How Do Temperature and Precipitation in the Columbia River Basin Differ between 1800-1850 and Today?

Photo: Courtesy Jessica Heppler

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Abstract

Billions are spent annually in the Columbia River Basin (CRB) attempting to restore salmon runs to some fraction of a previous level. Usually, the baseline benchmark for total salmon abundance, absent any human influence, is the pre-1850 salmon abundance. Thus, the implicit assumption is that salmon runs pre-1850 were governed by the same climatic conditions as those affecting salmon runs today. However, that implicit assumption has never been rigorously evaluated. Specifically, temperature and precipitation are important in determining the abundance of salmon. Using primarily peer-reviewed scientific literature and available contemporary written records, I estimated the temperature and precipitation in the Columbia River Basin from 1800 to 1850. As with all historical reconstructions, the results are not unequivocal, but they mainly support the conclusion that the CRB was both relatively cooler and wetter from 1800 to 1825 compared to current conditions. The Basin became somewhat drier and warmer from 1826-1850 relative to 1800-1825, but still wetter and cooler than current conditions. These results indicate that the cooler temperatures and above-average precipitation prevailed compared to current conditions. Because cool and wet conditions in the CRB are relatively more favorable for salmon, it is likely that overall salmon abundance 1800-1850, all other factors being equal, was likely greater than that of salmon living in current climatic conditions (i.e., warmer and drier).

Introduction

Over the past 40 years, more than $9 billion has been spent directly by governments to restore salmon in the Columbia River Basin (CRB) (Jaeger and Scheuerell 2023). This estimate does not include "foregone revenue and opportunity costs", so the actual costs are higher. Their overall conclusion was that, after 40 years of restoration efforts, there were no net "benefits" from such expenditures.

Many factors have driven overall salmon abundance down to a few percent of their prior levels. Those factors are well known (Lackey et al. 2006) and include intense forms of fishing, both commercial and recreational, freshwater and estuarine habitat alteration from activities like mining and timber extraction, dams built for agriculture and flood control, and electricity, water withdrawals for commercial and other needs, stream and river channel modification through diking, riparian corridor modifications, intensified predation, competition with non-native fish species, water pollution, and diseases and parasites.

One factor not on the typical list of causes of the salmon decline in the Columbia River Basin is changes in climate, particularly regarding temperature and precipitation. Although billions are spent annually in the CRB to restore salmon runs to some fraction of a previous level, usually, the baseline is the pre-1850 overall Basin abundance. Thus, the implicit assumption is that salmon runs before 1850 were affected by the same climatic conditions as exist today.

At a conceptual level, climate affects species abundance. For example, the total salmon run in the CRB was estimated to be 6-15 million in the 1850s (Alldredge et al. 2015, CRITFC 2018). Assuming that 6 million salmon (a commonly used estimate) returned to the CRB in the 1850s, the Basin's overall salmon run is now about 2-5% of the 1850s levels (Meengs and Lackey 2005, Lackey et al. 2006). However, this extrapolation implicitly assumes that climatic conditions were what they are today. If climatic conditions were different than what they are today, then rehabilitation and recovery targets of climate-sensitive species like salmon may be unrealistic. For example, 1800 - 1850 occurred at the end of the Little Ice Age, therefore it is likely that relative to today, the temperatures in the CRB at that time were lower, and there may have been more precipitation.

No consistent formalized weather-keeping records for 1800-1850 exist in the Columbia River Basin, but data sources do exist that provide proxy ways to infer temperatures and precipitation. There are also direct observations from groups such as the Lewis and Clark Expedition (Knapp 2004). Records derived from tree ring (dendrology) studies yield assessments of the prevailing temperatures and precipitation levels.

Dendrological studies offer insights into precipitation (Baek et al. 2017), cycles of drought (Herweijer et al. 2007), patterns of glaciation (Anchukaitis et al. 2017), prevailing temperatures (Briffa et al. 1992), as well as precipitation and temperature patterns that allow us insight into the likely weather patterns (Wise and Dannenberg 2017). Studies on glacier behavior revealed by sediment moraines, lichens, and other data sets in both the CRB and in nearby geographic locales provide another opportunity to study the early 1800s. Finally, external influences such as volcanic activity and the El Niño Southern Oscillation that are known to be particularly influential to climate, provide a different perspective for assessing temperature and precipitation(Luterbacher and Pfister 2015, Wirakusumah and Rachmat 2017).

The goal of this paper is to determine how temperature and precipitation differed between the years spanning 1800-1850 and the 2020s in the CRB. 1800 to 1850 was a particularly critical time frame because it was at the end of the Little Ice Age (Mann 2002) and just before the onset of the Modern Warm Period. Relative to salmon, this period of climatic transition is often overlooked concerning climate and, thus, critical information like precipitation and temperature. The results of this research will give natural resource managers an estimate of the most likely prevailing temperature and precipitation conditions that existed in the CRB 1800-1850, and whether those conditions might have affected "baseline" salmon recovery conditions.

Methods

I searched collections and databases from many peer-reviewed journals. ResearchGate was utilized heavily due to its connections and access to a large number and wide variety of peer-reviewed journals. ResearchGate was favored because it had entries for papers so that even if they did not have the actual paper on hand, the site would often identify where a PDF copy could be found. Google Scholar was also used to identify other relevant papers and where copies might be found. Other locations of online research for papers included JSTOR, the American Meteorological Society online journal archive, Springer Online, and Elsevier. I also looked at papers on websites run by the National Oceanic and Atmospheric Administration and the US Geological Survey. Examples of search terms were 'late Holocene', '1800s', 'little ice age', 'Columbia River basin', 'climate', 'Pacific Northwest', 'Lewis and Clark'. Later searches also involved 'ENSO' (El Niño Southern Oscillation), 'climate forcing', 'volcanism', 'deep-ocean cooling', and 'medieval climate anomaly.' I avoided sources that were not peer-reviewed unless they were contemporaneous observations. To that end, out of the many sources I chose for this paper, a scant handful are represented by books, encyclopedia entries, and Government agency technical information or papers. Most of the sources I used in this research were thus peer-reviewed, and most of those materials appeared in peer-reviewed journals.

A Brief History of the Columbia River Basin

The CRB, like every region of the planet, is affected by climate and has been subject to periods that were relatively warmer and cooler. Some of these spans of time included much cooler, longer lengths of time in the form of major Ice Ages (Kuhle 2011), but recent centuries have been more moderate periods of warming and cooling at roughly 500-year intervals (Ljungqvist 2010). The last major Ice Age in North America ended approximately 10,000 years ago, and while the Earth might not reach the same frigid temperatures of that last glaciation cycle, the Earth continues to follow complex long (multiple millennia) and short-term (multiple centuries) oscillations in climate." Such 'cycles within cycles' present a difficult analytical challenge.

One of these more moderate, cooler periods, known as the 'Little Ice Age,' was ending just as the newly formed United States and other countries were exploring the lands in and around the CRB and expanding influences westward. While the exact start of the Little Ice Age is subject to scientific debate, the years spanning approximately 1300 to 1850 are commonly used as the duration of this climatic phenomenon (Mann 2002). Unlike other periods of cool climate North America has undergone, it offers us a unique opportunity to study a time period that is known on a broad scale to be climatically cooler and wetter than the preceding or succeeding years (Mann 2002), and without reliance on a fossil record. 1800 to 1850 is viewed as particularly important as those years are the transition out of the period still under the climatic influence of the Little Ice Age, therefore a more favorable climate for species like salmon. Unlike previous major ice ages, the Little Ice Age was thought to have been much more limited in length and actual temperature decline (Barbuzano 2019). Overall, it is hypothesized that the years from 1800 to 1850 were cooler with more precipitation in the CRB than the current climate, which is relatively unfavorable to salmon (Beamish and Bouillon 1993).

Further, 1800-1850 was characterized as politically turbulent from the human perspective for the CRB. Great Britain, Spain, Russia, and the newly founded United States all had designs and intentions on the land in and around the Basin. These years were also notable in that they saw mass westward migrations of American and European settlers to the CRB for many reasons. Among other things, the area was abundant with highly valuable natural resources, particularly fur (Müller-Schwarze 2011), and several territorial disputes between Great Britain and the United States would arise over the control of these resources (Galbraith 1959). The United States would not unequivocally own any of the CRB until the signing of the Oregon Treaty in 1846 (Commager 1927). A large section of the Basin would ultimately wind up in the United States, with the remainder owned by Great Britain in what is now Canada.

Contemporaneous Observations

The efforts to explore the CRB in the early 1800s by the Lewis and Clark Expedition provide a valuable resource in this effort to examine the past climate of that region. The Expedition, led by Meriwether Lewis and William Clark, offers the first series of systematically recorded observations of the temperatures and precipitation of the CRB. The expedition started in 1804 from Illinois and ended in 1806 upon arrival in St. Louis, Missouri (Buckley 2023). The public purpose of the Expedition was to explore the lands newly acquired from the Louisiana Purchase of 1803. Self-described 'men of the enlightenment', Lewis and Clark recorded and documented many pieces of information that became valued historical documents, including comments and observations about the prevailing temperatures and precipitation in the CRB.

The Expedition did not arrive at what is now known as the CRB until 1805 and would depart the Basin the following year. While the Expedition lost its only thermometer for this portion of the journey (Lewis et al. 2002), there have been efforts made to reconstruct the climate based on the observations of the Expedition, more recent climate data, and dendrological data. Knapp (2004) provides us with the most comprehensive look at the likely conditions by highlighting the fact that Expedition came through the CRB during a period best described as 'lucky' in terms of weather with relatively mild wetter and cooler conditions, with no occurrence of the massive droughts the upper regions of the CRB are historically known to be prone to (Knapp 2004). Despite this, there appears to be an extraordinary number of precipitation observations made while the Expedition overwintered at Fort Clatsop (Burnette 2002). Precipitation was observed on at least 90% of the days spent at Fort Clatsop (Knapp 2004). The Expedition is known to have thought the amount of precipitation experienced at this location to have been categorized as 'miserable', and the observations provided underscore that the prevailing conditions were abnormally high for precipitation (Solomon and Daniel 2004).

There are few other documented observations from 1800 to 1850 in the CRB, and thus greatly limit the ability to study this period from human-collected observations. There is a whole year's worth of weather observations at Fort Vancouver from June 7th, 1833, to May 31st, 1834, found in The Edinburgh New Philosophical Journal (Volume 20). These observations were taken by Dr. Meredith Gairdner and include several noteworthy observations about temperature and precipitation. Gairdner noted freezing temperatures where the thermometer did not rise above 32° F for 61 days. One of the observations made during this span of freezing weather included "The Columbia [River], which is here 1660 yards wide, and 5 to 7 fathoms [fathom = 6 ft] deep, closed when the temperature fell to 14°, and continued frozen for three weeks, permitting of free traffic across it." (The Edinburgh New Philosophical Journal 1835). This passage describes the Columbia River freezing over at Fort Vancouver to the point where people were walking on the iced-over river, something that is unimaginable in today's climate. Gairdner also noted 22 days of snow, 130 days of rain, and a little over 40 inches of rainfall. Snowfall amounts were not recorded and thus cannot be used to estimate total precipitation amounts. It should be noted that the rainfall total alone almost matches the modern-day average precipitation observed at Fort Vancouver (*NOAA NCEI U.S. Climate Normals Quick Access*, n.d.). Unfortunately, Gairdner's data, providing such detailed observations, proved to be a rare exception in the CRB in 1800-1850.

A singular observation made at Fort Vancouver revealed the winter temperatures of 1834 were described as unusually cold, with below freezing temperatures observed from December 26th through the end of January, and a low of 6°F (The Edinburgh Medical and Surgical Journal ... 1836). A handful of observations are reported in "Journal of an Exploring Tour Beyond the Rocky Mountains: Under the Direction of the A. B. C. F. M." about the temperatures and precipitation at Fort Vancouver through the winter of 1835. The journals wrote of the presence of rain and snow on October 24th, 1835, at Fort Vancouver and other snowfall and rain events through the winter (Parker 2015).

While the few measured temperatures available hint at cold temperatures, the rain and snowfall occurrences were considerably earlier than they are now (*Western Regional Climate Center*, n.d.). These sparse observations are often all that are available for precipitation and temperature on the CRB. Even such small clues as the date of the first observed snowfall can help infer the cooler and wetter conditions on the CRB at this time.

Dendrochronology

Tree rings can be analyzed to make inferences about many factors, including temperature and precipitation (Wiles et al. 1996*a*). When looking simply at dendrologically determined temperature data, much of the broader-scale studies support the conclusion that 1800-1825 was cooler, followed by a slight warming trend from 1825 to 1850 (Briffa et al. 1992, Anchukaitis et al. 2017). Trees studied in concert with glacial activity particularly supported that conclusion, both at the finer scale on the CRB (Miller 1969) and at broader scales including Canada and Alaska (Wiles et al. 1996*b*). The trees at broad scales also demonstrate the ability to capture widespread changes in temperatures, such as those caused by volcanic eruptions (Zhu et al. 2022, Leland et al. 2023).

Trees captured data concerning precipitation and drought conditions on the CRB from 1800 to 1850. Consistent with the premise that this span of years was wet and cool, while there does appear to be some evidence of relatively dry conditions, particularly from 1825 to 1850, there does not appear to be evidence to support the conclusion that there were common or widespread moderate or severe drought conditions during these years, especially when compared to the preceding years or following (Brubaker 1980, Wise 2016, Littell et al. 2023).

Moderate to severe drought conditions were not noted at broader scales from 1800 to 1850, including areas adjacent to the Columbia River Basin (Knapp et al. 2004, Cook et al. 2007, Herweijer et al. 2007). While some slightly dry conditions do appear to have happened from about 1826 to 1850, it is noteworthy that there is almost a complete absence of mild, moderate, and severe dry conditions from 1800 to 1825 (Brubaker 1980, Knapp et al. 2004, Herweijer et al. 2007). This is consistent with wetter conditions from 1800-1825, followed by slightly drier conditions from approximately 1826 to 1850. Data gathered simply on the precipitation variation present on the Basin during these years further supports this idea, with average to above average precipitation observed in the majority of years from about 1800-1825, gradually tapering into what appears to be a somewhat drier pattern with more years of less than average rainfall observed than above average from 1826-1850 (Graumlich 2005, Lutz et al. 2012).

Tree-ring studies with finer scale show that location in the Basin matters greatly for precipitation data. Looking at data concerning the flow of the Columbia River close to the confluence with the Pacific Ocean implies that the precipitation on the Basin flowing to the Columbia River generally agrees with the premise of wetter precipitation conditions found from 1800-1850 (Littell et al. 2016). However, Littel et al. (2023) documented from tree-ring data that river flows from different areas of the CRB may yield quite different results than from one reading along the main stem of the river. It is implied that some areas of the Basin were drier than others, and the pattern of wet from 1800 to 1825, then dry from 1826 to 1850, is not as clear at smaller scales.

Lastly, the influences of the El Niño Southern Oscillation (ENSO) are a climate driver in which tree rings can be valuable assets to utilize to study the phenomenon. With data derived from trees, some generalized observations can be made about what temperature and precipitation were like from 1800 to 1850 in the CRB. Researchers looking at tree rings found weak La Niña influence from 1800 to 1825, consistent with these years being characterized as being wet and cool (Peterson et al. 1999, Knapp 2004). Cook et al. (2007)

found that, similar to most of the other broad-scale data, ENSO also points to increasing chances for La Nina-like conditions and strengthening overall ENSO influences, but relatively warmer and drier conditions for approximately 1825 to 1850.

Glaciers

Glaciers can be strong indicators of climate activity (Lowell 2000), and the CRB and Northern Cascade Mountain Range are home to a series of well-studied glaciers. Washington state alone accounts for over 75% of the glaciers present in the lower 48 states of the United States (Meier 1961), and several areas of glaciers have been studied immediately adjacent to the Columbia River Basin. Overall, conditions that appeared to have been favorable to glacier growth were observed primarily from 1800 to 1823, as most glaciers in the CRB and the surrounding areas grew during this time (Miller 1969, Burbank 1981). However, after about 1830, glacial patterns became much less comparable to each other, and while there was overall CRB and regional agreement for conditions before about 1830, the data suggest that glacier behavior in the CRB was much more disparate from glacier to glacier than before 1830.

Glaciers are useful in looking at temperatures and precipitation because they require very specific conditions to expand or contract (Lowell 2000). Conditions that favor the growth of glaciers tend to be driven heavily by complex factors (Kumar 2011) but can be generalized to include cooler conditions and readily available precipitation. Conditions that are dry and warm may lend themselves to the glaciers shrinking through melting, sublimation, or other environmental influences (Copland 2011). One of the ways to assess glacier activity is by looking at the presence and age of moraines created by glaciers moving rocks, sediments, and other material (Schomacker 2011). Moraines can be dated and utilized to examine the historical footprint of a glacier (Briner 2011). Over time, many of these footprints may be present as the glacier expands or contracts. Examining the dates moraines were created, it can offer insights about when the glacier may have been at its maximum size (Schomacker 2011).

Glacial moraines created synchronously across and near the Columbia River Basin point to the growth of these glaciers due to favorable temperature and precipitation conditions before 1830, and the subsequent shrinking of the glaciers to have left these moraines (Lowell 2000). For example, in Mount Baker, a peak found on the upper Columbia River Basin, near the US and Canadian border, a significant moraine was dated to 1823 (Heikkinen 1984). Moraines created on Mount Ranier, a large volcano located in the upper CRB, were noted as also being formed around 1823 (Burbank 1981). Miller (1969) noted several glaciers in the Dome Peak area in the upper CRB near the modern US-Canada

Border, built moraines in approximately the same timeframe, and Coe Glacier on Mount Hood in the lower CRB was likewise found to have moraines created around 1823 (Lillquist 1988).

After 1830, Luckman et al. (2000) did not find the same level of agreement between the data sets on when glaciers may have expanded or contracted. A plausible explanation for these sorts of finer-scale differences might be as simple as the glaciers responding to local precipitation and temperature phenomena (Huybers and Roe 2009). In Alaska, Canada, and other areas in North America, glaciers continued to increase well past 1830 (Luckman 2000, Gaglioti et al. 2019), implying that cool and wet conditions prevailed in those locations. In the CRB, there is more disagreement about the observed glacier behavior. For example, for Mount Baker and Mount Rainier, there did not appear to be any more significant moraine activity until just after 1850 (Burbank 1981, Heikkinen 1984), and for the Dome Peak area, there is little to no moraine activity observed until much closer to 1900 (Miller 1969).

Unfortunately, the presence of moraines alone does not give a particularly close inference about temperatures and precipitation for 1800-1850. Dendrochronology can fill some of the gaps in a few of the cases where data were taken concurrently or as part of a glacier study. In the case of Heikkinen (1984), tree rings were studied in concert with glacier behavior, and offer more attuned insights for temperature from both the glacier and the trees. As temperatures declined and the glaciers grew, there was a remarkable correlation between when the trees exhibited very narrow rings and the formation of moraines. Tree ring samples yielded narrow rings up until approximately 1823, but then the rings grew wider after that point, seeming to indicate a warming trend post 1823 (Heikkinen 1984). Wiles et al. (1996) similarly used glacial advance data in concert with tree ring data and noted a similar pattern of relatively cooler temperatures from 1800 to 1823, with a shift to relatively warmer temperatures from 1824 to 1850 (Wiles et al. 1996*b*).

Volcanic Activity and the El Niño Southern Oscillation

Phenomena external to the CRB, such as the El Niño Southern Oscillation (ENSO) and volcanic eruptions, are known to be important factors in Pacific Northwest climate concerning precipitation and temperature (Robock 2000, McGregor and Timmermann 2010). These broad-scale facets of climate are often studied at scales too large to infer temperature and precipitation conditions in the CRB itself or confined to a 50-year timespan. Nevertheless, they are important factors for determining wet and cool conditions in the Columbia River Basin (Praskievicz and Chang 2009, McAfee and Wise 2015).

Volcanic activity has been linked to cooler temperature phenomena at a global scale, particularly when the eruption is large, and it is well documented to cause cooling that can span the entire globe (Robock 2000). One of the noteworthy volcanic events that happened in the years spanning 1800 to 1850 is the 1815 eruption of Mount Tambora in Indonesia. The 1815 eruption is the largest recorded volcanic eruption in human history (Britannica et al. 2024). Many times larger than the 1980 eruption of Mt. Saint Helens and the 1991 eruption of Mt. Pinatubo, it is widely regarded that the 1815 eruption would lead to the extreme cool weather events of 1816, more commonly known as "The Year Without a Summer"(Lautenbacher and Pfister 2015). The effects of this cooling were felt around the globe (Warde and Fagan 2002), including in the CRB. Accounts of the cooling caused by the eruption of Mt. Tambora are unknown on the CRB; the cooling effects, which, among other things, caused crops to fail and unseasonable cold weather, are well-known from more populated areas like Europe and the eastern United States (Warde and Fagan 2002).

A second large volcanic eruption, only slightly smaller than Mt. Tambora, is known to have occurred in 1808; the location of this eruption is unknown (Guevara-Murua et al. 2014). Additionally, while not as large as the eruptions of Tambora or the unknown eruption, Mt. Saint Helens from 1800 to 1857 was volcanically active (Clynne et al. 2005). Many other smaller eruptions occurred worldwide in the years between 1800 and 1850, but the two larger eruptions from Tambora and the unknown locale are known to have been particularly influential in the cold temperatures observed (Brönnimann et al. 2019), particularly the years spanning 1800 to 1825. Therefore, it is likely that these two large eruptions contributed to the low temperatures during 1800-1850.

Similar to volcanic activity, the El Niño Southern Oscillation is known to be a wide-reaching influence on temperatures and precipitation in the Columbia River Basin and beyond (Cayan et al. 1999, Clark et al. 2001). One of the earliest indicators of ENSO influence was previously mentioned: the Lewis and Clark Expedition. Knapp (2004) found that the Expedition observed temperatures and precipitation patterns that, when studied in concert with dendrological data, reveal a distinct La Niña influence. The temperature was observed to be cooler and wetter than average, which was consistent with La Niña influence in the Pacific Northwest, even with what was thought to be a relatively weak signal (Knapp 2004). Larger-scale studies similarly grounded in tree-ring data confirm these wetter-than-average and cool La Nina conditions for the years spanning approximately 1800- 1825 (Cook et al. 2007). The years spanning 1826-1850 were found to be characterized by increasing strength and variability of ENSO events with fewer incidences of cool and wet conditions as observed from 1800 to about 1825 (Gedalof and Smith 2001, Barron and Anderson 2011). Some of the data seem to suggest that the prevalent La Niña ENSO signal from 1800-1825 could have been in part attributed to the cooling known to occur from volcanic activity (Leland et al. 2023, Pausata et al. 2023). Thus, the increasing strength of ENSO signals from 1825 to 1850 is congruent with the waning influence of volcano-driven climate cooling, decreasing amounts of precipitation, and slightly warmer temperatures towards 1850 (Wiles et al. 1996*b*).

Despite the ready availability of recent hindcasting studies looking at ENSO, many of the studies available were unsuitable for use in this paper. Some of the studies, such as the one conducted by Steinman et al. (2012), concluded with an outlier opinion that the Little Ice Age (including the span of years 1800-1850) was likely drier than the years prior. Such a conclusion is incongruent with the ground observations, recorded glacier activity, and tree-ring data, and serves as a reminder that some forms of modeling may yet need more work to accurately reflect past conditions.

Conclusion

While it will never be truly known with the accuracy of modern standards, the CRB 1800-1850 most likely was cooler and wetter than current conditions, and thus it is likely that climatic conditions during this period were better (from a salmon perspective) than they are now.

The information analyzed provides a picture of what temperature and precipitation conditions existed for salmon two centuries ago in the CRB. The early 1800s were before any major alteration of the CRB, and ecological conditions would be natural and minimally affected by human actions. If the CRB today could somehow be returned to its pristine 1800-1850 state, overall salmon abundance would likely be less than the early 1800s simply because climatic conditions were better (for salmon) in the earlier period.

The implicit assumption that the 1800-1850 climate was the same as it is now is an assumption that, while it is likely not an explicit assumption, it is one that is prevalent in most salmon recovery strategies. The factors driving the decrease in salmon populations are generally well understood, at least in broad terms, but most policy makers do not consider factors like changes in precipitation and temperature, nor do they consider how or when they might have changed from conditions more favorable to less favorable.

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