

Peering Into the Past: Species Identification of Archaeological Pacific Salmon on  
Southwest Vancouver Island

by

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## Abstract

With anthropogenic climate change accelerating, environmental scientists, historical ecologists, and fisheries scientists alike have been asking questions about the future of our oceans. Understanding Pacific salmonid species composition at archaeological sites through very long-time horizons could provide answers to some of those questions. Archaeological studies of five species of northeast Pacific salmon (*Oncorhynchus gorbuscha*, *O. nerka*, *O. keta*, *O. tshawytscha*, and *O. kisutch*) on the Northwest Coast have become increasingly important for understanding the historical distribution and exploitation of these significant cultural and ecological species. This is a regionally grounded study utilising archaeological salmon vertebrae collected from the Tseshaht village site of Kakmakimih on the southwest coast of British Columbia. Vertebral morphometric analysis has been proposed as an inexpensive, non-destructive supplementary method to other more established methods of identification (ancient DNA testing, and collagen peptide analysis [ZooMS]) to infer or identify salmon species in archaeological assemblages. I apply the method of vertebral morphometric measurements to characterise and identify archaeological salmon species from vertebrae. I also investigate morphometric variability throughout the vertebral column and apply the morphometric measurements method to anatomically ordered vertebrae from modern salmonid specimens. Through data exploration and statistical analysis, I find that vertebral morphometric analysis has the potential to refine salmon species identifications in archaeological assemblages. This methodological approach contributes to the broader theme of evolution and ecology in anthropology by providing insight into human-non-human relationships in the past and present, and by reconstructing salmon populations that are so crucial to Indigenous fisheries.

**Keywords:** Archaeology, Zooarchaeology, Indigenous Fisheries, Vertebra, Morphometrics, Morphology, Salmon

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## Introduction

Pacific salmon (*Oncorhynchus spp.*) have and continue to play a vital role in sustaining Indigenous communities on the Pacific Northwest coast. The relationship between Indigenous People and salmon on the Pacific Northwest coast spans thousands of years and goes beyond its use as a food source but is part of the collective identity of many different Indigenous Nations up and down the North Pacific Coast. (Suttles, 1990; McMillan et al., 2008; Coté, 2022). Salmon bones occur frequently in archaeological sites on the Northwest Coast but identifying these bones to a specific species is challenging. Morphological similarities between salmon species has contributed to the lack of research on species level designation through osteological differences. However, in the last two decades, archaeological studies reveal that ancient DNA combined with vertebral morphometric analysis can be successful in determining the specific species of salmon from their vertebrae (Cannon & Yang, 2006; Moss et al., 2014; Huber et al., 2011). Currently, methods to identify archaeological salmon vertebrae to a species level is expensive, time consuming, destructive, and largely inaccessible, especially for processing the large quantities of vertebrae typically found in archaeological assemblages. Conversely, bone measurements are quicker, less costly, and can be applied much more widely. Using both archaeological vertebrae from a Tseshaht village site in the Broken Group Islands, BC, and modern vertebrae from the University of Victoria's zooarchaeology comparative collection, I investigate the method of vertebral morphometric measurements and explore its potential utility in species identifications.

## Overview

Vertebrae are large, generally, robust bones that often withstand handling, cooking, and environmental wear better than laminar cranial bones; thus, they preserve relatively well in the archaeological record (Rojo, 1988; Butler, 1994). Despite making up a substantial proportion in coastal archaeological fish assemblages (McKechnie and Moss 2016), little is known about the distribution of salmon species over space and time on the Northwest Coast including Barkley Sound. Utilizing available data on sophisticated analysis techniques such as ancient DNA (aDNA) and collagen peptide analysis (ZooMS), already applied to Barkley Sound salmon vertebrae, I investigate the possibility of vertebral morphometric analysis as a cost effective, and non-destructive method and expands on the smaller sample sizes for these specialized analyses. I hope to add to the growing body of research in support of this method to efficiently identify archaeological salmon to a specific species. Fish vertebrae are some of the more common skeletal elements recovered in coastal archaeological sites, prior research on the species composition of salmon at has tended to focus on ancient DNA (Cannon and Yang 2006), and more recently collagen peptide analysis otherwise known as ‘ZooMS’ (Richter et al. 2020). In addition, a statistically rigorous method of morphometric analysis of salmon vertebrae has been suggested (Huber et al. 2011) but subsequent application of this method in other coastal regions (Moss et al. 2014) have shown the importance of application to regionally specific datasets as salmon species and sizes will differ between major river systems and regions.

As discussed, salmon vertebrae occur frequently in Pacific Northwest archaeological sites, but, lumping all salmon vertebrae into the broad category of “salmon spp.” prevents researchers asking important questions about species abundance in the present and the past. A lack of ability to track species designations in archaeological assemblages furthers species

declines, and economic losses caused by overfishing, and finally, can result in uninformed restoration goals (Pauly 1995). Morphological similarities between salmon species have limited research despite its outsized importance as emphasised in cultural histories and ethnography. However, in the last two decades, archaeological studies have revealed that vertebral measurements of archaeological salmon are useful in narrowing down the specific species of salmon. (Cannon & Yang, 2006; McKechnie 2012; Moss et al., 2014; Huber et al., 2011).

## **Research Questions**

This study explores the use of salmon vertebral morphometric measurements in a regional case study focused on Tseshaht territory in Barkley Sound, British Columbia as well as comparing results from available ZooMS, and aDNA identifications. I ask the following research questions:

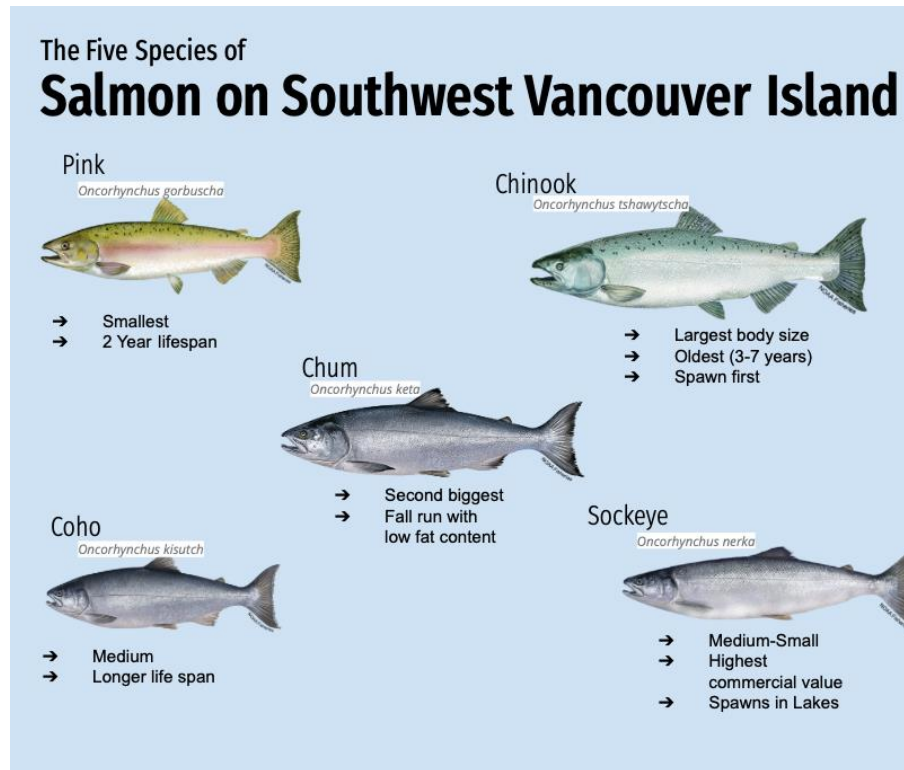
1. *Are salmon vertebral morphometric measurements an effective method in characterizing species level identification?*
2. *Is there significant variation within the vertebral column of a single salmon?*
3. *How much vertebral size variation is there between salmon species?*

I hope that by asking these questions, I can contribute a method that will be applicable to answering an even bigger question of what species of salmon were being harvested by Indigenous Peoples up and down the Northwest Coast.

## Pacific Salmon

In the north-eastern Pacific Ocean, there are seven types of marine salmon and two closely related species of freshwater trout. These species include Chinook (*Oncorhynchus tshawytscha*), Chum (*O. keta*), Coho (*O. kisutch*), Pink (*O. gorbuscha*), Sockeye (*O. nerka*), as well as Steelhead (*O. mykiss*) and Cutthroat (*O. clarki clarki*) trout which are found in various rivers and streams (Groot and Margolis 1992). For the purposes of this study, I focus my research on the five marine species of Pacific salmon present in the study area on western Vancouver Island. These five species consist of the following salmonids: Pink (*Oncorhynchus gorbuscha*), Sockeye (*O. nerka*), Chum (*O. keta*), Chinook (*O. tshawytscha*), and Coho (*O. kisutch*) (fig.1). The body sizes of salmon differ, Chinook are considered to be the largest in body size and live from 3-7 years old. Chum are the second largest Pacific salmon species, and Pink and Sockeye are among the smallest (Bartosh & Hrynshyn, 2001; Hillis et al., 2022).

Figure 1 Overview of the 5 species of Pacific salmon on Southwest Vancouver Island. Salmon images adapted from NOAA (2022).



The life history of Pacific salmonids (*Oncorhynchus* spp.) is considered to be a relatively complex one as it involves both freshwater and marine environments. Often described as a keystone species, a term introduced by Robert Paine in 1969, salmon play a crucial role in maintaining the structure and function of an ecological community (Paine, 1969). Quinn (2005) provides in depth detail of their role, describing how Pacific salmon provide a key source of food for many predators including bears, eagles, orcas, and as a result are participants in complex food webs that support a diverse variety of other species. The annual migration of Pacific salmon helps to distribute essential nutrients throughout the ecosystem, a process known as “Nutrient cycling” (Quinn, 2005). When salmon die after spawning, their bodies provide a rich source of nutrients for other organisms in the ecosystem and help to fertilise the surrounding land and water (ibid.). Because Pacific salmon have and continue to play such a significant role in their

environments, understanding species distribution through time can help us to conserve and manage Pacific salmon populations in the future.

### *Cultural Significance of Pacific Salmon*

For thousands of years, Indigenous Peoples of the Pacific Northwest coast have had a deep and multifaceted relationship with salmon that extends beyond its use as a food source. This relationship is an integral part of the cultural identity of various Indigenous Nations along the North Pacific Coast (Suttles, 1990; McMillan et al., 2008; Coté, 2022). Charlotte Coté highlights the importance of salmon to Tseshaht and other Nuu-chah-nulth speaking nations in her book “*A Drum in One Hand and a Sockeye in the Other*” (2022). Coté states

“With access to so many fishing areas in the Somass River, Alberni Inlet, and around the Broken Group Islands, the Tseshaht have harvested a variety of salmon utilising different methods to catch and process them. This iconic species in the Northwest Coast plays a critical role in supporting and maintaining the region’s ecological health, and it is entwined in the social fabric of our Indigenous culture and food traditions. Indigenous Peoples have a cultural concept of “food as medicine”, which promotes a holistic approach to maintaining and restoring the dietary, emotional, and spiritual health of our bodies. It means maintaining the ecosystems that provide us with food.” (Coté, 2022, pp 61).

### **Methods of Identification: aDNA & ZooMS'**

In the 1990s ancient DNA technology demonstrated that DNA could be recovered from bone and used to identify specimens to a species level designation (Moss et al., 2014). Ancient DNA refers to DNA that has been extracted from the remains of ancient organisms, fossils, or bones. It involves a long process with steps requiring a highly qualified technician, and specialised equipment and laboratory space. In a study conducted by Yang et al. (2004), researchers were able to extract DNA from ancient salmon vertebrae that were dated to a range

of 7000-2000 years before present. This study involved the development of highly sensitive PCR methods that were specifically designed for degraded DNA samples. This technique was used to accurately identify the species of salmon remains found at the site of Namu, located on the central coast of British Columbia. Ancient DNA has proven to be an effective method of identification and has been used in a variety of studies regarding archaeological fish (Moss et al., 2022; Palmer et al., 2018). Including studies of herring and rockfish in Barkley Sound (Rodrigues et al., 2018; Speller et al., 2012).

Zooarchaeology by mass spectrometry is a comparatively new method but is increasingly being used to identify archaeological remains in the Pacific (See Richter et al., 2011, 2022). ZooMS, which stands for Zooarchaeology by Mass Spectrometry, is a method of identifying animal remains found in archaeological or paleontological sites. This method is based on the identification of the collagen protein found in bones, which is one of the most abundant proteins in animal tissues. ZooMS works by extracting collagen from animal bones and analysing it using mass spectrometry, which can provide information about the molecular weight and composition of the protein (Richter et al., 2011). By comparing the results to a reference database of known animal collagen profiles, researchers can identify the species of the animal from which the bone came. One advantage of using ZooMS over aDNA is that it can be used on small bone fragments, however, the method is still costly, destructive, time consuming, and requires specialised equipment and a dedicated laboratory space.

While both aDNA and ZooMS are well respected and accurate methods for identification in archaeology, the associated cost, time, and destructive nature presents limitations and cannot

identify skeletal elements or indicate size or age at harvest. A cost-effective alternative or complement to aDNA testing is vertebral morphometric analysis. This method was first explored by Cannon and Yang (2006) who observed that the greatest diameter corresponded to three categories of small, medium, and large species. In 2011, Huber and colleagues developed a series of measurements and a complex statistical analysis tool to identify vertebrae to species using samples of hatchery raised fish on the upper Columbia River. In 2014, Moss and colleagues tested this method for salmon in southeast Alaska and observed that only a portion of the vertebrae matched Huber et al.'s species designations, suggesting that species in that region might not be suitable for Huber et al.'s vertebral size categories. More recent aDNA research on archaeological salmon has been conducted at other sites on the Northwest Coast (Morin et al. 2021; Royle et al. 2018) but have neglected to explore the question of morphometric analysis further. As a result, the issue of how measurements of salmon vertebrae have relevance remains unaddressed.

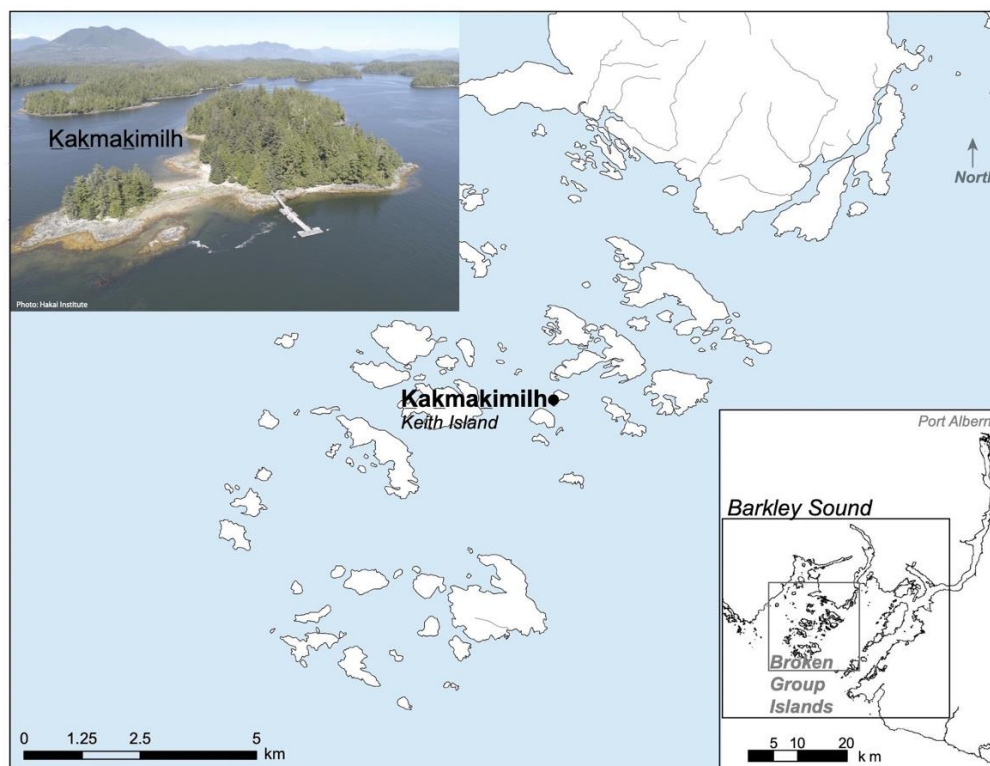
## Methods

Building on this prior research, this thesis focuses on measurements from identified archaeological salmon in a specific region as there has been considerable change in salmon fisheries in the late 20<sup>th</sup> century. This study focuses on archaeological salmon vertebra from the Tseshaht village site of Kakmakimih, Barkley Sound (Figure 2). I additionally consider modern salmon vertebra from known species present in the University of Victoria's zooarchaeology lab and comparative collection. Using both an archaeological and modern dataset with secured species identifications attached to each vertebrae allowed me to ask several questions. In this research, I ask, *are vertebral morphometric measurements an effective method in characterizing*

*species level identification of salmonids? Is there significant variation within the vertebral column of a single salmon? And how much vertebral variation is there between salmon species?*

I hope that by asking these questions, I can contribute to answering this bigger question of what species of salmon were being harvested by Indigenous Peoples up and down the coast of Vancouver Island.

*Figure 2: Tseshahat village site of Kakmakimih, Barkley Sound. Image courtesy of Iain McKechnie.*



## Archaeological and Modern Salmon Vertebrae

While there were many archaeological salmonid vertebrae found at the Tseshahat village site of Kakmakimih throughout the five-year project, my inclusion criteria for this research project was that they had to be securely identified to a species by means of ZooMS or ancient DNA testing, and that the same vertebra had to be measured following Huber et al.'s (2011)

morphometric measurements. In total there were 27 identified archaeological salmon vertebrae from the site of Kakmakimih that met these criteria and, as a result were included in this study. The collagen peptide analysis (ZooMS) and ancient DNA testing was completed at UBC's ADαPT lab and provided the following results (see Table 1). Seven vertebrae were identified as Chinook, 16 Chum, two Sockeye, and two Coho. Based on past studies using aDNA, and ZooMS demonstrating the methods' reliability (see Cannon and Yang 2006; Palmer et al., 2018; Moss et al. 2022; Richter et al. 2011, 2020, 2022), I decided that for this study I would use vertebrae that were identified by either aDNA or ZooMS.

*Table 1 Measured Archaeological Vertebrae with ZooMS and aDNA Identifications from UBC's ADαPT lab (n=27).*

ZooMS_ID	aDNA_ID	Transverse_Diameter (mm)	Length (mm)	Height (mm)
Chinook	N/A	14.58	8.54	14.17
Chinook	N/A	14.96	8.48	13.86
Chinook	Chinook	15.35	10.39	14.09
Chinook	Chinook	15.07	9.19	13.22
Chinook	N/A	15.95	10.71	14.71
Chinook	Chinook	12.3	7.34	11.13
Chinook	N/A	15.47	9.3	13.98
Chum	Chum	10.34	5.69	8.99
Chum	Chum	10.24	10.17	8.89
Chum	Chum	9.81	4.97	7.54
Chum	N/A	9.11	5.94	7.64
Chum	Chum	11.09	8.02	10.19
Chum	Chum	10.41	7.33	9.62
Chum	N/A	11.18	8.32	9.73
Chum	N/A	11.02	7.89	10.52
Chum	N/A	9.97	7.05	9.37
Chum	N/A	9.26	8.23	10.12
Sockeye	N/A	6.78	4.57	6.03
Sockeye	N/A	6.82	4.09	6.06
Coho	Coho	8.45	6.15	8.17
Coho	Coho	8.9	6.29	7.93
Chum	Chum	10.88	8.05	10.64
Chum	N/A	10.75	6.78	9.56
Chum	N/A	9.03	4.7	8.28
Chum	N/A	11.6	8.1	8.72
Chum	N/A	7.84	7.6	9.57
Chum	N/A	11.26	8.47	10.18

To extend this small sample size of archaeological salmon vertebrae, I additionally utilise modern salmon vertebrae from the University of Victoria's Zooarchaeology Comparative Collection (McKenzie, 2021). Not only does including modern salmon extend perspective and sample size, but has allowed for questions about vertebral column uniformity, and separation through vertebral size between species. From the comparative collection I have selected five individual fish, one of each Pacific salmon species found in the waters around Vancouver Island (Pink, Sockeye, Chum, Chinook, and Coho). The selected specimens were all adults, identified before skeletal preparation in the zooarchaeology collection, and had their vertebrae strung in anatomical order (Figure 3). In total, I measured 282 vertebrae from five fish following Huber et al (2011) which involves three measurements per vertebrae. This resulted in a total of 846 measurements taken from the five modern salmon specimens.

Figure 3 Adult Sockeye (*O.nerka*) Vertebrae in Anatomical Order.

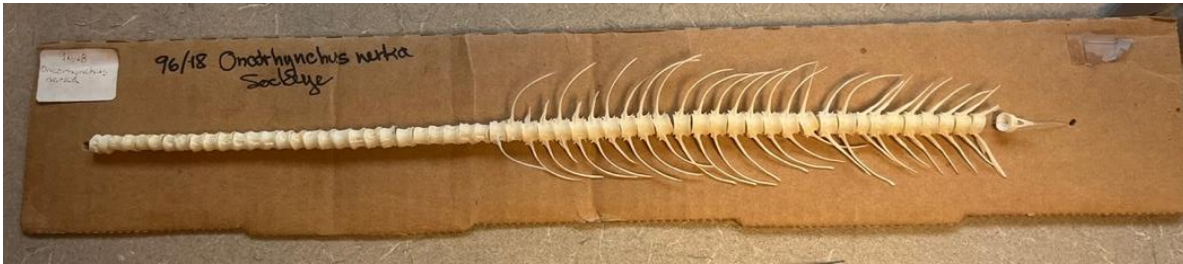
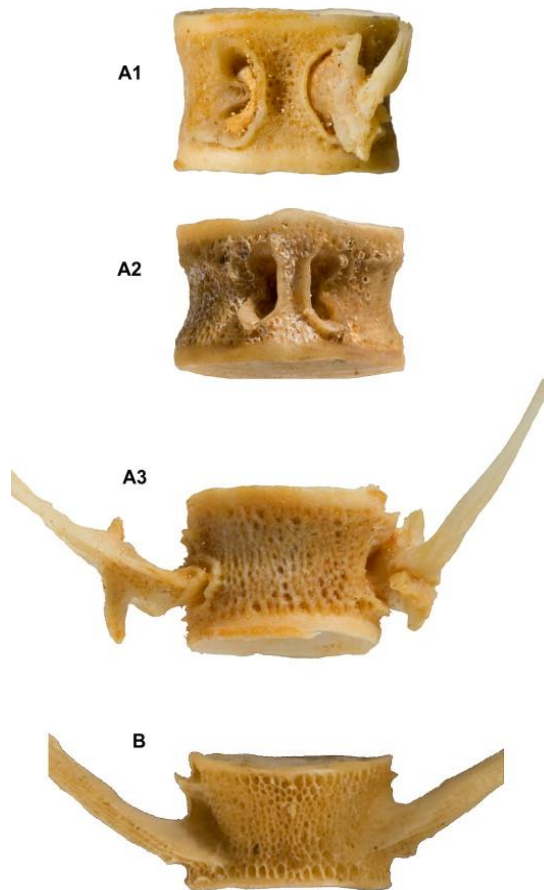


Figure 4 Image from Huber et al (2011) depicting abdominal (A1, A2, & A3) and caudal vertebrae (B). Highlighting the difference of unfused centra (abdominal) and fused dorsal/haemal (caudal).



## **Vertebral Morphometric Measurements**

Vertebral morphometric analysis has been proposed as an inexpensive, non-destructive supplementary method to other more established methods of identification (aDNA ZooMS) to infer or identify salmon species in archaeological assemblages (Huber et al, 2011; McKechnie, 2012; Grier et al, 2013, Moss, 2014). In this study, I follow the Huber et al (2011) measurements but do not apply the same complex statistical methodology. Rather I use exploratory data analysis to consider how these measurements may cluster together by species.

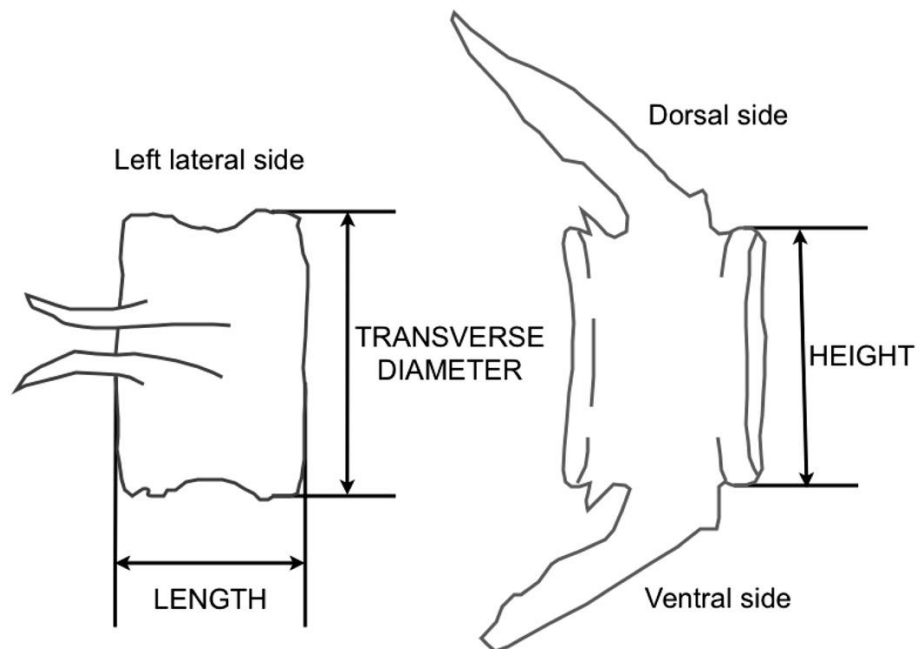
Though there are four types of vertebrae in Pacific salmonids, abdominal (type 2) and caudal (type 3) vertebrae make up 90% of the vertebral column (Butler, 1994). For this study, I concentrate on the two most abundant vertebrae in the column, caudal and abdominal. To identify the differences between abdominal and caudal vertebrae I turn to Huber et al (2011), and Butler (1994) who clearly define abdominal vertebrae as showing centra with unfused processes, and caudal as having fused dorsal/haemal spines (Figure 4). Following Huber et al (2011), I measured each vertebra in three distinct ways. Using Bluetooth enabled callipers, I measured the transverse diameter, length, and height of each vertebra (see Figure 5 & 6) and noted the vertebrae type.

## **Methods of Analysis**

The primary methodology used in this research was that of exploratory data analysis (EDA). I used EDA to analyse, investigate, and summarise both my archaeological and modern datasets. I applied this method to the modern salmon vertebrae, looking specifically at the size variation of vertebrae within a single salmon using all five of the specimens. I then used the same

modern data to investigate variation between the five different species of salmon, and eventually integrated the archaeological dataset into this analysis. To evaluate these relationships, I created a series of multivariate and bivariate plots. This helped me to identify patterns and observations in these data, as well as laying the groundwork for further statistical analysis to be completed. To complete this data analysis, I relied heavily on statistics software including RStudio, and Past4.

*Figure 5 Image from Moss et al. (2014) measurements of length, height, and transverse diameter on a Type III salmon vertebra.*



The secondary method of analysis that I use in this study is multivariate hierarchical clustering analysis (MHCA). This is a statistical method used to group subjects into clusters based on multiple variables. These clusters are built using a hierarchical approach, which involves analysing the relationship between multiple variables simultaneously rather than focusing on a single variable at a time. (Tinsley & Brown, 2000: Ch. 11). This kind of analysis considers the hierarchical structure of the data, by incorporating the relationships between the different levels of the hierarchy into the clustering process.

Multivariate hierarchical analysis is considered a type of machine learning technique, as it involves grouping similar individuals based on their attributes by using an algorithmic approach (Tinsley & Brown, 2000: Ch. 11). Because hierarchical clustering analysis is part of unsupervised machine learning, it uses the inherent structure of the data to group similar observations together. To understand the relationship between archaeological salmon vertebrae size and species designations, I completed a multivariate hierarchical analysis using the three measurements (transverse diameter, length, and height) of each of the 27 vertebrae (Figure 10).

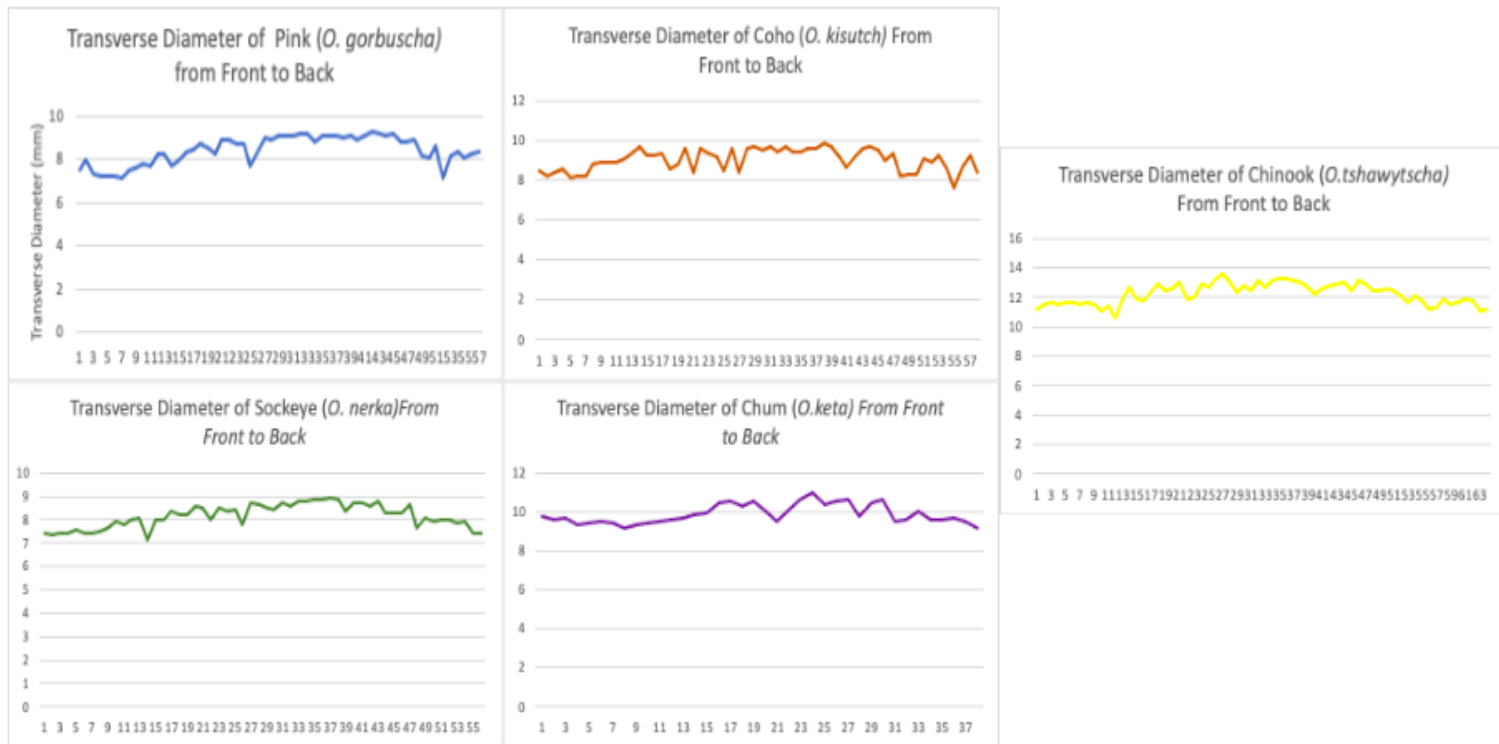
## **Findings & Results**

The results of this analysis provide insights into the potential of vertebral morphometric measurements for the species-level identification of Coho, Chinook, Sockeye, Pink, and Chum in Pacific archaeological assemblages. These results emphasize the relationship between salmon body size and vertebrae size, and reveal that the vertebral measurements of height, length, and transverse diameter in multivariate hierarchical clustering analysis clearly separates the archaeological salmon into their identified species with a high degree of accuracy. In this section, I also discuss height as having the potential to be the most diagnostic vertebral measurement, as demonstrated in the modern salmon vertebrae from UVic's Zooarchaeology Comparative Collection. Finally, I question the regional and environmental influence of salmon size by comparing the size of archaeological salmon to that of modern salmon vertebrae.

## Modern Salmon

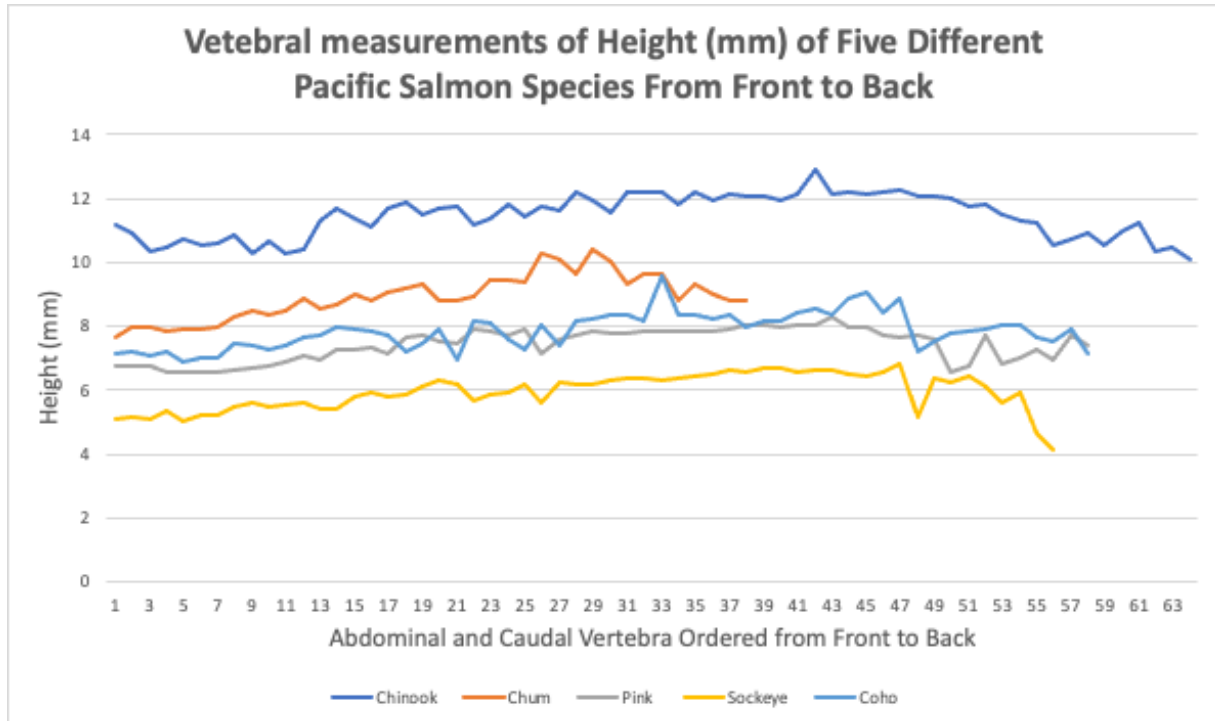
Through the use of exploratory data analysis using bivariate plots, I observe that through the five modern specimens that were in anatomical order from front to back there is little variation within a single salmon individual (Figure. 6). This means that even though abdominal and caudal vertebrae can be distinguished from one another morphologically, their size throughout the vertebral column is relatively uniform when it comes to using the transverse diameter measurement. (Figure.6). I use the transverse diameter in this analysis, based on Huber et al (2011) observation that the transverse diameter is a diagnostic measurement. I also find in the modern vertebrae sample that the number of caudal vertebrae is larger than the number of abdominal vertebrae. In the five individual salmon vertebral columns used in this study, I identified 145 of those vertebrae to be caudal (Type 3), and 137 as abdominal (Type 2). The average ratio of caudal to abdominal vertebrae in the five modern salmon specimens is 29:27. This finding is supported by Huber et al (2011) and Butler (1990) who observe a higher number of Type 3 to Type 2 vertebrae in their research.

Figure 6 Transverse Diameter Measurements of the Vertebrae from Five Individual Salmon Specimens from Front to Back



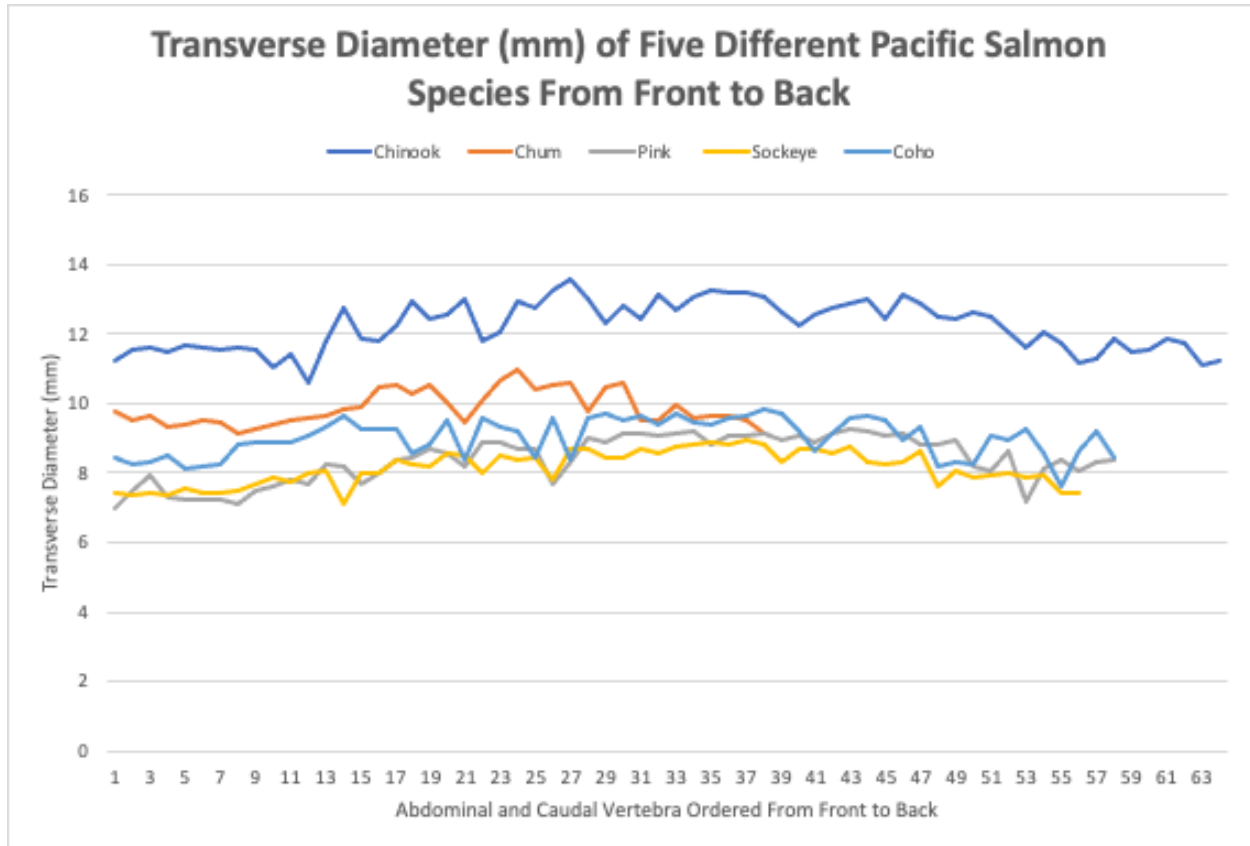
After finding limited variation between the abdominal and caudal vertebrae of a single salmon, I look to the modern salmon vertebrae to answer my next research question, *how much does vertebrae size vary between salmon species?* I plot the five individual salmon from front to back using the transverse diameter measurement (Figure 7), and the height (Figure 8). The Chinook individual shows a high degree of separation from the other five species as being larger using the measurements of both transverse diameter and height. Chinook salmon (*Oncorhynchus tshawytscha*), being of the largest body size of all five salmonid species used in this study, demonstrates a clear relationship between vertebral size and body size of species (Fisheries, 2022). The Sockeye (*O. nerka*) individual shows clear separation from the four other species of salmon in this plot (Figure 7 & Figure 8). The Sockeye individual is smaller than the other four species showing no overlap with any of the other species when using the vertebral measurement of height. Another interesting result is that the Chum (*O. keta*), shows a high degree of separation using the height measurement, and Pink (*O. gorbuscha*) and Coho (*O. kisutch*) overlap in both plots of height and transverse diameter. I find that the use of height may be a more diagnostic measurement than that of length or transverse diameter, showing a higher degree of separation between the individual species of Pacific salmon measurement than that of length or transverse diameter.

Figure 7 Vertebral height measurement of vertebrae from five different Pacific salmon species ordered front to back.



The modern salmon data set consisting of five securely identified specimens, a total of 282 vertebrae revealed that the vertebral column is relatively uniform in size in both abdominal and caudal vertebrae. While this sample could be expanded considerably and include salmon caught directly within the Barkley Sound study area, the analysis also demonstrated the high degree of separation that exists in vertebrae size between Sockeye, Chum, and especially Chinook (Figure 8). Finally, the modern sample revealed that height may be a more diagnostic measurement than transverse diameter, which differs from previous studies (Huber et al, 2011; Cannon & Yang, 2006) that observed transverse diameter to be the most distinguishing measurement.

Figure 8 Transverse diameter measurement of vertebrae from five different Pacific salmon species ordered front to back.

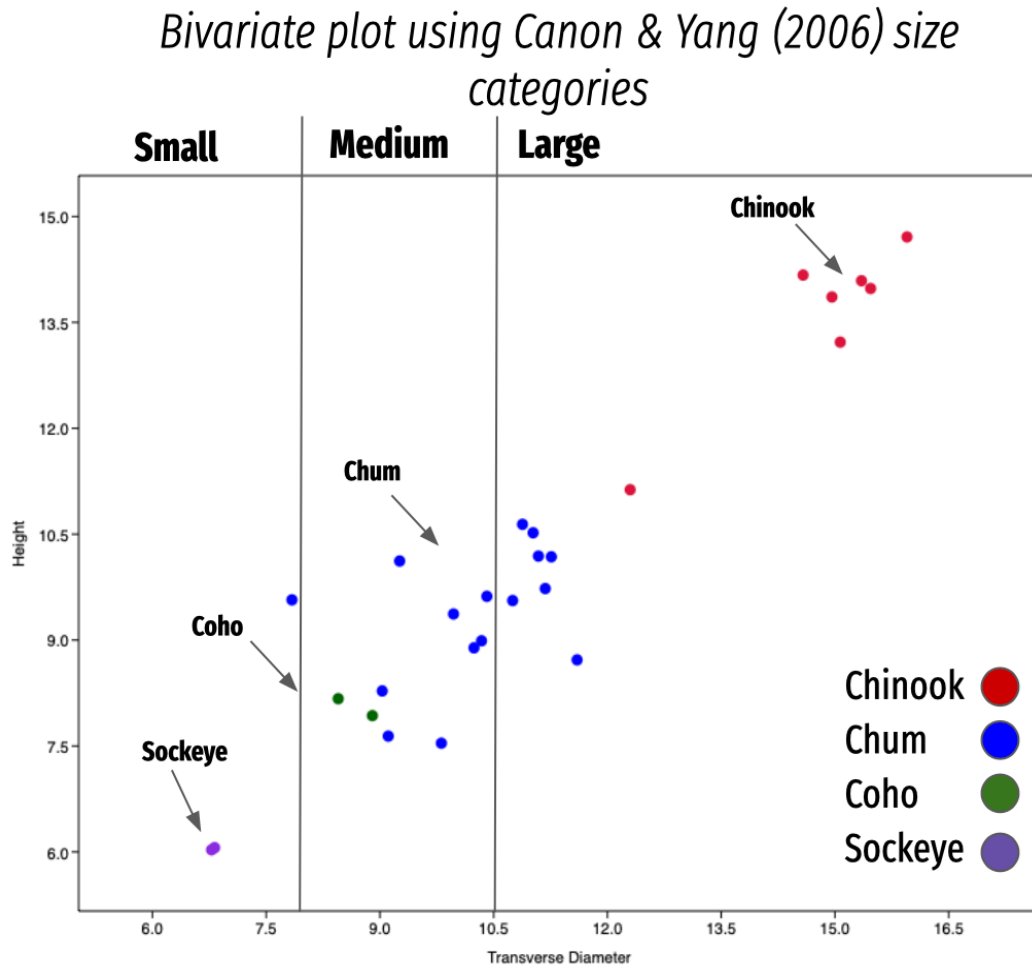


## Archaeological Salmon

I completed statistical analysis of 27 salmon vertebrae that also have aDNA or ZooMS, data securely identifying them to a species level designation. I created a dendrogram, showing the hierarchical relationship between different sets of data (Figure 10) Using a multivariate hierarchical clustering analysis, I imputed the vertebral measurements of height, length, and transverse diameter for each vertebra. The dendrogram shows the degrees of difference (or dissimilarity) between each of the vertebrae using all three measurements for analysis with clear clustering by species based on the three measurements. Resulting in a provisional success rate of

96% for clustering salmon species together. The exception represented by a single outlier which was a small Chinook salmon, as shown in Figure 10.

Figure 9 Using the 27 securely identified archaeological vertebrae from Kakmakimilh, to apply Canon & Yang size categories.



At the archaeological site of Namu, researchers Cannon & Yang (2006) determined size categories for salmon vertebrae based on their species identifications using aDNA. Using a plot of the 27 securely identified salmon from the archaeological contexts in Barkley Sound I applied these same size categories to the transverse diameter measurements from each vertebra (Figure 9). This bivariate plot provides another visualisation with clustering of species based on the transverse diameter measurements, for example, the small Chinook outlier can be seen on both the dendrogram (Figure.10) and bivariate plot (Figure 9&10). As shown on Figure 9 the size categories used by Cannon & Yang (2006) are somewhat consistent with the archaeological salmon from Barkley Sound (Figure 9). In Cannon & Yang's study, all transverse diameter measurements that were 10.5 mm or greater were identified to be Chum, and all the vertebrae measuring 8.0mm or less were identified as either Pink or Sockeye. The archaeological salmon vertebrae mostly align with these size categories, apart from a single Chum outlier measuring 7.84mm. While the archaeological salmon from Barkley Sound in this study do fit into these size categories, they show a trend of being much larger than those at Namu on the Central Coast of British Columbia This same result is reflected when plotting both the archaeological salmon vertebrae (n=27), and the modern vertebrae together (n=282) (fig.6). In this analysis, Chinook clearly show the most separation from the other four species of salmon by having the largest vertebral height. Chum is the second biggest, and Sockeye is the smallest. The archaeological salmon have a larger vertebral height than the modern salmon from UVic's Zooarchaeology comparative collection. Pink and Coho have a lot of overlap, and there are no archaeological Pink vertebrae in the 27 identified sample. Based on this analysis (Figure 8), archaeological salmon from Barkley Sound tend to be bigger than the sample of modern salmon, at least those measured in the comparative collection. The analysis of both the archaeological and modern

salmon vertebrae revealed several important findings in regard to vertebrae size throughout the vertebral column of a single fish, vertebrae size between species, and the most diagnostic vertebral measurement to distinguish size differences. These results responded to the research questions and demonstrated the value and potential of zooarchaeology, and more specifically morphometric measurements in archaeology, and species identifications.

*Figure 10 Multivariate Hierarchical Clustering (Paired group) using Height, Length, and Transverse Diameter on Identified Archaeological Salmon (aDNA + ZooMS)*

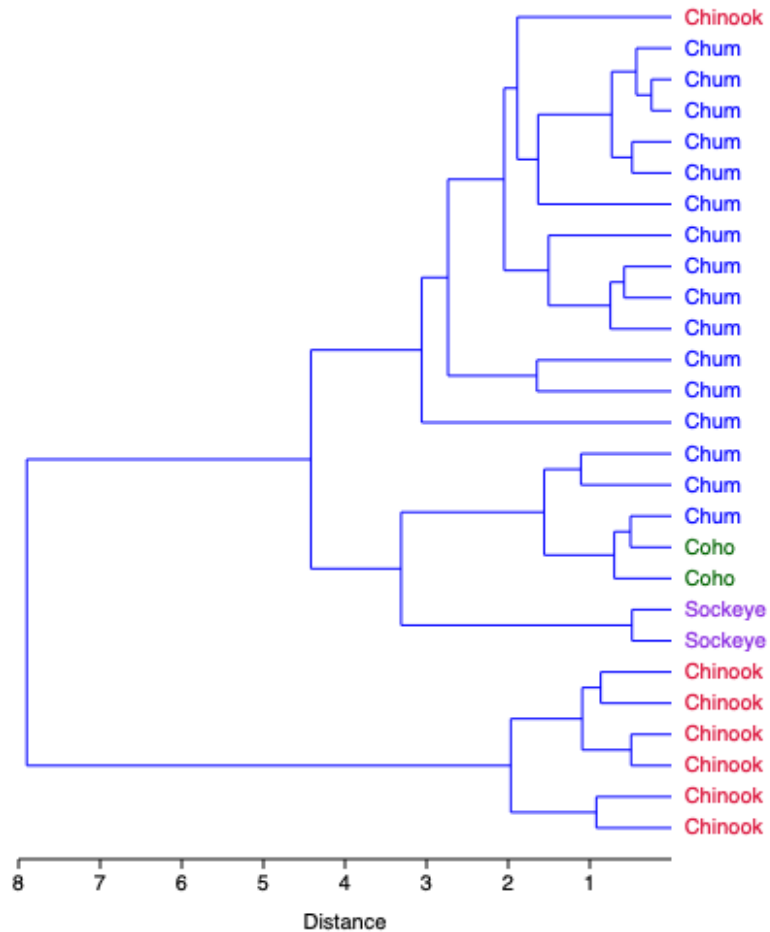
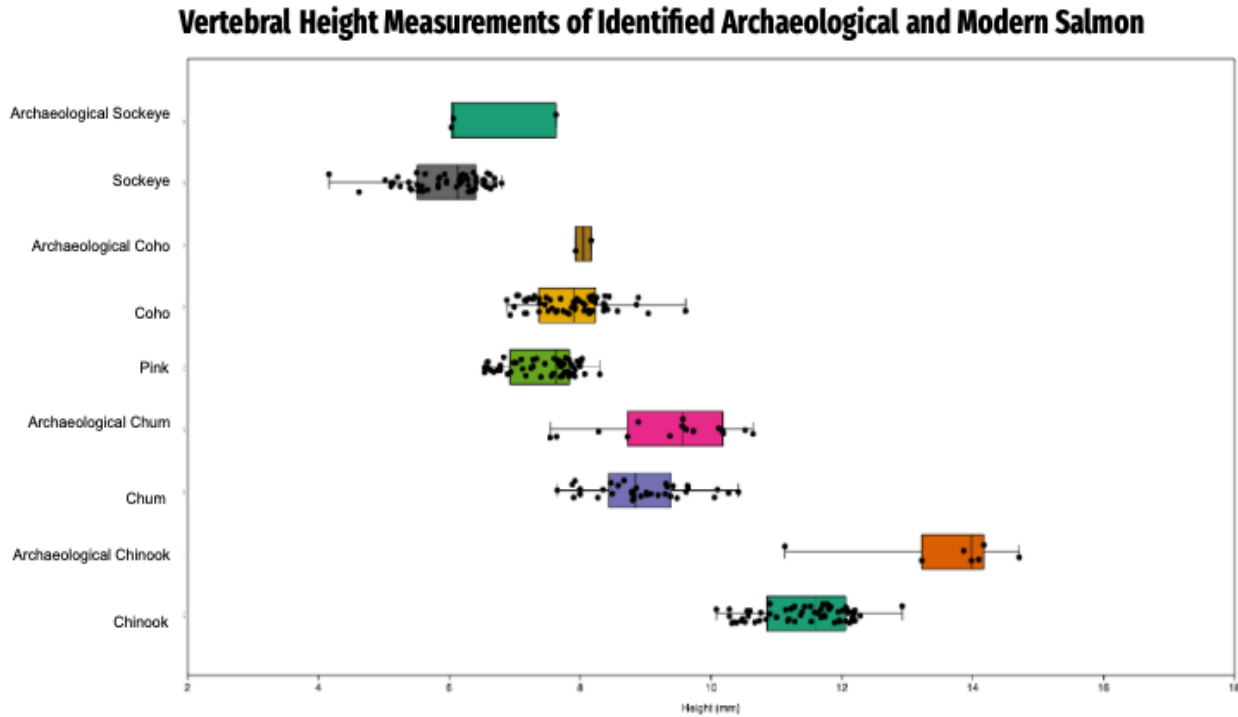


Figure 11 Archaeological and Modern Salmon Species Vertebrae Measured in Height (mm)



## Discussion

Identifying salmon species through the frequently occurring vertebrae found in archaeological sites along the coast is important for understanding the historical distribution and exploitation of these important cultural and ecological species. Through this study, I have demonstrated that there is a clear connection between salmon identified by aDNA and ZooMS and their vertebral size for the sample I analyzed. I also found that abdominal and caudal vertebrae are relatively uniform along the vertebral column. Vertebral height is potentially more useful in determining species than transverse diameter (based on modern measurements), and Sockeye, Chum, & Chinook are clearly distinguished based on vertebral measurements (particularly height measurements). Based on these findings, I also observed that salmon from Barkley Sound were larger than those on the central coast of British Columbia. There is an

ethnographic record indicating that there are multiple Chinook rivers in Barkley Sound, along with reference to noticeable size variation between the Chinook in different rivers (St. Claire., 1991; McMillan et al., 2008). A further exploration of this ethnographic record is worth exploring in future research. Another finding is that the use of a multivariate hierarchical clustering model demonstrated promise for clustering salmon species together based on the three vertebral measurements of length, height, and transverse diameter.

Refining salmonid species identifications through simple bone measurements can extend the interpretive confidence of necessarily small samples identified from DNA or ZooMS identified in a particular region. A combined strategy that considered the variation in locally available salmon species and morphometric analyses could have far reaching impacts on questions relating to fisheries science, anthropogenic climate change, and even influence modern day treaty negotiations. An example of this is in the case of a First Nation seeking to assert an aboriginal right to fish a certain species of salmon or a range of salmon species. The methods and data outlined here could be used to help address the Supreme Court of Canada's tests which require Nations to demonstrate ancestral fishing practices such as what species of salmon was (and is) a central and significant part of their distinctive culture and was it integral to their culture prior to contact. As a result, Tseshah, who do not have modern day treaty recognition of their rights, may find this method helpful as they gather evidence to demonstrate their ancestral right to fish a distinctive species previously not acknowledged by the state as a right. These are important issues at the species level in bringing rights-based arguments to allocation determinations. Such evidence of long-standing traditional practices can be useful in government-to-government negotiations.

Recent studies have revealed that Pacific salmon species may be decreasing in size, having a larger impact on their surrounding ecosystems (Oke et al., 2020). This change in body size would also impact fisheries, and those relying on salmon as a resource. By refining the method of vertebral morphometrics a baseline of body size could be better established to track body size over time, historically, and geographically. As revealed in this study, archaeological salmon from Barkley sound were significantly larger than those from UVic's comparative collection. This would be an interesting area of future research and possible application of the method of vertebral morphometrics.

## **Future Directions**

While multiple observations were made during this study, the small sample size may prevent the findings from being statistically significant. As a result, preliminary conclusions drawn here should be interpreted with caution and not generalised to a larger population. Future research with a larger sample size is recommended to strengthen the accuracy of these findings. In the future, multiple measures of the same element would be valuable to reduce measurement error, and to increase reliability. Another limitation of this study is the lack of Pink salmon identified and used in the archaeological sample. A bigger sample size from additional sites will likely remedy this, and it is premature to make an observation about the lack of Pink salmon harvested by Tseshaht. I would like to also highlight the potential of further integration of ethnographic data and oral history (e.g., McMillan & St. Claire, 2005; St. Claire, 1991). Both ethnographic data and oral history could bring a wealth of knowledge to the conversation about salmon species and size in Barkley Sound. In this study, I advocate for the use of the vertebral

morphometric method as a quick, non-destructive, cost-effective method that can extend & refine salmon identifications that have been grounded in aDNA or ZooMS identifications. However, an increased sample size of securely identified salmon vertebrae and measurements is an area for future research.

## **Conclusion**

This study highlights the importance of archaeological analysis of salmon species in understanding the historical distribution and exploitation of these ecologically significant species. The use of vertebral morphometric measurements provides an affordable, quick, and non-destructive method to extend and refine salmon identifications in archaeology. By exploring morphometric variability throughout the vertebral column and applying the method to both anatomically ordered vertebrae from modern salmonid specimens, and archaeological vertebrae, the study provides a method for broadening insight into human-non-human relationships in the past and present. A lack of ability to track species designations in archaeological assemblages furthers inhibits knowledge of long-term declines, and may magnify economic losses caused by overfishing, and under informed restoration goals (Pauly 1995). Morphological similarities between salmon species have limited research on the Northwest Coast despite the outsized importance of salmon as emphasised in cultural histories and ethnography. As anthropogenic climate change continues to accelerate, this research has the potential to inform our understanding of the future of our oceans and the crucial role that salmon populations play in the Pacific Northwest Coast.

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