

Identification of Salmon Species from Archaeological Remains on the Northwest Coast

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Introduction

Fish were universally an important resource to Northwest Coast First Nations ethnographically (e.g., Donald 2003; Suttles 1990), and a wide variety of fish species are represented in archaeological assemblages from the culture area (e.g., Butler and Campbell 2004; Hanson 1991; Orchard and Clark 2005). The most commonly utilized taxa prehistorically and ethnographically tend also to be those species that have been prominent in modern commercial fisheries, namely salmon (*Oncorhynchus* spp.), Pacific cod (*Gadus macrocephalus*) and other gadids (Gadidae), herring (*Clupea pallasii*), and halibut (*Hippoglossus stenolepis*). Salmon have been particularly prominent in discussions of Northwest Coast culture history (Butler and Campbell 2006; Coupland, Stewart, and Patton 2010; Schalk 1977), and in some areas they have been a major component of traditional diets for as many as 9000 years (Butler and O'Connor 2004; Cannon 1991; Cannon and Yang 2006). Although the Northwest Coast is thus often characterized as dominated by salmon fishing (Butler and Campbell 2006; Donald 2003; but see Monks 1987), the region is perhaps better characterized by considerable variability in the local use of fish species (Cannon 2000; Orchard 2007, 2009). Even in areas where salmon was a predominant resource ethnographically, it is increasingly evident that there is considerable variability in the timing of the adoption of salmon-focused economies. Documenting and understanding this variability in both the adoption of salmon-focused economies and the use of other fish taxa is critical

for understanding variability in Northwest Coast cultural developments, and more generally for understanding the rise of the sedentary, socially complex cultures documented ethnographically (e.g., Ames 2003; Lepofsky et al. 2005; Prentiss et al. 2007). Insights into long-term patterns of fish use are also becoming increasingly important as baselines for understanding more recent historic patterns in fisheries and fish populations (Jackson et al. 2001; McKechnie 2007; Pauly et al. 2002).

Salmon pose a particular problem for archaeological analysis. A thorough understanding of the timing, technology, and logistics of prehistoric salmon fishing depends largely on the species of salmon involved (Kew 1992). Unfortunately, as with other sets of closely related animal species (Bochenski 2008), salmon bones are notoriously difficult to identify to species, particularly when the bulk of salmon assemblages tends to consist of vertebrae (Butler and Bowers 1998; Cannon 1988).

Pacific Salmon Life Histories

The various species of Pacific salmon typically spawn at different ages and at different adult sizes (Table 2.1; Hart 1973; Healey 1986; Quinn 2004). In coastal British Columbia, pink salmon (*Oncorhynchus gorbuscha*), with only very rare exceptions, spawn at two years of age and at mean weights of roughly 2.2 kg. Coho salmon (*O. kisutch*) spawn at ages ranging from two to six years, with the vast majority (95 percent) spawning during their third

Table 2.1. Summary data on the sizes and life history characteristics of Pacific salmon

Species	Length at maturity	Weight at maturity*	Age at spawning	Freshwater	Oceanic
Pink (<i>O. gorbuscha</i>)	48.5 to 57.2 cm (♂) 46.0 to 56.1 cm (♀) Mean (♀): 52 cm	Typical: 1.4–2.3 kg (3–5 lbs) Mean: 2.2 kg (4.8 lbs) Max: 5.5 kg (12 lbs)	2 years	Rapid migration to ocean following emergence of fry	Reside in ocean 18 months
Chum (<i>O. keta</i>)	51.6 to 88.9 cm (♂) 55.5 to 77.6 cm (♀) Mean (♀): 68 cm	Typical: 4.5–6.8 kg (10–15 lbs) Mean: 5.4 kg (11.7 lbs) Max: 15 kg (33 lbs)	2–7 years; usually 3–5 years	Rapid migration to ocean following emergence of fry	Reside in ocean 2–7 years (usually 3–5)
Coho (<i>O. kisutch</i>)	21.0 to 72.7 cm (♂) 27.8 to 70.0 cm (♀) Mean (♀): 64 cm	Typical: 2.7–5.4 kg (6–12 lbs) Mean: 4.1 kg (9 lbs) Max: 14 kg (31 lbs)	2–6 years; usually 3 years	Typically reside in streams for 1 or 2 years	Typically spend 1–2 years at sea
Sockeye (<i>O. nerka</i>)	30.0 to 73.7 cm (♂) 46.6 to 72.4 cm (♀) Mean (♀): 55 cm	Typical: 2.3–3.6 kg (5–8 lbs) Mean: 2.7 kg (6.0 lbs) Max: 6.8 kg (15 lbs)	3–8 years; usually 4 or 5 years	Typically reside in lakes or rivers for 1–3 years	Reside in ocean 1–4 years
Chinook (<i>O. tshawytscha</i>)	10.2 to 115.0 cm Mean (♀): 87 cm	Typical: 4.5–6.8 kg (10–15 lbs) Mean: 6.8 kg (15 lbs) Max: 57 kg (125 lbs)	3–8 years; usually 4 or 5 years	Rapid migration or 1 year spent in rivers	Reside in ocean 1–5 years

*With the exception of pink salmon, mean weights are from Kew (1992) for Fraser River stocks specifically. These provide some general indications of average sizes.

Source: Compiled from Hart (1973), Healey (1986), Kew (1992), and Quinn (2004).

year of life, and are slightly larger than pinks, averaging 4.1 kg at maturity. Chum salmon (*O. keta*) spawn at ages ranging from two to seven years, with the vast majority spawning at three to five years of age, and are larger still, averaging 5.4 kg at maturity. Finally, sockeye salmon (*O. nerka*) and chinook salmon (*O. tshawytscha*) generally spawn at four or five years of age, though both species can spawn at ages ranging from three to eight years. Sockeye are relatively small, spawning at a mean size of roughly 2.7 kg, while chinook are the largest of the Pacific salmon, reaching a mean size of 6.8 kg at maturity. Importantly, the life histories of these five species of Pacific salmon consist of variable amounts of time spent in freshwater and saltwater environments. Pink and chum salmon spend the majority of their lives in saltwater, chinook may spend their first year in freshwater, coho typically spend one to two years in freshwater, and sockeye typically reside in freshwater for the first one to three years of life. In fact, some sockeye populations, known as “kokanee,” are permanently resident in freshwater environments (Quinn 2004:15).

Two other species of salmon are also represented along the Pacific coast. The steelhead (*O. mykiss*) and the coastal cutthroat trout (*O. clarkii*) are somewhat less common than the five species discussed above, and they do not form the massive spawning runs typical of the other Pacific salmon species. While specimens of steelhead and cutthroat may, and undoubtedly have, turned up in archaeological assemblages in low numbers, they will not be considered further here.

Species Identification of Salmon Assemblages: Previous Approaches

The variable spawning ages of the different species of Pacific salmon led Cannon (1988) to propose a method of ageing salmon remains based on examination of growth lines or annuli in vertebrae. Cannon's experiments indicated that these annuli were easily visible through radiographic analysis, and relatively large numbers of vertebrae could be examined quickly and easily on X-ray plates. Given the tendency of the various salmon species to spawn at different ages, the resulting age profiles could be used to infer the probable species compositions of the assemblages under consideration. Surprisingly, relatively few researchers have employed this technique subsequent to Cannon's (1988) initial article, though the application of this approach has increased slightly in recent years. Berry (2000; Hayden 1997) employed radiography to infer the species of salmon represented in assemblages from the Keatley Creek site. Notably, Berry's interpretations have been challenged by more recent ancient DNA (aDNA) analysis of salmon remains from that site (Speller, Yang, and Hayden 2005). More recently, Coupland and colleagues (Coupland, Colten, and Conlogue 2002) and Trost (2005) utilized the radiographic technique to examine the composition of salmon assemblages from sites in the Prince Rupert Harbour area and in the Gulf of Georgia, respectively. Most recently, Clark (2007) employed radiographic analysis of salmon vertebrae from sites in the Gulf Islands of the southern Gulf of Georgia to explore the rise of reef netting in that area. These applications of Cannon's (1988) radiographic technique highlight the potential utility of this approach, and the relative ease with which it can be applied.

In recent years, aDNA analysis has also been increasingly used to identify salmon species from archaeological vertebrae (Butler and Bowers 1998; Cannon and Yang 2006;

Speller, Yang, and Hayden 2005; Trost 2005; Yang, Cannon, and Saunders 2004). This approach has proven very successful, with archaeological salmon vertebrae generally showing excellent DNA preservation and facilitating the secure species identification of small samples of vertebrae from a number of sites. While aDNA analysis is the most accurate means of speciating salmon bones, it is prohibitively expensive in many cases. The increasing study of aDNA, however, has led to a refinement in the more cost-effective method of radiography, and it has also highlighted the potential of using metric characteristics of salmon vertebrae to provide additional information on the species composition of archaeological assemblages. Specifically, Cannon and colleagues have compared the results of aDNA analysis of salmon vertebrae from Namu to the results obtained through radiographic analysis and to measurements of the transverse diameter of the vertebrae (Cannon and Yang 2006; Yang, Cannon, and Saunders 2004; also see Trost 2005). Two particular observations arising from these comparisons are of interest here. First, aDNA analysis of Namu salmon vertebrae revealed that pink salmon was the most common species represented in the assemblage, contributing roughly 42 percent of the analyzed vertebrae (Cannon and Yang 2006:128). In contrast, previous analyses based entirely on radiography had concluded that pink salmon contributed less than 5 percent of the salmon vertebrae at Namu (Cannon 1988:107). Pink salmon generally spawn during their second year, and thus their vertebrae should show only a single winter annulus. However, Cannon and Yang (2006:128) found that both a modern comparative specimen of pink salmon and many archaeological vertebrae identified by aDNA analysis as pink salmon showed two growth lines. This is in accordance with biological studies that indicate that pink salmon often exhibit a supplementary growth check line on their scales that can be confused with a winter annulus (Bilton and Ricker 1965). Second, through the comparison of the metric traits of vertebrae to the species determination of those vertebrae through aDNA analysis, Cannon and Yang (2006:132) found that vertebrae with a transverse diameter of 10.5 mm or greater were all identified as either chum or chinook salmon, while vertebrae with a transverse diameter of 8.0 mm or less were all identified as either pink or sockeye salmon. Vertebrae falling between 8.0 and 10.5 mm derived from the full range of species except chinook (Cannon and Yang 2006:132). These results have been expanded by subsequent data from Namu that indicate that vertebrae less than or equal to 8.0 mm are overwhelmingly dominated by pink and sockeye salmon, but also contain small numbers of chum and coho (Aubrey Cannon, pers. comm., May 2010).

Species Identification of Salmon Assemblages: Moving Forward

The recent applications of Cannon's (1988) radiographic technique, combined with the insights arising from applications of aDNA analysis (Cannon and Yang 2006) outlined above, provide a basis for employing a more refined technique combining radiography and metric analysis. While Cannon and Yang (2006), for example, suggest that the confusion arising from the tendency of pink salmon vertebrae to display two radiographic annuli reduces the utility of the radiographic method, we argue that the realization that pink salmon can exhibit one or two apparent growth annuli under radiographic analysis can

improve the radiographic technique and allow more accurate assessment of the possible range of species present in an archaeological assemblage. Similarly, the apparently consistent patterning in metric characteristics (i.e., transverse vertebral diameter) exhibited by the different salmon species identified by Cannon and Yang (2006) provides a means for providing better estimates of the composition of large assemblages of salmon vertebrae (e.g., Trost 2005).

Consideration of a limited number of modern comparative specimens generally supports the metric observations of Cannon and Yang (2006). Transverse vertebral width was measured for all vertebrae from twenty individual Pacific salmon from the zooarchaeological comparative collections of McMaster University, the University of Toronto, and the University of Victoria (Table 2.2). The sample sizes for some species, particularly chum (one individual, sixty-one total vertebrae), are small, and the comparative samples as a whole likely do not encompass the full range of sizes of each species (Table 2.1). Measurements of additional comparative specimens in the future will help to refine this approach. Nevertheless, these data generally support the size categories suggested by Cannon and Yang (2006). For example, only specimens of chum and chinook include vertebrae greater than 10.5 mm, while neither chum nor chinook include vertebrae that fall below 8.0 mm in width. Only two aspects of these comparative data are different from the results presented by Cannon and Yang (2006). First, chinook salmon represent a relatively wide range of sizes, and need to be included in the 8.0 mm to 10.5 mm size category. Cannon and Yang's (2006) failure to include chinook in this category resulted from the very limited number of chinook present in their sample (only a single vertebra measuring 18.0 mm). Similarly, coho are well represented in the 8.0 mm or less size category among the comparative specimens measured for this paper, while the Namu coho sample was again too small to represent this diversity (Cannon and Yang 2006). As indicated above, subsequent analysis of Namu samples has identified coho in the small size category (Aubrey Cannon, 2010, pers. comm.). Notably, small numbers of chum vertebrae also fall into the small size category in these more recent Namu analyses, though the proportion of chum vertebrae less than or equal to 8.0 mm is very small (Aubrey Cannon, 2010, pers. comm.). Overall, the suggestion of a tripartite division of salmon vertebrae by size is supported.

In Cannon's (1988) original application of the radiographic technique, he used a portable dental X-ray machine to generate radiographs of salmon vertebrae on dental X-ray

Table 2.2. Metric data from modern comparative salmon specimens of spawning age

Species	Individuals (n)	Vertebrae (n)	Mean transverse diameter (mm)	Standard deviation	Range (mm)
Chinook	7	437	12.46	1.12	9.82–15.37
Chum	1	61	10.09	0.64	8.84–10.86
Coho	5	303	8.30	0.84	6.08–9.78
Pink	3	179	6.86	1.35	4.55–8.94
Sockeye	4	242	7.89	0.54	6.55–8.96

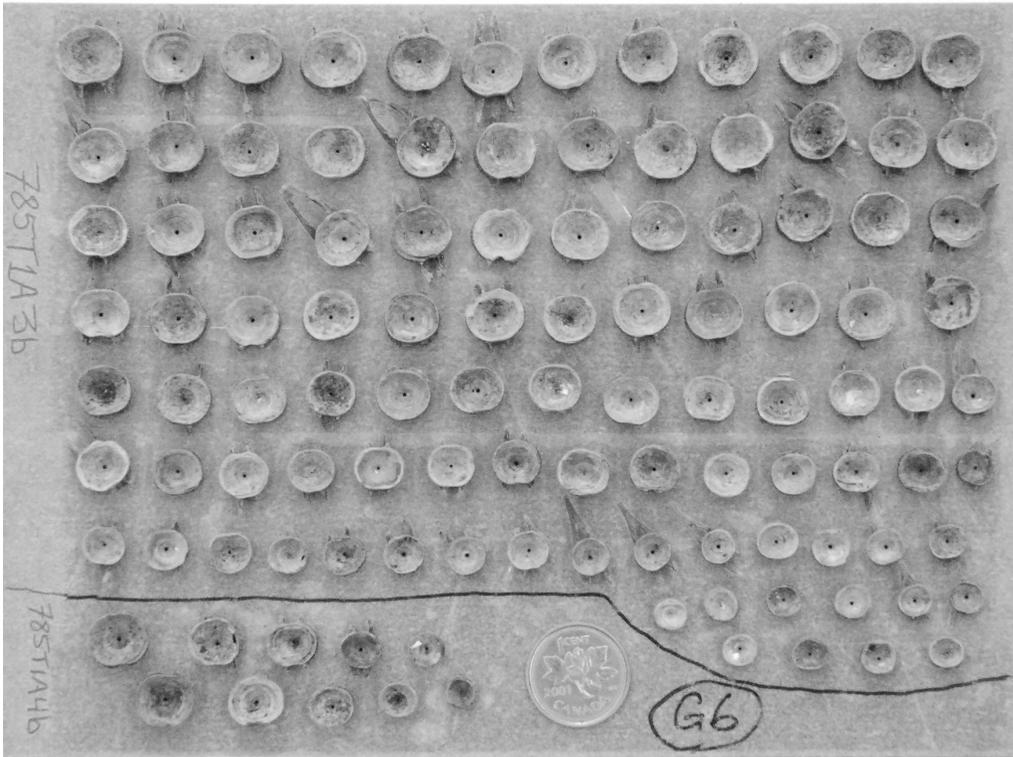


Figure 2.1. Example of a sheet of cardstock (13.5 x 18.5 cm) with vertebrae attached using double-sided tape.

films. While this approach was straightforward and facilitated the radiography of relatively large numbers of vertebrae with some ease, advances in radiographic technologies have further simplified the process. In particular, the development of digital radiography machines allows for the rapid processing of large numbers of vertebrae without the expense or time required for the purchasing and processing of radiographic films. In a case study of the approach outlined here, for example, Orchard (this volume) imaged a large sample of vertebrae with the assistance of Gord Mawdsley using a General Electric Senographe 2000D digital mammography machine at Sunnybrook Health Sciences Centre in Toronto (also see Clark 2007). Vertebrae were prepared by fixing them to 13.5 cm by 18.5 cm sheets of card stock using double-sided tape. As many as 100 to 120 vertebrae could be affixed to a single sheet using this method (Figure 2.1). Completed sheets of vertebrae were placed in sealed plastic Ziploc bags to further secure the vertebrae to the sheets. Sheets of vertebrae in their plastic bags were directly placed in the digital mammography machine and exposed to a radiographic output of 24 kV and 56.0 mA. High-resolution digital images (Figure 2.2) were generated for each sheet and were outputted to a CD-ROM for later analysis. The use of such a digital radiography machine allowed a large number of vertebrae to be imaged very quickly and easily. The total sample of 1908 vertebrae, on twenty sheets of card stock, was imaged in less than an hour. The digital images were viewed and analyzed using a computer program called QuickQC, developed internally within the Sunnybrook

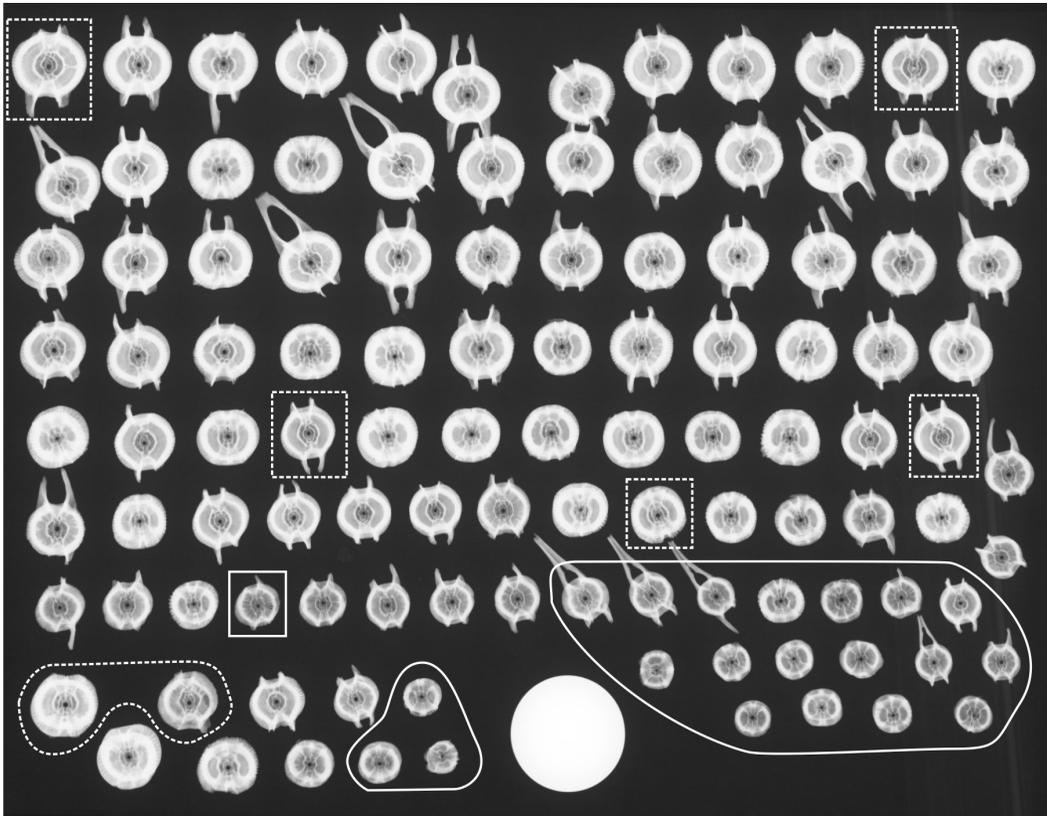


Figure 2.2. Digital radiograph of imaged vertebrae showing the denser growth annuli. Vertebrae show a combination of four-year-old fish (three annuli; vertebrae enclosed in dashed lines), two-year-old fish (one annulus; vertebrae enclosed in solid lines), and three-year-old fish (two annuli; all remaining vertebrae).

and Women's College Health Sciences Centre. This program facilitated the adjustment of image contrasts to improve the visibility of radio-opaque growth lines in the vertebrae.

Combining the expectations for salmon vertebrae characteristics based on metric and radiographic approaches provides a means of categorizing archaeological salmon vertebrae to better assess the species composition of an assemblage. As summarized in Table 2.3, the combination of vertebral width (transverse diameter) and annuli as revealed through radiography provides twenty-one potential combinations of vertebral traits. These combinations in many cases allow the attribution of vertebrae to a single species while at worst narrowing down the possible species. Given the relative ease and generally low cost with which large numbers of salmon vertebrae can be digitally radiographed and measured, this approach can provide a good estimate of the various salmon species in an archaeological assemblage.

An additional, and as yet largely unexplored, line of evidence for the species composition of salmon bone assemblages comes from the analysis of stable isotopes of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$). Together, these values can provide insight into the diet of the animals through chemical analysis of their tissues (e.g., Cannon, Schwarcz, and Knyf 1999; DeNiro and Epstein 1978, 1981; Pollard et al. 2007). Stable carbon isotope ratios can be used to assess the relative contributions of isotopically distinct sources of primary

Table 2.3. Summary of metric and radiographic vertebral categories useful in the consideration of salmon assemblage compositions

Radiographic annuli	Transverse diameter (mm)		
	≤ 8	8–10	≥ 10.5
1	Pink; (coho); (chum)	Pink; (coho); (chum)	(chum)
2	Pink; Coho; (sockeye); (chum)	Pink; Coho; Chum; (chinook); (sockeye)	Chum; (chinook)
3	Sockeye; (coho); (chum)	Chum; Sockeye; Chinook; (coho)	Chum; Chinook
4	Sockeye; (coho); (chum)	Chum; Sockeye; Chinook; (coho)	Chum; Chinook
5	(coho); (sockeye); (chum)	(coho); (chum); (chinook); (sockeye)	(chum); (chinook)
6	(sockeye); (chum)	(chum); (chinook); (sockeye)	(chum); (chinook)
7	(sockeye)	(chinook); (sockeye)	(chinook)

Note: More likely categories are capitalized; less likely categories are in parentheses.

production (e.g., macrophyte algae and seagrass versus particulate organic matter) to an animal's diet, while stable nitrogen isotopes indicate the trophic level of those animals within the food web, with a regular enrichment in $\delta^{15}\text{N}$ at each successive trophic level (e.g., Fredriksen 2003; Kaehler, Pakhomov, and McQuaid 2000). Isotopic values of primary producers, and the animals consuming them, are distinct in freshwater and oceanic environments, with the latter characterized by higher $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values (Schoeninger and DeNiro 1984). In terms of general dietary trends, five species of Pacific salmon can be broadly divided into two major subgroups (Healey 1986). The first, including sockeye, chum, and pink, primarily consume amphipods, euphausiids, and copepods and spend the marine component of their lives pelagically in the open ocean. The second, containing coho and chinook, are primarily piscivorous and spend much of their marine lives in coastal and continental shelf waters.

These variable diets are reflected in typical nitrogen and carbon stable isotope values. Satterfield and Finney (2002) record three groups of salmon based on carbon and nitrogen isotope values (also see Welch and Parsons 1993). The group with the lowest values for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ contains pink, chum, and sockeye salmon (Satterfield and Finney 2002), corresponding well with their consumption of low trophic-level (zooplankton) foods. An intermediate group with slightly higher values for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ consists primarily of coho salmon, though with some chum and sockeye (Satterfield and Finney 2002). Finally, chinook salmon are completely distinct from the other four species, with the highest values for both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ (Satterfield and Finney 2002), because this species consumes relatively higher proportions of fish. Based on these data, chinook salmon are clearly distinguishable from the other four species due to their foraging behavior, while

coho salmon show moderate separation from the other species. The data presented by Satterfield and Finney (2002), however, are not directly applicable to species identification in archaeological contexts because they are derived from muscle tissue, which remodels very rapidly (Hobson and Clark 1992). Muscle tissue only records the oceanic portion of an adult salmon's life, while the same would not be true for bone collagen extracted from archaeological specimens. This is particularly relevant since salmon are anadromous, as discussed below. Satterfield and Finney's (2002) data do demonstrate that chinook salmon are distinct in both $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values. Given the relatively lengthy amount of time this species spends in the ocean, this elevation in isotopic values should also be present in bone collagen. This is consistent with bone collagen data presented by Schoeninger and DeNiro (1984), though this was based only on single specimens of chinook and pink salmon.

In addition to these dietary differences, Pacific salmon species spend variable portions of their life cycles in fresh and marine waters. Since bone collagen remodels slowly and reflects dietary intake over several years or the entire lifetime of an animal (Hobson 1990), isotopic values of salmon bone collagen reflect a mix of both oceanic and freshwater dietary input (Schoeninger and DeNiro 1984). Because the different salmon species spend variable amounts of time in freshwater, the degree to which this is reflected in stable isotope values of bone collagen should be species specific. Coho and sockeye salmon, which spend significantly more time in freshwater as juveniles than do chum, pink, or chinook, should exhibit $\delta^{13}\text{C}$ values indicative of the consumption of more substantial amounts of freshwater protein. Ben-David (1996) demonstrates that juvenile coho salmon exhibit significantly more depleted $\delta^{13}\text{C}$ values than do adults (~5 percent), while juvenile chum and pink salmon tend to be very similar to adults (difference of 0.91 percent and 1.12 percent, respectively). Based on this and because sockeye spend even longer periods in freshwater than do coho, it is likely that a similar or even greater difference in stable carbon isotopes exists between adults and juveniles of this species. The isotopic data obtained thus far for modern salmon, fragmentary though they are, suggests a pattern in isotopic composition for $\delta^{13}\text{C}$ of bone collagen of sockeye < coho < pink \approx chum < chinook, and pink < sockeye \approx chum \leq coho < chinook for $\delta^{15}\text{N}$. Although more detailed analyses of the isotopic composition of bone collagen of Pacific salmon would be immensely useful, the species-specific variability in $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values discussed here demonstrate that stable isotope analysis has the potential to contribute to the species identification of archaeological salmon remains, particularly when combined with radiography and metric analyses (Orchard, this volume).

Conclusions

While ancient DNA analysis provides the most accurate means of speciating archaeological salmon bones, a combination of radiographic and metric analyses provides a much more cost-effective approach. Digital radiography simplifies the process, reduces the cost, and allows for the contrast of radiographs to be fine-tuned during analysis to aid in visual identification of annuli. Combining the counting of radiographic annuli with the recording of the size (transverse diameter) of salmon vertebrae provides a series of discrete cat-

egories, each corresponding to at most four and in many cases only one or two possible species of Pacific salmon. This combined technique can thus provide more reliable identification of species in an archaeological assemblage (Orchard, this volume). The analysis of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotopes in archaeological salmon bone samples is another promising technique. Given the importance of salmon to virtually all First Nations groups on the Northwest Coast, and given the variable timing and nature of the seasonal spawning aggregations of the different species of Pacific salmon, the ability to identify the species represented in archaeological salmon bone assemblages in the region facilitates a greater understanding of the timing, technology, process, and location of prehistoric subsistence activities. Furthermore, the determination of the relative abundance of the various species of salmon in archaeological sites that span the temporal and geographic range of human occupation on the Northwest Coast will provide data that are of considerable use in understanding the long-term histories of these species from biological, ecological, and commercial perspectives (e.g., Jackson et al. 2001; Pauly et al. 2002).

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