Trends in body size of Puget Sound Chinook salmon: Analysis of data from the Tengu Derby, a culturally unique fishery

Thomas P. Quinn

School of Aquatic and Fishery Sciences

Box 355020, University of Washington

Seattle, WA 98195 USA

Mark D. Scheuerell

U.S. Geological Survey Washington Cooperative Fish and Wildlife Research Unit

School of Aquatic and Fishery Sciences

Box 355020, University of Washington

Seattle, WA 98195 USA

[and presumably James, and Neala if she wants,

Keywords:

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Abstract

In Pacific salmon, downward trends in size and abundance have been reported for species and stocks for over forty years, but the patterns are inconsistent among regions and species, with many possible contributing factors, including mixed stocks and gear types. Here we present data on the size of Chinook salmon, *Oncorhynchus tshawytscha*, caught in the winter from 1946 to 2019 in central Puget Sound, Washington by participants in the Tengu Derby. In this annual recreational fishing competition established by Japanese-Americans immediately after release from internment camps at the end of World War II, participants follow strict gear, area, and methods regulations, and catch almost exclusively salmon originating from Puget Sound. Records revealed several shifts in fish mass over the decades, including a decline over the most recent 30 years. These salmon, displaying a form of differential migration by remaining in Puget Sound rather than migrating to the ocean coast, showed different trajectories compared with size trends of Puget Sound Chinook salmon sampled in an independent research survey.

Introduction

Long-term trends in size and age at maturity of fishes have been the subject of interest for many decades, as they may reflect natural changes in environmental conditions ([Cox and Hinch 1997](#_ENREF_7)), density dependence ([Pyper and Peterman 1999](#_ENREF_18)), fishery management ([Richards and Rago 1999](#_ENREF_22)), lift history adaptation as part of fishery induced evolution ([Swain et al. 2007](#_ENREF_30)), and other processes. For example, scientists have investigated long-term trends in body size and age at maturity in Atlantic salmon, *Salmo salar* ([Gardner 1976](#_ENREF_9), [Summers 1995](#_ENREF_29)). In addition to data from commercial fisheries ([Shearer 1990](#_ENREF_27)), these studies have also used data from recreational fisheries, recorded by governmental bodies ([Bal et al. 2017](#_ENREF_2)), angling clubs ([Bielak and Power 1986](#_ENREF_3)), privately held fisheries ([Quinn et al. 2006](#_ENREF_21)), or newspapers ([Valiente et al. 2011](#_ENREF_31)).

As with Atlantic salmon, there is also a long history of interest in trends in Pacific salmon (*Oncorhynchus* spp.) body size, with reports of decreases in many species, regions, and periods of record ([Ricker 1981](#_ENREF_24), [1995](#_ENREF_25), [Bigler et al. 1996](#_ENREF_4), [Lewis et al. 2015](#_ENREF_14), [Oke et al. 2020](#_ENREF_16)). However, as noted by [Ricker (1980](#_ENREF_23)), analysis of such data and attribution to causal agents is very complicated, and especially so for Chinook salmon (*O. tshawytscha*) owing to their variation in age at maturity, marine distribution patterns, and timing of return to fresh water ([Quinn 2018](#_ENREF_19), [Riddell et al. 2018](#_ENREF_26)). As outlined by Ricker (1980) and many subsequent reviews of trends in size, many factors may cause genuine or apparent changes over decades. 1) Data may come from commercial fisheries on immature and maturing fish of multiple ages, and the proportions may change over the years. 2) Catches may occur at different times of the year, affecting average size because in some years the fish have had less time to grow. 3) The greater size of smolts produced in hatcheries compared to wild populations can reduce the number of years spent at sea, and hatchery production has become an increasing proportion of the runs in some areas. 4) Oceanographic conditions have changed, as has salmon density, and these can both affect growth. 5) Impassable hydroelectric dams extirpated some runs, and if they were especially large then the average size of the salmon might decline. 6) Fisheries themselves can be size selective, and thus shift the observed distribution depending on where and when sampling occurs, and can also result in an evolutionary shift in age and size at maturity. There is an extensive scientific literature on these and other factors, and the fact that they are not mutually exclusive makes it especially difficult to explain the many declines (and some increases) in size and age in Pacific salmon (see Quinn (2018) for a discussion and review of these factors).

Most of the data sets examined for patterns of body size in Pacific salmon come from commercial fisheries as they are the primary if not exclusive fisheries on the most numerous species: sockeye (*O. nerka*), chum (*O. keta*), and pink (*O. gorbuscha*) salmon. However, Chinook and coho salmon (*O. kisutch*) are also widely sought by anglers in coastal marine waters and rivers. Recreational fisheries can complicate analysis of size trends because they may occur at different places and times of the year from commercial fisheries, and the lack of centralized processing means that often no data on size are recorded. However, when used with appropriate caution, recreational fisheries can also be a source of data to augment and complement data from commercial fisheries and recoveries at hatcheries. For example, [Fagen (1988](#_ENREF_8)) examined data from recreational fishing derbies for Chinook salmon in four areas of southeastern Alaska going back as much as four decades, and reported significant declines in the largest fish in two of the four, but no clear trend in the other two. Interpretation of these data was complicated by the factors noted by Ricker (1980), especially because southeastern Alaska is a feeding area for wild and hatchery Chinook salmon originating from a range of locations ([Healey and Groot 1987](#_ENREF_11), [Weitkamp 2009](#_ENREF_33), [Weitkamp 2012](#_ENREF_32)).

Recent analysis of trends in survival, abundance, and body size of Puget Sound Pacific salmon, based on commercial purse seine fishery data, revealed a decline in average body mass in Chinook salmon from 1970 through 2015 ([Losee et al. 2019](#_ENREF_15)). However, these salmon would have originated from different regions, been feeding in various locations, and were caught at different times of the year. These factors complicate interpretation of the data, with respect to the ecology of the species in Puget Sound. The objective of this study was to examine and report data pertaining to sub-adult “resident” Chinook salmon (locally known as blackmouth, in reference to the black gum line characteristic of the species in marine waters), caught in central Puget Sound in a culturally unique recreational fishery. Annual records were maintained of the mass of the five largest individual fish, numbers over 10 pounds (4.54 kg) and 5 pounds (2.27) since 1946. These data were examined for trends over the decades and compared to the number of derby registrants as a co-variate. We then compared these trends, specific to Chinook salmon originating in Puget Sound and representing only resident salmon, with those of the species caught in Puget Sound as a whole ([Losee et al. 2019](#_ENREF_15)).

Methods

The Tengu Salmon Derby

The history and origins of the derby are described on a monument plaque at the current weigh-in station in West Seattle. “The Tengu Club of Seattle, formed in the 1930s by Japanese Americans, held its first Tengu Blackmouth Salmon Fun Derby in 1946. Arguably the longest continually running salmon derby in North America, it continues to be held each winter in Elliott Bay. Club members, returning from wartime internment camps, were denied entry into local salmon derbies so they organized the first Tengu Derby in December of 1946. More than 170 people, including about a dozen non-Japanese, fished in the first four Sundays-long competition. The technique of “mooching” was invented in Elliott Bay by these fishers, who perfected a way to entice salmon by working bait in an up-and-down motion while drifting. This method proved to be so effective that non-Japanese would “mooch” herring from them. The Tengu Club recognized the historical significance of mooching and adheres to this “purist” way of salmon fishing to this day. The name ‘Tengu’ is from Japanese folklore that describes mythical creatures that were mischievous braggarts. Their long noses are symbolic of exaggerating the truth, which is typical of fish stories.”

In the decades that followed, participants in the Tengu Derby continued to use the same technique (e.g., no artificial lures, no use of a motor while fishing, no downriggers, etc.) and in precisely the same area (Fig. 1), from Alki Point northward to Four Mile Rock. The derby long pre-dated electronic navigation but this small area is well-defined and most anglers are within sight of each other for much of the time, so fishing outside the area would be quickly detected. Each year the club’s Board of Directors determines the specific dates but typically fishing occurs on Sundays in November and December. Dates and other details are posted annually and registration in the derby provides a record of the number of participants. However, records were not retained of how many days each registrant fished that season, so the assessment of effort is imprecise in this regard. Fish are brought to a central weighing station rather than being self-reported, and thus the data on fish mass (recorded in pounds, and later converted to kg) can be considered to be very accurate.

Each year the mass of the largest five fish was recorded, and these data were the focus of our analysis, but the numbers of Chinook salmon over 10 pounds and over 5 pounds were also recorded, and we present these in graphical form for comparison. The numbers of days the derby was open and registered participants, and the total number of Chinook salmon caught was also recorded each year. However, changes in the size limits over the decades preclude some analyses of those data because fish were retained and counted in early decades that would now have to be released and so not counted. For the present analysis we used the average mass of the top five fish from 1946 - 2017, omitting two years (2010 and 2013) when fewer than five Chinook salmon were recorded, and 2015 when fishing was closed. In 2018 and 2019, fewer than five salmon were caught so the averages were not included. The trends were then compared to data from 1970 – 2014 previously reported by [Losee et al. (2019](#_ENREF_15)) on the annual mean body mass of Chinook salmon caught in Puget Sound commercial purse seine fisheries (chosen because for their lack of size-selectivity). [Mark – if we use the average of the top four fish, we add 2010 and 2018 data; if we make it the average of the top three fish, we add 2010, 2013, and 2018, and if we make it the average of the top two, we add 2019 as well.]

Statistical models

We modeled the sizes of fish caught in both the Tengu Derby and WDFW surveys using simple forms of multivariate state-space models. These models consist of two parts: 1) a state model that describes the changes in the true, but unknown size of fish; and 2) an observation model that relates the observed time series of fish sizes to the true state. Each of the component models varied subtly depending on the underlying hypothesis about how the 2 sources of data were related. Here we wanted to evaluate 1) if there was any evidence for a systematic change in fish size over time; and 2) whether or not adult salmon caught in the derby reflected changes in their size over time that were similar to those fish caught by WDFW.

Beginning with the state model, we modeled changes in fish size using a random walk, for which the change in size over time was assumed to be either biased or unbiased, indicating whether the changes in fish size over time were random or generally trending upward/downward. Specifically, the model takes the form

(1)

where *xi,t* is the natural logarithm of fish size from source *i* in year *t*, *ui* is the bias term for source *i*, and *wi,t* is a residual process error for source *i* in year *t*, such that *wi,t* ~ N(0, *q*). We compared the data support for models with and without a bias term using AICc, in combination with different forms of observation models (see below).

The observation model treats the observed lengths of adult salmon in a given year as a sample from the distribution of true lengths in the population. Specifically, the model is

(2)

where *yj,t* is the natural logarithm of observed fish size from source *j* in year *t*, *aj* is on offset term for source *j*, and *vj,t* is a residual sampling error for source *j* in year *t*, such that *vj,t* ~ N(0, *r*). When *i = j*, each of the two methods (i.e., derby and WDFW) are assumed to be sampling their own unique populations.

We can write equations (1) and (2) in a more compact form using matrix notation. The first case, where each set of fish lengths are assumed to come from two different groups of fish, becomes

(3a)

. (3b)

The second model, where each set of lengths is assumed to be a sample from one large population, is

. (4a)

(4b)

In equations (3a), (3b), and (4b), the errors are distributed as a multivariate normal. In all of those cases, we assumed that the errors were independent, but not identically distributed, such that the covariance matrices had a different variance term in each of the elements of the diagonal, and 0’s in the off-diagonals.

Resident Chinook salmon

It has long been known that Chinook and coho salmon occur in Puget Sound and other inland waters at all months of the year ([Jordan and Evermann 1896](#_ENREF_12)), in addition to the fraction of the populations feeding along the coast ([Pressey 1953](#_ENREF_17), [Haw et al. 1967](#_ENREF_10)). These salmon are fully anadromous but exhibit differential migration ([Quinn 2021](#_ENREF_20)), remaining in the general vicinity of their natal rivers for much of their period of marine life ([Chamberlin et al. 2011](#_ENREF_5), [Chamberlin and Quinn 2014](#_ENREF_6), [Arostegui et al. 2017](#_ENREF_1), [Kagley et al. 2017](#_ENREF_13)). At the time of year when the Tengu Derby occurs, maturing Chinook salmon would have already entered rivers to spawn, leaving only immature fish subject to capture. These salmon might mature and spawn the following year, or thereafter. Analysis of coded wire tagging (CWT) data indicated that Chinook salmon caught in Marine Area 10 (central Puget Sound, including the location where the derby occurs) were almost exclusively from Puget Sound. Specifically, 90.2% of CWT recovered from Chinook salmon from October through April (the resident period) in central Puget Sound between 1973 and 2018 originated from Puget Sound (WDFW data, average of annual values). Consistent with this analysis, [Shelton et al. (2019](#_ENREF_28)) examined coded wire tagging data from the west coast of North America and concluded, “Virtually all fish estimated to be present in the Salish Sea (Puget Sound, Strait of Georgia) originated there, indicating few Chinook salmon from the outer coast migrate into the Salish Sea.” Consequently, it is appropriate to consider the fish caught in the winter as having originated from Puget Sound rivers and hatcheries.

Results

The Tengu Derby data indicated that body size was initially high in the late 1940s and 1950s, declined to a low in about 1980, rose to another peak around 1990 that was about as high as the first peak, and then declined to the present to levels as low as those seen about 40 years ago (Fig. 2). These trends were also evident in the average mass of the five largest salmon and the numbers caught that exceeded 5 and 10 pounds (Fig. S1). Given these large-scale changes in fish mass over time, it was perhaps expected that we did not find any data support for a random walk model that included a systematic bias in the trend of log-mass over the entire time period; the AICc for the unbiased random walk was ~0.6 units lower than that for the biased random walk.

During the period from 1970 to 2014, observed changes in the mass of fish from the Tengu Derby were not similarly reflected in the mean size of fish caught in the WDFW purse seine survey, despite some similarities in fish mass from the late 1980s to the late 1990s (Fig. 3). Models with only one underlying state had AICc values that were about 35 units greater than models with two unique states. Furthermore, although the mean fish mass from the WDFW surveys appeared to generally decrease over the period of record, we found minimal data support for a model with a consistent downward bias in either time series (AICc for the model with biases was -57; AICc for the model without a bias was -56).

Discussion

Main points:

Compare the ups and downs in the derby to the steadier decline in PS Chinook size, and then to Chinook trends in general, and salmon in general. The two data series do not completely correspond, which can result from 1) error (i.e., lack of total precision, unrepresentative sample, etc.) in each data set, 2) possible biases in one or both data sets (e.g., changes in salmon distributions or commercial fishing locations within Puget Sound that might affect fish caught), and 3) genuine differences in the trends in resident salmon growth and age composition from those of the population complex’s contingent that migrates to the Pacific Ocean, and 4) differences in the proportions of Puget Sound salmon that join the resident contingent. TQ can provide lots of references to things that have been changing in Puget Sound that might affect residents, the lack of correlation in survival and abundance between Puget Sound and coastal populations and so forth.

Indicate that these data are not without some biases, as with other kinds of data on size. For example, Bowersox et al. compared steelhead caught in sport and gillnet fisheries and at the hatchery. Cite this paper, etc.

Acknowledgments

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Figure 1. Map of Puget Sound, Washington, with an insert showing the location of the Tengu Blackmouth Derby.

Need basic Puget Sound map



Figure 2. Time series of the mean mass of the five largest fish caught in the Tengu Derby (blue), along with the model fitted values (black) and approximate 95% confidence intervals (gray).

Chart

Description automatically generated

Figure 3. Time series of observed fish mass from the Tengu derby (blue) and WDFW surveys (red) from 1970-2014, including fits from the multivariate random walk model for both time series (dashed lines).

Chart, line chart

Description automatically generated

Figure S1. Time series of the mass of the largest fish caught in the Tengu Derby (top), and time series of the proportion of fish exceeding 5 pounds (~4.5 kg; light blue) and 10 pounds (~2.3 kg; dark blue).

Chart, histogram

Description automatically generated

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