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The Role of Bone Density in Structuring Prehistoric Salmon Bone Assemblages

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Archaeologists working in north-western North America often suggest that the low frequency of salmon cranial elements and abundance of vertebrae in prehistoric deposits reflects the cultural use of stored fish. While empirical documentation of salmon storage is certainly important, a variety of noncultural factors, particularly bone density, should be considered in interpreting body part frequencies. Bone densities of representative cranial and postcranial elements from 10 chinook salmon (*Oncorhynchus tshawytscha*) were measured using X-ray absorptiometry. Except for the otolith, most cranial elements have lower densities than postcranial bones. The role of bone density in structuring prehistoric salmon assemblages is explored through comparisons of density measures with element survivorships in three archaeological assemblages with low cranial element survivorship. The scarcity of cranial elements in two of the assemblages is best explained by density-mediated destruction, while cultural processing probably accounts for the dearth of head bones in the third assemblage.

Keywords: SALMON BONE DENSITY, X-RAY ABSORPTIOMETRY, BONE VOLUME, SALMON TAPHONOMY, SALMON STORAGE, PREHISTORIC SALMON, FISH BUTCHERING, NORTH-WESTERN NORTH AMERICA.

Introduction

Archaeologists have shown increasing interest in documenting prehistoric fish butchering practices using body part frequencies (Colley, 1984, 1986; Seeman, 1986; Stewart, 1991; Belcher, 1992). This interest is particularly strong in north-western America, where numerous investigators have suggested that the low frequency of salmon cranial elements and abundance of vertebrae in prehistoric deposits reflect the cultural use of stored fish. Calvert (1973), citing ethnographic evidence that heads were removed before preparation for storage, suggests that prehistoric salmon assemblages with greater frequencies of postcranial bones relative to cranial elements reflect the practice of drying and storing salmon. Huelsbeck (1983: 113) posits that the high representation of salmon vertebrae and fin elements at the Ozette site on Washington's outer coast results from the human transport of fillets, backbones and tails to the site. The extremely low frequency of cranial remains at the site suggests that heads were consumed fresh (presumably off-site). Ham (1982) and Stiefel (1985: 137) suggest that the low frequency of cranial elements in numerous sites in the Fraser River Delta represent the use of preserved salmon backs. Finally, Chatters (1984: 103) suggests that at sites where salmon carcasses were processed for storage, assemblages should bear relatively higher proportions of cranial elements; at sites where stored fish parts were used, higher frequencies of postcranial elements are expected to occur. (See Moss (1989) for alternative explanations of the complex of cultural and natural factors mediating prehistoric salmon element representation.)

The search for direct evidence of salmon storage is certainly important. However, a variety of noncultural factors also affect body part frequencies and should be considered in interpreting faunal assemblages. Bone shape, size, and most importantly density, have been shown to mediate element survival in archaeological deposits (Lyman, 1984, 1985; Lyman, Houghton & Chambers, 1992; Grayson, 1989; Kreutzer, 1992). Investigators of mammalian faunas have directly measured bone density of mammalian skeletal elements using water displacement methods (Brain, 1969; Behrensmeyer, 1975; Binford & Bertram, 1977) and photon absorptiometry (Lyman, 1984; Lyman, Houghton & Chambers, 1992; Kreutzer, 1992). Among

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other values, independent density measures have allowed researchers to distinguish human transport of carcass parts from density-mediated destruction of elements (e.g. Lyman, 1985; Grayson, 1988, 1989; Klein, 1989; Kreutzer, 1992). Grayson (1989) argues that when high correlations are found between rank order density values and fossil element survivorship, it would be wise to assume that whole carcass deposition followed by *in situ* destruction occurred, given the ubiquity of destructive processes.

Density measures have not been determined for fish skeletal elements, although several researchers have speculated on the differential density of cranial elements versus vertebrae:

> Vertebrae of fish are probably more durable than the majority of cranial bones. Many fish cranial bones are thin and flattened, while vertebrae tend to be denser and round. Certainly in many shell middens, vertebrae are recovered in higher numbers than are cranial bones, despite the fact that most fish have 2–3 times as many cranial bones as vertebrae . . . Subjectively, we think that salmon cranial bones are particularly fragile . . . (Wigen & Stucki, 1988: 106).
>
> cranial fragments . . . being laminar, are more readily broken by pressures applied on their surfaces than the spool-shaped vertebrae (Morales, 1984: 51).
>
> The head skeleton of a ripe or ripening salmon is paper thin, even the jaw bones being much lighter than those of a comparable sized pike, for example, the vertebral centra are also lightly calcified but here the reduction is not so marked (Wheeler, 1978: 74).

Given the significance of bone density in mediating preservation of mammal bone, it would be useful to move beyond subjective judgements of fish bone density and establish an empirical basis of assessing density-mediated destruction for fish assemblages. Here, we describe our recent investigations of salmon bone density. Representative cranial and postcranial elements from 10 chinook salmon (*Oncorhynchus tshawytscha*) skeletons were scanned using X-ray absorptiometry. We explore the role of bone density in structuring prehistoric salmon assemblages by comparing density measures with element survivorships obtained from several coastal and inland sites in the Pacific Northwest.

Methods

Lyman (1984), Lyman, Houghton & Chambers (1992) and Kreutzer (1992) argue convincingly that unambiguous measures of bone density of nonhuman vertebrates can be derived using photon absorptiometry. This method has been developed over the past 30 years in the field of nuclear medicine in order to measure the mineral content of bone. It involves measuring the differential transmittance of a photon beam through bone either *in vivo* or apart from the organism (Cameron & Sorenson, 1963; Cameron, Mazeness & Sorenson, 1968). We used photon absorptiometry, in particular, Dual Energy X-Ray (DEXA) (see Lai *et al.*, 1992; Kreutzer, 1992, for discussion of operation), the Norland XR-26 model, to measure the mineral content of the salmon specimens. This instrument can be adjusted to measure mineral content of small animal bones (e.g. mice); we show below that the instrument is capable of measuring the mineral mass of relatively small fish elements.

As recently described by Kreutzer (1992) and Lyman, Houghton & Chambers (1992), the instrument provides the average bone mineral content of the scanned area measured in grams. The instrument also measures the area scanned (cm^2), which is divided into the bone mineral content to estimate a "linear density" (*sensu* Lyman, 1984) of bone (gm/cm^2). Kreutzer (1992; see also Carter, Bouxsein & Marcus; 1992) points out that while linear density measures are appropriate in longitudinal studies designed to evaluate bone loss in single subjects, the measures are ambiguous at best when used to compare elements of varying shapes. Linear density treats all bones as flat, 2-dimensional objects; it cannot distinguish flat, mineral-rich bones from thick, mineral-poor ones and is highly dependent on the orientation of the bone specimen to the light beam (Kreutzer, 1992). As Kreutzer (1992) notes, a third measure, volume density (gm/cm^3), addresses these problems by including scan site volume in the bone density calculation.

In their work on mammal bone density, Lyman (1984), Lyman, Houghton & Chambers (1992) and Kreutzer (1992) estimate bone volume by measuring the dimensions (length, width, thickness) of the scan sites using calipers. Because the shape of most salmon (and other fish) bones is highly irregular, we reasoned that this dimensional measurement approach would provide a poor estimate of fish bone volume. Another widely used method estimates object volume using water displacement, which simply involves placing an object in a water-filled graduated cylinder and recording the amount of water displaced by the object. Because the fish specimens are small, and the amount of water displaced is slight, this approach lacks precision. Instead, we used the hydrostatic weighing method (Taylor, 1967: 4598). This method involves measuring the mass of the water displaced by the bone, which is equivalent to the volume of the object. The precision of the hydrostatic weighing method is limited only by the precision of the balance used. (See Appendix for discussion of bone volume measurement.)

Elements included in the study were from 10 chinook salmon (*Oncorhynchus tshawytscha*) carcasses (Table 1). We assume that the density values obtained from chinook salmon may be applied to prehistoric assemblages comprised of chinook or other salmonid species, for two reasons. First, the skeletal elements of salmonid species are remarkably similar; indeed, such anatomical similarity prevents species level

Table 1. Chinook salmon skeletons measured with X-ray absorptiometry

Catalogue no.	Collection location	Sex	Standard length (mm)	Weight (g)
	Neah Bay, WA	F	720	6229·8
	Neah Bay, WA	M	590	3077·1
	Neah Bay, WA	F	605	4169·4
	Neah Bay, WA	F	645	4563·7
	Neah Bay, WA	F	505	1739·1
	U.S. Nat'l Fish Hatchery, Leavenworth, WA	M	825	9407·7
	U.S. Nat'l Fish Hatchery, Leavenworth, WA	F	645	4884·5
	U.S. Nat'l Fish Hatchery, Leavenworth, WA	M	655	4556·9
	U.S. Nat'l Fish Hatchery, Leavenworth, WA	F	640	4589·3
	U.S. Nat'l Fish Hatchery, Leavenworth, WA	M	865	8913·5

identifications of most salmonid elements. Second, the chinook salmon carcasses included in the study represent a size range (Table 1), which encompasses the sizes of the seven anadromous species of Pacific salmon. Our modern sample included five fish in the pre-spawning phase collected from Washington's outer coast and five fish that had migrated over 750 km up the Columbia River and were about to spawn (Table 1). Skeletons were prepared by water maceration and degreased using dilute ammonia.

Element selection was based on the desire to sample different parts of the skeleton, elements of different shape (e.g. flat versus cuboid), and elements that are common and rare in archaeological assemblages. Eight cranial elements and eight elements associated with the vertebral column and paired fins were selected for study (Table 2).

Decisions regarding the portion of the bone to scan were based on the extent of variation in shape or thickness within the element, whether the portion could be identified easily, and the portion generally found in archaeological assemblages. As Figure 1 illustrates, the scan site on nine of the elements is the complete specimen; only portions of the remaining seven elements were scanned. For example, the posterior portion of the angular and the centrum of vertebra type-3 (Butler, 1993), exclusive of neural and haemal spines, were scanned (Figure 1). For partially scanned elements, bone volume was obtained by cutting the element along the scan site border using a scalpel and including this portion in the volume measurements. For paired elements, the right side was used in analysis.

The results provided by the DEXA system are replicable. Ten vertebrae were scanned on two occasions one week apart; the maximum difference between measured values is 0·01 g, and the mean difference is only 0·004 g, or 2·9% of the mean of the two measures (Table 3).

To determine the accuracy of the instrument, we scanned 16 additional vertebrae, burned them to ash to isolate their inorganic components, and compared the resulting mineral content estimates. For the ashing procedure, crucibles were cleaned in a 50% nitric acid solution and then oven-dried. Vertebrae were put in the crucibles, weighed, and then placed in a muffle furnace. Over a 5-h period, the furnace temperature was raised to 600°C where it remained for 15·5 h. The temperature was then gradually lowered to room temperature. The materials were cooled and then reweighed.

As shown in Table 4, the bone mineral masses provided by X-ray absorptiometry and ashing are in close agreement, although the ashed values are systematically higher. The mineral content estimated by DEXA

Table 2. Scanned salmon elements

Element*	Common	Rare
Neurocranium		
exoccipital (exo)	X	
sagittal otolith (oto)	‡	‡
pterotic (pto)		X
Jaw		
angular (ang)	X	
maxilla (max)	X	
dentary (den)	X	
Hyoid		
ceratohyal (cer)		X
Opercle series		
opercle (opc)		X
Pectoral fin		
coracoid (cor)		X
pectoral fin ray (pec)	X	
Pelvic fin		
basipterygium (bsp)	X	
Vertebral Column		
vertebra type-1 (vt1)	X	
vertebra type-2 (vt2)	X	
vertebra type-3 (vt3)	X	
vertebra type-4 (vt4)	X	
hypural (hyp)		X

*Element nomenclature follows Norden (1961), except for pectoral fin ray and vertebra types described in Butler (1990, 1993) and illustrated in Figure 1; abbreviations are those used to identify elements in Figures 2–6.

‡otoliths are relatively common in inland Plateau sites, while rare in coastal/estuarine sites.

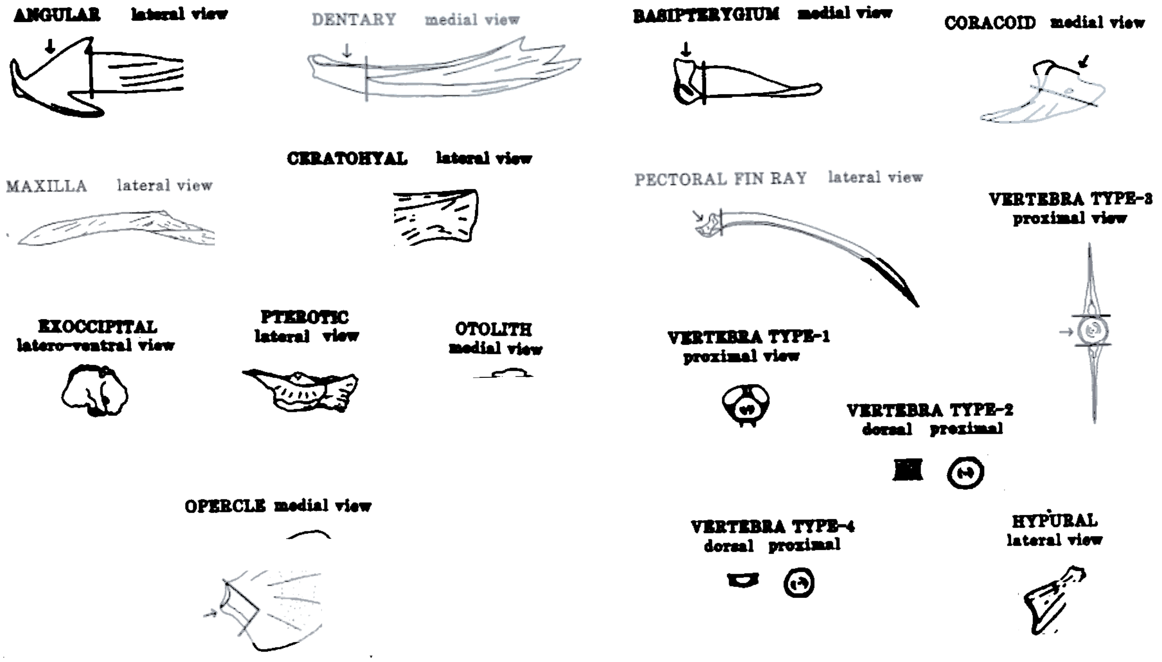

Figure 1. Scanned salmon elements (arrows indicate portion scanned; vertebrae scanned on their anterior or posterior face; the right side of paired elements illustrated; not drawn to scale).

Table 3. Comparison of vertebra type-2 bone mineral content (g) using X-ray absorptiometry, measured one week apart

Catalogue no.	19 June 1992	27 June 1992	Difference	% Difference*
	0·115	0·124	0·009	
	0·072	0·072	0·000	
	0·086	0·086	0·000	
	0·092	0·087	0·005	
	0·040	0·039	0·001	
	0·261	0·271	0·010	
	0·114	0·120	0·006	
	0·078	0·077	0·001	
	0·083	0·085	0·002	
	0·311	0·309	0·002	

*Difference between measures divided by the mean of the measures.

deviates only slightly (6·0% average) from the ashed mineral content. The largest difference between weights is only 0·025 g, and the mean difference is 0·011 g. The slight differences may result from retention of some portions of organic components in the ash or instrument calibration. These data demonstrate the instrument's ability to measure mineral content of bones considerably smaller than human bones, for which the instrument was designed.

Results

Table 5 lists the mean volume density and the bone mineral content of the scanned salmon elements. Density of most of the postcranial elements, particularly vertebrae, far exceeds that of cranial elements, except for the otolith. The fact that otoliths have densities exceptionally higher than other elements is not surprising. Unlike bone, which has a sizeable component of organic collagen, otoliths (small concretions in the neurocranium that assist with equilibrium and hearing) consist almost exclusively of mineral in the form of calcium carbonate. Within the cranium, density of the jaw bones (angular, maxilla, dentary) is higher than the flat bones of the hyoid and gill cover (ceratohyal, opercle) and the spongy bones of the neurocranium (exoccipital, pterotic). Of the paired fin elements, densities of the coracoid and basipterygium are relatively low, while density of the pectoral fin ray is as high as that of the vertebrae (Figure 2).

These data support intuitive perceptions that, at least for salmon, vertebrae are more robust than head

Table 4. Comparison of bone mineral content (BMC) of salmon vertebra type-2, based on X-ray absorptiometry (DEXA) and ashing

Catalogue no.	DEXA BMC (g)	Ashed BMC (g)	Difference
VLB92-6-11-			
1	0·194	0·210	0·016
2	0·231	0·256	0·025
3	0·272	0·287	0·015
4	0·284	0·303	0·019
5	0·209	recording error	—
6	0·317	0·335	0·018
7	0·264	0·276	0·012
8	0·208	0·221	0·013
VLB92-6-10-			
	0·109	0·115	0·006
	0·103	0·110	0·007
	0·101	0·108	0·007
4	0·131	0·137	0·006
5	0·113	0·122	0·009
6	0·125	0·134	0·009
7	0·083	0·089	0·006
8	0·074	0·076	0·002

Table 5. Mean volume bone density (VD) and bone mineral content (BMC) of salmon elements

Element	*N*	VD (g/cm^3) S.D.	BMC (g) S.D.
Angular	10	0·20	0·23
		0·02	0·15
Ceratohyal	8	0·06	0·10
		0·01	0·06
Dentary	10	0·19	0·12
		0·04	0·08
Exoccipital	9	0·11	0·17
		0·01	0·10
Maxilla	10	0·20	0·24
		0·04	0·14
Opercle	7	0·07	0·02
		0·02	0·01
Otolith	10	1·41	0·07
		0·15	0·03
Pterotic	8	0·12	0·17
		0·02	0·13
Coracoid	10	0·07	0·04
		0·01	0·02
Pectoral fin ray	9	0·29	0·03
		0·05	0·02
Basipterygium	10	0·11	0·05
		0·03	0·03
Vertebra type-1	8	0·27	0·09
		0·04	0·05
Vertebra type-2	10	0·31	0·12
		0·02	0·09
Vertebra type-3	10	0·34	0·16
		0·02	0·08
Vertebra type-4	10	0·30	0·08
		0·04	0·04
Hypural	10	0·14	0·07
		0·04	0·06

bones. All things being equal, vertebrae should resist destruction better than most cranial bones. Beyond these gross patterns, the data highlight more subtle variation in density *within* body parts (head, paired fins, trunk). Thus jaw bones should survive density-mediated destructive agents better than neurocranial and gill cover specimens; the pectoral fin ray will resist attrition better than the coracoid. These values provide a valid and reliable ordinal scale measure of salmonid element densities. To explore the possible role of bone density in structuring prehistoric salmon bone assemblages, we compare rank order density values with rank order survivorship (%MAU) of salmon remains in three archaeological assemblages.

Archaeological Assemblages

45-DO-211

Excavated by the University of Washington as part of the Chief Joseph Dam project, 45-DO-211 is located on a low terrace beside the Columbia River in eastern Washington, U.S.A. (Lohse, 1984; Campbell, 1985). Discussion here focuses on Analytic Zone 4, which represents a housepit-residential base occupation and provided 839 identified salmon specimens, over 80% of the site's salmon remains. The materials were excavated using 1/8 in. (0·32 cm) mesh, adequate for recovery of salmonid elements used in analysis (Butler, 1990, 1993).

Salmon vertebrae are easily identified as small fragments whereas highly fragmented cranial and fin elements are not. To address the problem of differential identifiability of body parts, element counts were based on the Minimum Number of Elements (MNE: Binford, 1984) which selects the best represented section of each element and counts the number of times it occurs in a given aggregate (Grayson, 1988). The MNE for vertebrae types was based on the presence of 50% or more of the centrum. The salmon remains in Zone 4 provide a Minimal Animal Unit (MAU: Binford, 1984) of 5·51, based on vertebra type-3. Element survivorship (%MAU) were scaled to this element. For a given MAU, this measure calculates the number of elements expected, compared to the number observed (Binford, 1984; Grayson, 1988).

We expect a high correlation between element density and survivorship for the 45-DO-211 assemblage for several reasons. The fragmentary condition of the bony remains confirms that some bone destruction has occurred. The site's location next to the river, where the fish were presumably caught, certainly suggests that whole carcasses were transported to the site. Thus it is reasonable to suppose that element survivorship results from *in situ* destruction.

As shown in Table 6, our expectation is met. Salmon element survivorship is highly correlated with bone density (r_s=0·762; P<0·001). Except for the otolith, cranial element survivorship is generally low; vertebrae are more common (Figure 3). The conclusion that the 45-DO-211 assemblage results from whole carcass deposition and *in situ* destruction is supported by the

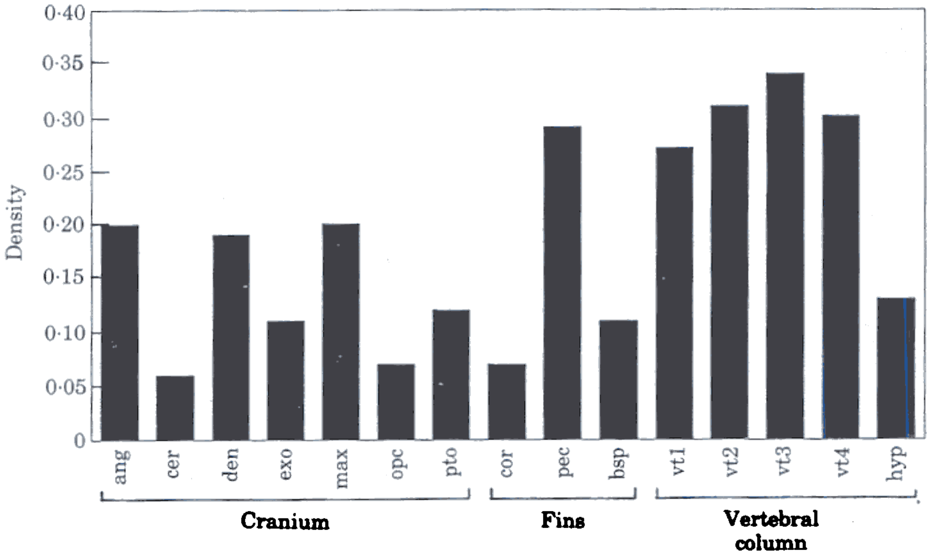

Figure 2. Salmon element volume density (VD), excluding otolith (which has a volume density of 1·41).

Table 6. Rank order salmon bone volume densities (VD) compared with element survivorship (%MAU) in three archaeological assemblages

Element	VD rank	Survivorship					
		DO-211	rank	Duwamish	rank	Keatley Cr.	rank
Otolith	-	72·59	2	0	13·25	0	16
Vertebra type-3	2	100·00	1	66·59	3	100·00	1
Vertebra type-2	3	61·29	3	69·07	2	74·95	3
Vertebra type-4	4	39·29	4	43·06	6	12·18	7
Pectoral fin ray	5	27·22	6·5	100·00	1	30·94	6
Vertebra type-1	6	36·63	5	50·00	4	77·35	2
Angular	7·5	0	9·125	3·90	9	4·4	12·25
Maxilla	7·5	0	9·125	0·78	10·33	4·4	12·25
Dentary	9	0	9·125	0·78	10·33	4·4	12·25
Hypural	10	0	9·125	19·53	8	11·05	8
Pterotic	11	0	9·125	0	13·25	8·8	9·5
Exoccipital	12·5	9·07	8	44·53	5	4·4	12·25
Basipterygium	12·5	27·22	6·5	34·37	7	45·30	4·5
Opercle	14·5	0	9·125	0	13·25	8·8	9·5
Coracoid	14·5	0	9·125	0	13·25	45·30	4·5
Ceratohyal	16	0	9·125	0·78	10·33	7·7	11
		r_s=0·762		r_s=0·472		r_s=0·159	

prominence of otoliths in the assemblage, suggesting that at least some of the carcasses deposited on the site were whole.

Duwamish No 1 (45-KI-23)

Located in Seattle, Washington, adjacent to the Duwamish River, the Duwamish No. 1 site is a large prehistoric shell midden that served as a major habitation during several seasons of the year (Campbell, 1981; URS Corporation and BOAS, Inc., 1987). The 3444 identified salmon remains described here were retrieved from 1/4 in. (0·64 cm) and 1/8 in. (0·32 cm) mesh screens from one of the 16 m^2 block excavation areas (Butler, 1987, 1990). The salmon assemblage provides a MAU of 64, based on the abundance of the pectoral fin ray.

As with 45-DO-211, we expect a high correlation between element density and survivorship for the Duwamish assemblage. The salmon remains from the shell midden are extremely fragmented; the site's location next to the river where the migrating salmon would have been readily available suggests that carcasses would have been brought to the site whole for processing.

As seen in Table 6, while the correlation between element density and survivorship is significant, the relationship is not particularly strong (r_s=0·472,

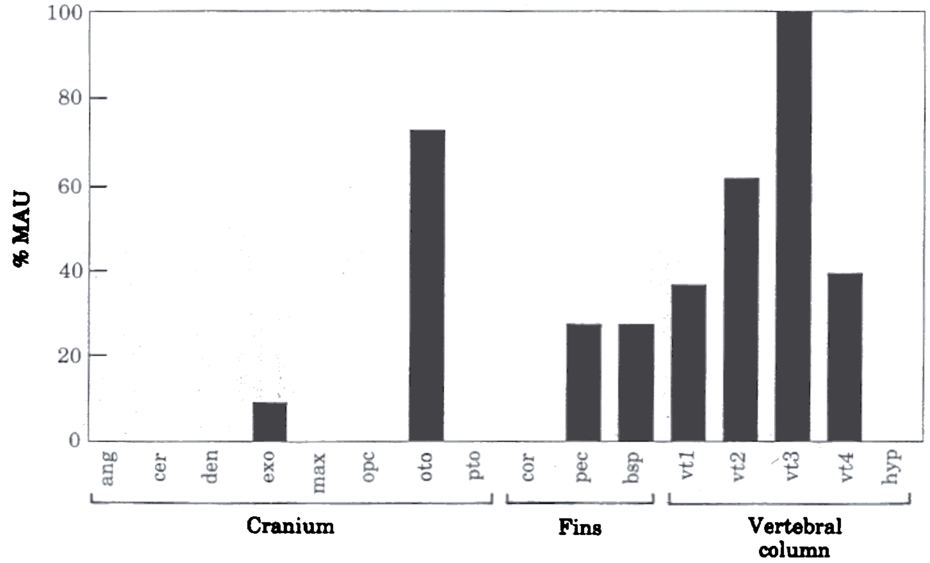

Figure 3. Salmon element survivorship (%MAU), 45-DO-211 (includes elements with density values).

$P<0.05$). The relationship is particularly weak for the exoccipital and basipterygium, which have relatively high survivorship but low bone densities (Table 6). The main discrepancy occurs with the otolith, which has the highest density and yet is absent from the archaeological assemblage.*

While the correlation between density and survivorship is not as high as we would expect, clearly some of the patterning in element frequency results from attritional processes. The assertion that some carcasses were brought to the site complete is supported by the relatively high frequencies of the quadrate and exoccipital (which have survivorships of 14·4 and 44·53, respectively); survivorship of the exoccipital rivals that of the vertebral elements (Figure 4). Further, only 11 of the 36 cranial elements recorded for salmon element survivorship analysis were identified in the Duwamish deposit (Butler, 1990). If the relative abundance of the exoccipital indicates that a least some heads were deposited, the absence of over 65% of the cranial element types certainly implies that some bone destruction has occurred. While attritional processes probably account for some of the patterning at Duwamish, the factors responsible for element representation are clearly complex, and are not readily explained by the simple alternative models under consideration here.

Keatley Creek (EeRl–7)

Keatley Creek, a site with over one hundred pit houses located on a terrace 220 m above the Fraser River, in central British Columbia, Canada, has been extensively excavated by Simon Fraser University for the past several years (Hayden, 1987). Here we describe materials from Housepit 7 which have been analysed by Butler. Most of the matrix from the floor, walls and pit features within the housepit was screened using 1/4 in. mesh, which provided a total of 4964 identified salmon specimens. In addition, over thirty litres of flotation samples, collected primarily from the house floor, were processed and identified to estimate recovery bias against salmonid elements lost through the 1/4 in. (0·64 cm) mesh. As shown in Table 7, very few elements included in survivorship analysis were identified from the water processing: three cranial elements, three paired fin remains, and seven vertebrae. The recovery of only a few identifiable elements in fine mesh screens at least in part reflects the fact that many of the elements are relatively complete (see below). Future analysis of flotation samples drawn from pit features will examine potential recovery bias in more detail. For now, we assume that use of the 1/4 in. mesh screens at Keatley Creek does not introduce a major bias in element recovery.

We expect a low correlation between bone density and element survivorship for the Keatley Creek assemblage for two reasons. First, the archaeological specimens are well preserved; many of the fragile neurocranial and pectoral girdle elements are virtually

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*Salmonid otoliths are rare in reported coastal-estuarine sites in the Pacific Northwest (Casteel, 1976; R. Wigen, pers. comm.). Although recovery bias or misidentification may explain the otolith's scarcity in some deposits, such factors do not explain their absence at Duwamish. Butler's (1990) sorting of about 50 kg of bulk samples that had been retained in 1/8 in. (0·32 cm) mesh from the excavated block provided no salmon otoliths. While the reasons for otolith scarcity are unknown, density *per se* is probably not the primary factor. Salmon otoliths are absent from a wide range of depositional contexts, the faunal remains of which have been exposed to varying levels of destruction. If mineral density was the key factor deciding survival, we would expect salmon otoliths to occur in at least some of those settings. The fact that they are scarce in all coastal or near-coastal sites suggests that other intrinsic factors, e.g. compositional or structural differences between otoliths and bone, account for their absence.

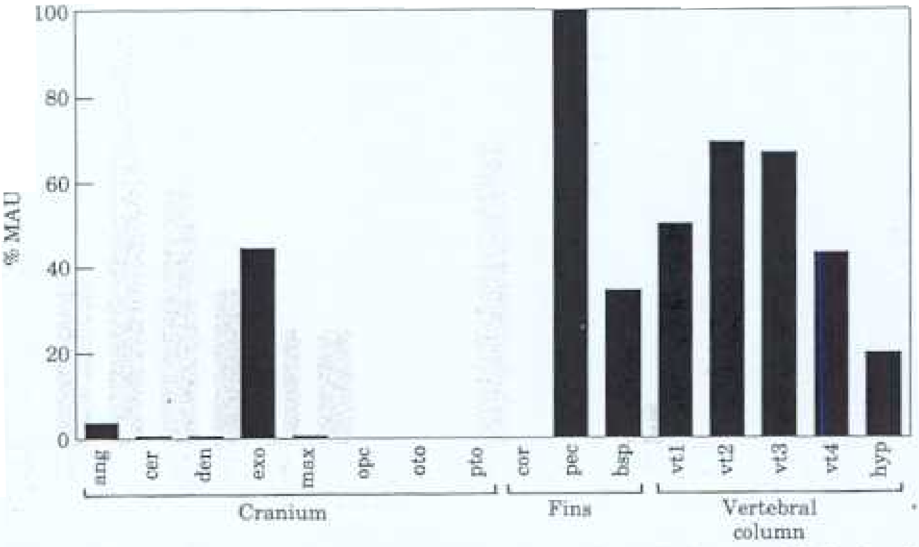

Figure 4. Salmon element survivorship (%MAU), Duwamish No. 1 (includes elements with density values)

complete, suggesting that bone destruction has been minimal. Second, the site is located on a terrace over 200 m above and 1 km removed from the river, suggesting that some carcass parts may have been left near the catch site to reduce the weight of material to be transported. For example, if the salmon were processed for storage, the heads may have been left behind, given their greater oil content and potentially greater processing costs (Romanoff, 1985; Butler, 1990). Regardless of the specific factors involved, the site's relatively distant location from the river suggests that only selected portions of the carcass would have been transported to the site. Thus element survivorship should not correspond to bone density, but rather indicate which body parts had been transported.

Table 7. Number of identified salmon specimens (NISP) in flotation samples, Housepit 7, Keatley Creek

Element	NISP
Epiotic*	
Palatine*	1
Supraoccipital*	1
Posttemporal*	1
Basipterygium*	2
Vertebra type-2*	6
Vertebra type-2, fragment	1
Vertebra type-3*	1
Vertebra type-3, fragment	1
Unidentified vertebra	4
Unidentified vertebra, fragment	132
Misc. vertebra & fin spine	59
Rib	15
Branchial	2
Branchiostegal	1
Tooth	2
Gill raker	6
Total	236

*Elements included in element survivorship analysis.

As shown in Table 7, the correlation between density and survivorship is low and insignificant ($r_s=0{\cdot}159$, $P>0{\cdot}50$), which supports our expectation. While the mineral-rich vertebrae have high survivorship, the density-poor basipterygium and coracoid also have relatively high survivorship, and the relatively dense jaw bones are represented by very few specimens (Figure 5). The argument that density-mediated destruction was minimal at Keatley Creek is supported by the presence of 43 element types (Figure 6). The 28 cranial elements present show a similarly low survivorship (average 4·75), while survivorship of the paired fin elements is considerably higher (average 22·4). These patterns of representation bear little resemblance to expectations based on bone density. Element abundance at Keatley Creek is not explained by differential element density, but rather indicates that selected parts of the carcass, in particular the trunk, were brought to the site.

Conclusions

The transition from direct consumption of foraged foods to a reliance on food harvest and storage is an evolutionary development as significant as that associated with the development of agriculture (see Schalk & Cleveland, 1983). Empirical documentation for the use of stored foods is a key to recognizing when this transition took place in various parts of the world. In the interior Plateaus of North-western North America, where researchers have been debating the relationship between storage and the development of logistically-organized (*sensu* Binford, 1980), semisedentary settlement systems, salmon is the pivotal resource (Schalk, 1977; Schalk & Cleveland, 1983; Richards & Rousseau, 1987; Chatters, 1989). Archaeologists concerned about

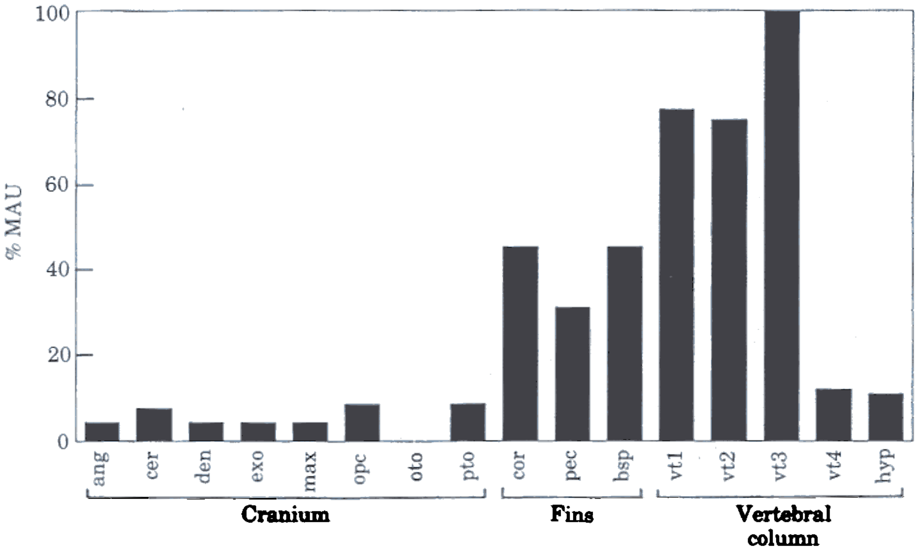

Figure 5. Salmon element survivorship (%MAU), Keatley Creek, Housepit 7 (includes elements with density values).

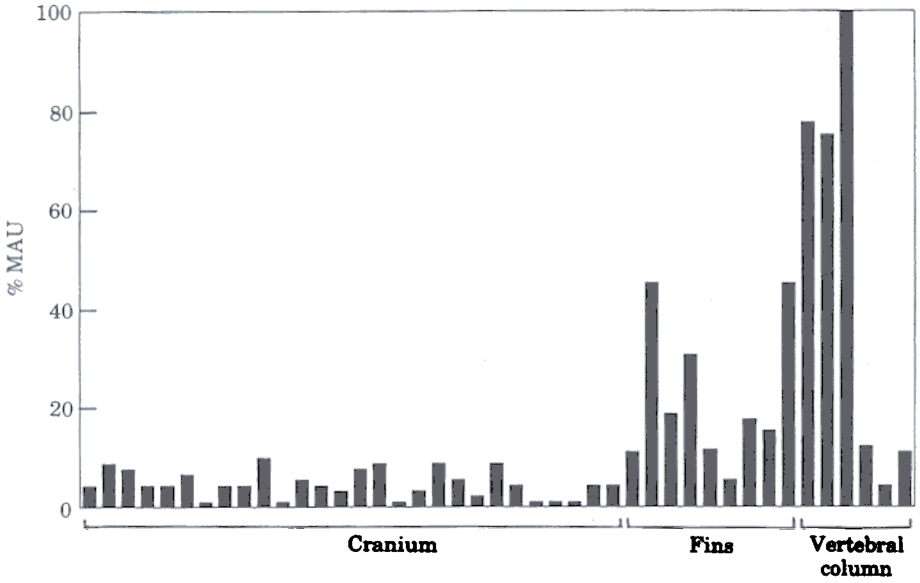

Figure 6. Survivorship (%MAU) of all salmon elements, Keatley Creek, Housepit 7.

the origins of salmon storage there and on the adjacent Northwest Coast have routinely used the scarcity of cranial remains and prominence of salmon vertebrae in base camps to argue that heads were disposed of off-site. This is taken as evidence that the fish were prepared for storage.

If salmon body part data bear some relation to cultural processing patterns, then clearly such data have the potential to inform on the spatial and temporal dimensions of the development of storage technology. To provide meaningful results, however, such studies will need to take into account other taphonomic factors, particularly bone density, which may also account for body part frequencies.

The salmon bone densities presented here provide a much-needed record with which to assess density-mediated destruction in prehistoric salmonid assemblages. Our photon absorptiometry study demonstrates that most cranial elements have lower mineral content per unit volume (density) than vertebrae. It also illustrates more subtle variation in element densities within body parts, enabling us to distinguish density-mediated destruction from differential transport, even when cranial elements in general are scarce. In all three assemblages described, cranial elements constitute 6% or less of the assemblage. At 45-DO-211, cranial element scarcity is best explained by *in situ* destruction, mediated by density, given the significant correlation between density and survivorship (as well as other supporting evidence, such as condition and completeness of bone specimens). On the other hand, the scarcity of cranial elements at Keatley Creek more likely reflects cultural processing behaviour; the low correlation between density and element survivorship suggests that heads were rarely deposited at the site in the first place. Our work has shown that because densities of some head and fin parts (e.g. angular, otolith, pectoral fin ray) rivals that of vertebrae, it may be appropriate to use this group of elements to help identify prehistoric processing behaviour, rather than the entire suite of elements. Clearly, we have found these elements most useful in the comparisons presented above. By focusing salmon body part analyses on elements of highest density, an analyst might minimize the effects of density-mediated destruction in interpreting faunal assemblages.

Following Grayson (1989), we have suggested that correlations between bone density and element representation are explained best by whole carcass deposition followed by *in situ* destruction. Importantly, such a correlation does not specify the agents or processes responsible for that destruction. To identify proximate causes of bone destruction (e.g. cultural processing, carnivore scavenging, sediment chemistry) will require additional, detailed study of how such agents modify salmon bone assemblages (e.g. Lubinski, 1993).

In conclusion, salmon body part data may inform on issues of prehistoric cultural processing patterns, which in turn will be useful to more general studies on the evolution of hunter–gatherer subsistence patterns in the Pacific Northwest. However, such analyses will need to take into account such factors as bone density if they are to achieve meaningful results.

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Appendix: Measuring Fish Bone Volume

The materials required include a ring stand with clamp, water-filled beaker, nylon thread, and a balance. Briefly, this technique involves:

1. weighing a water-filled beaker;
2. tying thread around the bone; suspending the bone specimen from the ring stand and lowering the bone into the water;
3. recording the weight of the beaker with the submerged bone; and
4. subtracting the water-filled beaker weight from the beaker weight with the submerged bone, a value that is equivalent to the volume of the bone.

(Protocol follows Technical Procedure No. SA-8, 1990, Pacific Northwest Laboratory, Richland, WA).

The following reasoning is used to derive volume from mass. The bone is suspended from the ring stand; thus, the bone mass is not included in the measurement of the total mass. Rather, only the mass of the displaced water is added to the beaker when the bone is

Table 8. Average and range of bone volumes of three salmon elements

Catalogue no. VLB92-6:	Angular		Vertebra type-1		Coracoid	
	Average	Range	Average	Range	Average	Range
2	1·13	1·12–1·15	0·45	0·44–0·47	0·57	0·54–0·60
3	0·72	0·71–0·73	0·27	0·26–0·29	0·23	0·22–0·25
4	0·99	0·98–0·99	0·29	0·28–0·31	0·42	0·42–0·43
5	1·22	1·12–1·29	0·25	0·25–0·26	0·50	0·50–0·51
6	0·38	0·37–0·38	0·18	0·16–0·20	0·11	0·10–0·13
7	1·93	0·186–2·03	specimen broken		1·06	1·03–1·09
8	0·73	0·72–0·75	0·25	0·23–0·27	0·37	0·37–0·38
9	0·77	0·77–0·78	0·28	0·28–0·29	0·43	0·42–0·43
10	0·77	0·76–0·78	specimen broken		0·42	0·41–0·43
11	2·40	2·34–2·43	0·63	0·62–0·64	1·10	1·07–1·14

immersed (Archimedes Principle). Knowing the density of water (which is close to 1 between 18° and 30°C), and the mass of the displaced water, we can calculate the equivalent volume of the bone.

$$V_o = \frac{M_{wd}}{D_w}$$

where:

V_o=volume of the object
M_{wd}=difference in mass between the water-filled beaker and beaker with submerged bone
D_w=density of water.

We modified the procedure outlined above to measure salmon bone volume. First, because most of the salmon elements are not as dense as water, we added ballast (2–4 g calibration weights) to each suspended bone to force it beneath the water surface. The ballast volume was measured using hydrostatic weighing, and the value was subtracted from the combined ballast-bone volume measurement. In addition, we coated each of the specimens with a thin layer of paraffin before water immersion to obtain a bone volume which included the pore space.

Bone volumes were measured at least three times to identify recording errors and gauge the precision of the procedure. Differences between measurements are not great, as shown in Table 8, which lists the average and range in bone volumes for three of the salmon elements. Most of the variation probably results from differences in the amount of thread immersed in the beaker, since the volume of the thread was not taken into account.