from that spawning that return to the coast prior to the onset of fishing.

To achieve our objective, we obtained data sets on abundance of spawners and their resulting adult returns for a total of 64 populations ("stocks") of sockeye salmon. These stocks included 19 from the Fraser River, with the rest from other parts of British Columbia, Washington state, and Alaska. Almost all of our data are from wild populations that are not confounded by hatchery stocking. Data sets were of varying length, some starting as early as 1950. We included data on sockeye populations outside of the Fraser River to determine whether the Fraser's situation is unique, or whether other sockeye populations are suffering the same fate. In addition to obtaining data on adults, we also obtained data on juvenile (i.e., fry or smolt) abundance in fresh water for 24 sockeye populations to help determine whether problems leading to the long-term decline survival arose mainly in fresh water or the ocean. Unfortunately, we were not able to include any 2010 salmon data because the responsible agencies are still processing field samples to determine what portion of the fish belong to which particular stocks.

We used three different measures of productivity: (1) number of adult returns per spawner, (2) an index that accounts for the influence of spawner abundance on returns per spawner and thus specifically represents productivity changes that are attributable to causes other than spawner abundance (e.g., environmental factors), and (3) an extension of the second index that uses a Kalman filter to remove high-frequency year-to-year variation ("noise") in productivity and thereby brings out the long-term trends that are of primary interest to sockeye managers. We compared time trends in these three productivity estimates across sockeye stocks within the Fraser River and among them and non-Fraser sockeye stocks using a variety of methods, including visual comparisons, correlation analysis, Principal Components Analysis, and clustering.

We found that most Fraser and many non-Fraser sockeye stocks, both in Canada and the U.S.A., show a decrease in productivity, especially over the last decade, and often also over a period of decline starting in the late 1980s or early 1990s. Thus, declines since the late 1980s have occurred over a much larger area than just the Fraser River system and are not unique to it. This observation that productivity has followed shared trends over a much larger area than just the Fraser River system is a very important new finding. More specifically, there have been relatively large, rapid, and consistent decreases in sockeye

productivity since the late 1990s in many areas along the west coast of North America, including the following stocks (from south to north).

- Puget Sound (Lake Washington)
- Fraser River
- Barkley Sound on the West Coast of Vancouver Island (Great Central and Sproat Lakes)
- Central Coast of B.C. (Long Lake, Owikeno Lake, South Atnarko Lakes)
- North Coast of B.C. (Nass and Skeena)
- Southeast Alaska (McDonald, Redoubt, Chilkat).
- Yakutat (northern part of Southeast Alaska) (East Alsek, Klukshu, Italio).

The time trends in productivity for these stocks are not identical, but they are similar. This feature of shared variation in productivity across multiple salmon populations is consistent with, but may have occured over a larger spatial extent than, previously published results for sockeye salmon. In contrast, western Alaskan sockeye populations have generally increased in productivity over the same period, rather than decreased.

Historical data on survival rates of Fraser sockeye stocks by life stage show that declines in total-life-cycle productivity from spawners to recruits have usually been associated with declines in juvenile-to-adult survival, but not the freshwater stage of spawner-to-juvenile productivity. Specifically, for the nine Fraser sockeye stocks with data on juvenile abundance (fry or seaward-migrating smolts), only the Gates stock showed a long-term reduction over time in freshwater productivity (i.e., from spawners to juveniles) concurrent with the entire set of years of its declining total life-cycle productivity from spawners to recruits. In contrast, seven of the nine stocks (excluding Late Shuswap and Cultus) showed reductions in post-juvenile productivity (i.e., from juveniles to returning adult recruits) over those years with declining productivity from spawners to recruits. These results indicate either that the primary mortality agents causing the decline in Fraser River sockeye occurred in the post-juvenile stage (marine and/or late fresh water), or that certain stressors (such as pathogens) that were non-lethal in fresh water caused mortality later in the sockeye life history.

The large spatial extent of similarities in productivity patterns that we found across populations suggests that there might be a shared causal mechanism across that large area. Instead, it is also possible that the prevalence of downward trends in productivity across sockeye stocks from Lake Washington, British Columbia, Southeast Alaska, and the Yakutat region of Alaska is entirely or primarily caused by a coincidental combination of processes such as freshwater habitat degradation, contaminants, pathogens, predators, etc., that have each independently affected individual stocks or smaller groups of stocks. However, the fact that declines also occurred outside the Fraser suggests that mechanisms that operate on larger, regional spatial scales, and/or in places where a large number of correlated sockeye stocks overlap, should be seriously examined in other studies, such as the ones being done by the other contractors to the

Cohen Commission. Examples of such large-scale phenomena affecting freshwater and/or marine survival of sockeye salmon might include (but are not limited to) increases in predation due to various causes, climate-driven increases in pathogen-induced mortality, or reduced food availability due to oceanographic changes. Further research is required to draw definitive conclusions about the relative influence of such large-scale versus more local processes.

The Harrison River sockeye stock in the Fraser River watershed is an important exception to the decreasing time trends in productivity that have been widely shared across sockeye stocks. Harrison fish have notable differences in their life history strategy from the majority of other sockeye populations that we examined, including other Fraser River stocks. These life history differences may provide an important clue about causes of the decline in other sockeye stocks. Specifically, (1) Harrison fish migrate to sea in their first year of life as fry instead of overwintering in fresh water and migrating to sea in their second year as smolts, (2) they appear to rear for some time in the Fraser River estuary, (3) they remain in the Strait of Georgia later than other Fraser River sockeye, and (4) there is some evidence that the fry migrate out around the southern end of Vancouver Island through the Strait of Juan de Fuca instead of through Johnstone Strait to the north. That southern fry-migration route is shared with Lake Washington sockeye, yet the latter stock was one of those that showed a decrease in productivity similar to that of other B.C. sockeye stocks. Thus, the reason for the Harrison's exceptional trend is probably not attributable simply to its different migration route. We hope that by using our data on productivity trends for Harrison and other stocks, the other contractors to the Cohen Commission will find an explanation for why the Harrison situation is anomalous.

In addition to describing similarities in productivity patterns, we also evaluated the hypothesis that large numbers of spawners could be detrimental to productivity (recruits per spawner) of Fraser sockeye populations. The downward time trend in productivity of these stocks, combined with successful management actions to rebuild spawner abundances, has led to speculation that these unusually large spawner abundances might in fact be to blame for declines in productivity and consequently also substantial declines in returns. For the Quesnel sockeye stock on the Fraser, there is indeed evidence that interactions between successive brood lines that are associated with large spawner abundances may have reduced productivity of subsequent cohorts. Thus, the recent decline in productivity for Quesnel sockeye might be more attributable to increased spawner abundance than to broad-scale environmental factors that affect other sockeye stocks in the Fraser and other regions. However, other Fraser sockeye populations do not show such evidence. Our data do not support the hypothesis that large spawner abundances are responsible for widespread declines.

Recommendations

We conclude with five recommendations.

Recommendation 1: Researchers should put priority on investigating hypotheses that have spatial scales of dynamics that are consistent with the spatial extent of the observed similarities in time trends in productivity across sockeye salmon populations. By examining data on mechanisms that match the scale of the phenomenon they are trying to explain (downward trends in sockeye productivity shared among numerous stocks), scientists are less likely to find spurious relationships with explanatory variables, i.e., those that show relationships by chance alone.

Recommendation 2: All agencies in Canada and the U.S.A. that manage or conduct research on sockeye salmon should create and actively participate in a formal, long-term working group devoted to, (a) regularly coordinating the collection and analysis of data on productivity of these populations, and (b) rapidly making those results available to everyone. Such an international collaboration is needed because the widespread similarity of decreasing time trends in productivity of sockeye salmon stocks in Canada and the U.S.A. south of central Alaska strongly suggests that large-scale processes may be affecting these diverse populations in similar ways. A new international working group would facilitate communication of current data and analyses, which would help to increase the rate of learning about causes of widespread trends across stocks and identification of what might be done about them. Such a working group's role might be critically important if global climatic change is responsible for the declines in sockeye productivity.

Recommendation 3: All agencies involved with salmon research and management on the west coast of North America should develop and maintain well-structured databases for storing, verifying, and sharing data across large regions. This step will improve data quality and consistency and make the data more readily accessible to researchers, managers, and stakeholders. They can then be used reliably and in a timely manner in research and provision of advice to managers and stakeholders. If such large-area databases had been created before, scientists might have noticed sooner how widespread the recent decline in sockeye productivity has been, and timely research efforts could have been directed toward understanding the causes of the decline.

Recommendation 4: All salmon management and research agencies in Alaska, B.C., and Washington need to strategically increase the number of sockeye stocks for which they annually estimate juvenile abundance, either as outmigrating smolts or fall fry. These additional long-term data sets are needed to permit attribution of causes of future changes in salmon populations to mechanisms occurring either in freshwater or marine regions. Without such juvenile data sets, research or management efforts might be misdirected at the wrong part of the salmon life cycle when productivity decreases.

Recommendation 5: Further research is required to better understand salmon migration routes and timing during outmigration, as well as their residence in the marine environment. Scientists also need more information on stressors and mortality that fish are subjected to at each life stage. Without such additional detailed data on late freshwater and marine life stages, most evidence for causal mechanisms of changes in salmon productivity will likely remain indirect and speculative.