THESIS APPROVAL

The abstract and thesis of Ross E. Smith for the Master of Arts in Anthropology were presented May 9, 2008, and accepted by the thesis committee and the department.

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ABSTRACT

An abstract of the thesis of Ross E. Smith for the Master of Arts in Anthropology presented May 9, 2008.

Title: Structural Bone Density of Pacific Cod (*Gadus macrocephalus*) and Halibut (*Hippoglossus stenolepis*): Taphonomic and Archaeological Implications

Describing prehistoric human subsistence strategies and mobility patterns using archaeofaunal assemblages requires archaeologists to differentiate the effects of human behavior from natural taphonomic processes. Previous studies demonstrate that differences in bone density both within and between taxa contribute to variation in element representation in archaeofaunal assemblages. Measurements of contemporary Pacific Cod (*Gadus macrocephalus*) and Pacific Halibut (*Hippoglossus stenolepis*) skeletal elements using Dual Energy Absorptiometry (DEXA) and hydrostatic weighing revealed differences in bone volume density between elements and taxa.

Density values were highest in Pacific cod and halibut jaw elements; the lowest bone volume densities were measured in Pacific cod and halibut basipterygia. While halibut and salmon often exhibited similar bone density values, the densities of Pacific cod elements were consistently higher than those from either salmon or halibut. These density data indicate that the remains of Pacific cod are more likely to persist in archaeological deposits. When combined with existing salmon bone density measurements, these data allow for the identification of density-mediated destruction in fish faunal assemblages from along the North Pacific rim.

Analysis of cod, halibut and salmon faunal assemblages from the North Point, Cape Addington Rockshelter, Rice Ridge, Uyak and Amaknak Bridge sites revealed that density-mediated element attrition has not consistently affected cod, halibut and salmon element representation in these sites. Significant correlations identified in aggregate site assemblages were not present at finer scales of analysis; the effects of density-mediated element attrition varied between depositional contexts. This research demonstrates that bone density data can be used to differentiate the effects of density-mediated element attrition from the results of human decision-making. Once density-mediated element attrition is ruled out, archaeologists can examine the effects of human processing, transportation, preparation and disposal activities on the distribution of Pacific cod and halibut skeletal elements both within and between archaeological contexts.

STRUCTURAL BONE DENSITY OF PACIFIC COD (*GADUS MACROCEPHALUS*) AND HALIBUT (*HIPPOGLOSSUS STENOLEPIS*): TAPHONOMIC AND ARCHAEOLOGICAL IMPLICATIONS

by

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CHAPTER 1: INTRODUCTION

This thesis examines the effects of bone density on Pacific cod (*Gadus macrocephalus*) and halibut (*Hippoglossus stenolepis*) body part representation in North Pacific archaeological sites and how these data can be used to examine variation in prehistoric processing and transportation decision-making across time and space. Archaeologists seeking to explain the development of complex social behavior among prehistoric hunter-gatherers have explored the associations between storage and population growth, changes in residential mobility, the development of social inequality, territoriality and the intensive use of subsistence resources (Ames 2005; Fagan and Maschner 1991; Fitzhugh 2002, 2003a, 2003b; Maschner 1991; Sassaman 2004). Along the North Pacific coast, intensive salmon harvesting, processing, storage and delayed consumption are commonly cited as important factors in the development of semi-sedentary complex societies during the prehistoric period (Ames 1994; Schalk 1977, 1981). How and when this pattern of salmon use developed is the focus of considerable research (Ames 1985; Burley 1980; Butler and Campbell 2004; Cannon 2001; Cannon and Yang 2006; Coupland 1985; Fladmark 1975; Hanson 1991; Kopperl 2003; Matson 1983, 1985; Moss and Erlandson 1995; O’Leary 1985; Partlow 2000; Schalk 1977; Suttles 1966). In an effort to document salmon storage, some researchers cite the uneven representation of salmon skeletal elements, specifically high counts of vertebrae and relative scarcity of cranial elements in archaeological deposits, as evidence for the prehistoric use of stored salmon. Such an argument is drawn from ethnohistoric accounts suggesting that the trunk was prepared for storage and that vertebrae were commonly associated with preserved salmon fillets (Boehm 1973; Matson 1992; Matson and Coupland 1995:166-167). However, researchers using this pattern of body part representation as an indicator of storage have not acknowledged that the physical properties of salmon bone affect preservation in archaeological contexts. Using salmon bone density data Butler and Chatters (1994) showed that differences in the density of salmon cranial and post-cranial remains differentially affect the preservation potential of certain salmon skeletal elements and that density-mediated destruction may mimic the effects of processing behavior on body part representation in some salmon archaeofaunal assemblages. Salmon have received considerable attention in studies of North Pacific prehistoric subsistence; however, some scholars have charged that the focus on salmon, sometimes referred to as “salmonopia,” has impeded study of other aquatic resources in the diets of North Pacific peoples (Hanson 1991; Monks 1987; Moss 1993; Partlow 2000) and that increasing emphasis should be placed on understanding the role of “secondary” resources in prehistoric subsistence and intensification strategies (Ames 2005).

Ethnohistoric accounts of North Pacific fish utilization suggest that Pacific cod and halibut were important storable resources vital to subsistence in areas where salmon were not available, during seasons when salmon were not abundant, or when stocks of stored foods were depleted (Boas 1921; Bowers and Moss 2001:172-173; Croes 1992; Drucker 1951; Emmons 1991; Lantis 1984:174-175; Swan 1869; Wigen and Stucki 1988). The abundance of halibut and cod skeletal remains in some archaeological sites suggests that these fishes were as important, or more important, than salmon in some precontact fisheries (Bowers and Moss 2001; Croes 1992; Huelsbeck and Wessen 1994; Wigen and Stucki 1988). In addition, since cod and halibut could be preserved and stored for long periods of time in a manner similar to salmon, hunter-gatherers could have intensified use of these fishes to compensate for temporal and geographic variation in salmon abundance and human population growth (Croes 1992). Behavioral inferences have also been made from differences in the proportions of cranial and post-cranial remains identified in cod and halibut archaeofaunal assemblages (see Bowers and Moss 2001; Croes 1992; Wigen and Stucki 1988). However, bone density data comparable to those generated by Butler and Chatters (1994) do not exist for Pacific cod and halibut. Therefore, researchers are currently unable to assess whether patterns of archaeological cod and halibut body part representation were produced by density-mediated destruction or whether the relative abundances of their skeletal parts truly represent the results human processing, storage and disposal behavior. While existing studies have focused on the taphonomic processes influencing salmon bone preservation and destruction, complementary studies of non-salmonid fish remains are needed.

The goal of my thesis research is to explore the effects of natural and cultural processes on halibut and cod element representation in North Pacific archaeofaunal assemblages by specifically addressing how structural bone density affects element representation and the inferences that may be drawn from archaeological deposits. I will generate bone density data for Pacific cod and halibut and use these data to determine whether or not density-mediated destruction has affected element representation in North Pacific archaeological assemblages. In so doing, I will determine whether it is possible to use halibut and cod body part representation as an indicator of butchery and transport practices. The cod and halibut bone density data sets produced by my analysis will be comparable to existing salmon bone density data, expanding the breadth of bone density research and allowing archaeologists to undertake inter-taxonomic comparisons of fish bone taphonomy. This research represents a crucial step towards more accurately documenting prehistoric variation in the use of anadromous and marine fishes associated with increasing cultural complexity and changing subsistence and settlement strategies along the North Pacific rim. Comparable bone density data presented in this thesis will also contribute to our understanding of the taphonomic factors that affect fish remains in archaeological contexts in other parts of the world where aquatic resources were and are a critical component of subsistence and commercial economies (Barrett 1997; Barrett et al. 1999; Barrett et al. 2004; Colley 1983, 1984; Nicholson 1992).

This thesis is organized into 5 chapters. In Chapter 2, I describe previous taphonomic studies and, including methods of analyzing bone density and the ways that bone density data are used to differentiate natural and cultural effects on archaeofaunal assemblages. I review ethnohistoric descriptions of human processing and disposal behavior from the North Pacific region and develop expectations regarding the effects of hunter-gatherer decision-making on cod and halibut element representation. Finally, I discuss examples of how archaeologists working along the North Pacific and North Atlantic coasts have used body part representation and bone density data to develop and test inferences about past human behavior. Chapter 3 presents the methods used to obtain Pacific cod and halibut structural bone density data and the results of my bone density analysis. I present an inter-taxonomic comparison of the Pacific cod, halibut and salmon bone density data sets and conclude chapter 3 with predictions regarding the potential effects of density-mediated element attrition on Pacific cod and halibut body part representation and taxonomic abundance in archaeological assemblages. In Chapter 4, I test these predictions using published North Pacific archaeofaunal assemblages to determine if density-mediated attrition has affected Pacific cod, halibut and salmon skeletal element representation. In Chapter 5, I summarize the results of my research and discuss the taphonomic and archaeological implications of my findings to the study of aquatic resources and past human subsistence.

CHAPTER 2: FISH TAPHONOMY, STORAGE AND THE DEVELOPMENT OF BEHAVIORAL INFERENCES FROM BODY PART REPRESENTATION

Taphonomy and Structural Bone Density Research

Taphonomic studies examine the physical processes operating on materials during their use and subsequent incorporation into sedimentary deposits such as archaeological assemblages. Faunal remains found in archaeological assemblages are affected by both cultural and natural processes of modification and attrition that occur as skeletal materials move from a living biological context, through a human behavioral context and into an archaeological context (Gifford 1981:385-389). After an animal is killed, the methods of processing faunal materials for use in a behavioral context have physical effects on these materials. For example, choices made during the butchering and transportation of faunal resources affect the spatial distribution of faunal materials. Cooking, particularly for extended periods with boiling water (e.g. Lubinski 1996; Nicholson 1996; Richter 1986; Roberts et al. 2002), consumption and digestion (e.g. Butler and Schroeder 1998; Jones 1984, 1986; Jordan 1997) can alter the physical and chemical characteristics of skeletal elements. Natural and secondary cultural processes affect the preservation or destruction of faunal materials after then enter sedimentary deposits. Post-depositional alteration or destruction may result from trampling, scavenging, and reuse of materials by people. The rate and mode of burial, composition of accumulated sediments, and post-burial alteration resulting from physical processes such as compaction or excavation, and chemical processes such as mineralization and leaching all affect the preservation of faunal materials (Lyman 1994:404-433). Finally, the methods employed in the collection and analysis of archaeological data, such as the use of different mesh sizes in the recovery of excavated faunal materials, affect the identification and quantification of certain taxa or skeletal elements (Cannon 1999; Grayson 1979; James 1997; Shaffer 1992; Shaffer and Sanchez 1994; Shaffer and Baker 1999).

Archaeologists conduct ethnoarchaeological and experimental research to better understand the effects that past human behavior can have on faunal materials. Often the goal of these projects is to understand how human behavior, in combination with natural processes, create and shape archaeofaunal assemblages. Ethnoarchaeological studies often focus on documenting the subsistence behavior of contemporary hunter-gatherers and how different behavior or activities shape faunal assemblages. For example, in his study of caribou hunting among the Nunamiut in northern Alaska, Binford (1978) sought to document the decision-making processes involved in the butchering and transport of different parts of a caribou carcass and how these decisions affect the frequencies of skeletal elements found in the faunal assemblages at kill/butchering and residential sites. To measure the effects of hunter-gatherer butchery and transportation decision-making Binford (1978) employed a measure of economic utility known as the Modified General Utility

Index (MGUI), which quantified the relative amounts of meat, marrow, grease or other usable materials associated with different parts of an animal carcass (Binford 1978:74; Jones and Metcalfe 1988; Metcalfe and Jones 1988; O'Connell et al. 1989). Measures of the frequency of skeletal parts, such as the Minimum Animal Unit (MAU) and element survivorship (%MAU), were also employed to describe the effects of different processing and transport strategies on skeletal element representation at kill/butchering and residential sites.

Experimental archaeological studies focus on identifying the physical factors (i.e. bone size, shape porosity and density) governing bone preservation and destruction in different behavioral and depositional contexts (Gifford 1981; Robinson et al. 2003). Understanding the physical properties of skeletal remains allows researchers to predict how natural and cultural processes affect the preservation of faunal materials. These predictions can then be tested using experimental and archaeological data. Bone structural density is one attribute that has received considerable attention as a proxy measure of bone preservation potential in studies of faunal taphonomy.

Beginning in the late 1960s, American archaeologists began to systematically examine the relationship between bone density and element representation in archaeofaunal assemblages. In an effort to account for variation in the frequencies of goat (*Capra hircus*) skeletal parts in a faunal assemblage produced and modified by humans and dogs, C.K. Brain measured the structural density [defined as the ratio of the mass of a substance to its volume (Lyman 1994:237)] of goat bones to determine which elements were more or less likely to survive human processing and dog gnawing (Brain 1969 described in Lyman 1994:235; Brain 1981:11-29). Using Spearman's rank order correlation coefficient (Spearman's rho), Brain compared goat skeletal element abundance with the structural densities of the goat remains and found a significant correlation between the two data sets (r_s=80, P=0.03) (Brain 1969 described in Lyman 1994:235). Based on this analysis, Brain concluded that bones with low structural densities were more likely to be destroyed by carnivore ravaging than elements with high structural densities. In 1975, Behrensmeyer presented measurements of domestic sheep (*Ovis aries*) bone structural density. Both Brain (1969 described in Lyman 1994) and Behrensmeyer (1975) measured a combination of whole and partial elements. However, comparisons between Brain and Behrensmeyers' density measures were complicated by differences in how the bones were measured, specifically, whether or not the volumetric measurement included or excluded the porosity of the element being measured (Lam and Pearson 2005:101).

Skeletal elements are composed of a mixture of mineralized and soft tissues. The soft tissues occupy open spaces in mineralized bone structures and these openings or pores affect the ratio of mass/volume measured when determining the density of the structure. Cancellous, or spongy bone, exhibits high porosity, while compact bone has low porosity. The amount of cancellous and compact bone, and its associated porosity, varies both within and between different skeletal elements. Porosity is a characteristic that describes the homogeneity or heterogeneity of a substance. Homogenous substances exhibit a constant structural density while the structural density of heterogeneous substances varies. If the density of heterogeneous skeletal tissue is measured, the value represents an average of the densities of its component parts (Lyman 1994:237). To differentiate density measures that included or excluded porosity, Lyman (1984) coined the terms *true density* and *bulk density*. True density is a measure of a substance exclusive of pore space volume, while bulk density measures include the volume of the pore space (Lyman 1994:237).

In the 1980s Lyman used photon densitometry/absorptiometry to measure the mineral content of bone at standardized scan sites on different artiodactyl elements. Photon densitometry measures changes in the strength of a beam of light as it passes through bone to determine the bone mineral mass (g) of the bone at the specific scan site. To convert the bone mineral mass value produced by photon densitometry into a density value (g/cm^3), it is necessary to calculate the area or volume of the bone at the scan site. Researchers using photon densitometry estimated the cross-sectional area of bone at scan site using a number of different methods. In his initial study, Lyman (1984) measured the maximum width and length of the element at the scan site and used these measurements to calculate a rectangular cross-sectional area. However, this method tended to over-estimate the scan site area, producing density values that were lower than the actual bone density. Subsequent researchers modified Lyman's approach to measuring the cross-sectional area of the scan site. Dirrigl (2001), Kreutzer (1992), Lyman et al. (1992) and Pavao and Stahl (1999) used combinations of geometric shapes to estimate the area of the scan site. Carlson and Pickering (2004) and Stahl (1999) more accurately estimated the external shape of the scan site using computerized analysis of digital images but were not able to adjust for internal cavities. Computed tomography (e.g. Cruz and Elkin 2003; Lam and Pearson 1999) and water displacement (e.g. Butler and Chatters 1994; Nicholson 1992) allowed researchers to measure the external and internal shape of the scanned area and produced more accurate density measures (Lam and Pearson 2005).

In spite of difficulties associated with measuring the volumes of scan sites, many researchers used photon densitometry with accompanying volumetric adjustments to measure bone density. In the last 20 years, the number of quantitative bone density studies expanded to include a range of mammalian fauna, two avian taxa, and three fishes (Table 1).

Table 1: Taxa Included in Previous Bone Density Studies

Common Name	**Genus species**	**Reference**
Mammal		
Llama	*Lama glama*	Elkin 1995
Vicuña	*Lama vicugna*	
Guanaco	*Lama guanicoe*	
Pig	*Sus scrofa*	Ionannidou 2003
Domestic cattle	*Bos taurus*	
Domestic Sheep	*Ovis aries*	
American Bison	*Bison bison*	Kreutzer 1992
Wildebeest	*Connachaetes taurinus*	Lam et al. 1999
Reindeer	*Rangifer tarandus*	
Burchell's zebra	*Equus burchelli*	
Przewalskii's horse	*Equus przewalskii*	
Deer	*Odocoileus spp.*	Lyman 1984
Domestic sheep	*Ovis aries*	
Pronghorn antelope	*Antilocapra americana*	
Woodchuck	*Marmota monax*	Lyman et al. 1992
Yellow-bellied marmot	*Marmota flaviventris*	
Domestic dog	*Canis familiaris*	Novecosky and Popkin 2005
Wolf	*Canis lupus*	
Coyote	*Canis latrans*	
Red fox	*Vulpes vulpes*	
Swift fox	*Vulpes velox*	
European rabbit	*Oryctolagus cuniculus*	Pavao and Stahl 1999
Eastern cottontail	*Sylvilagus floridanus*	
Snowshoe hare	*Lepus canadensis*	
Black-tailed jackrabbit	*Lepus californicus*	
Baboon	*Papio cynocephalus*	Pickering and Carlson 2002
Alpaca	*Lama pacos*	Stahl 1999
Domestic sheep	*Ovis aries*	Symmons 2004
Human	*Homo sapiens*	Willey et al. 1997
Avian		
Lesser rhea	*Pterocnemia pennata*	Cruz and Elkin 2003
Wild turkey	*Meleagris gallopavo*	Dirrigl 2001
Fish		
Tui Chub	*Gila bicolor*	Butler 1996
Chinook salmon	*Oncorhynchus tshawytscha*	Butler and Chatters 1994
Atlantic cod	*Gadus morhua*	Nicholson 1992

In addition to identifying patterns of bone density variation between skeletal elements from a specific taxon, bone density studies were increasingly used to make comparisons between specimens from different taxa. In his studies of the effects of carnivores on skeletal elements, Brain (1981:26) noted that baboon bones succumbed to carnivore ravaging more readily than equivalent ungulate bones and postulated that ungulate bones were more likely to be preserved in fossil assemblages than similar primate bones. Beginning in the 1980s, increasing use of standardized methods and instruments (i.e. photon densitometry) provided precise and accurate bone density values that allowed archaeologists to measure individual bone density variation within and between taxa.

Inter-taxonomic comparisons demonstrated that significant inter-taxonomic variation was present between different terrestrial mammal taxa (Ioannidou 2003; Kreutzer 1992; Lyman et al. 1992; Pavao and Stahl 1999; Skedros et al. 1997). Sex variability, nutritional stress and age also appear to affect individual variation in bone density (Ioannidou 2003). In some cases, greater variation may be present within a taxon than between taxa (Pavao and Stahl 1999). Using a combination of interval level statistics (e.g. *t*-tests and Pearson's r) to analyze the amount of bone density variation between individuals, Ioannidou (2003) found that differences in bone density were present between different taxa and that sex and age produced significant variations between individuals from the same species. Statistical inter-taxonomic differences in bone density led Ioannidou (2003:364) to conclude that taphonomic processes may differentially affect the preservation of the remains of some terrestrial mammal species.

While fewer comparable studies have included aquatic taxa, significant inter-taxonomic differences in bone density are also present between some fishes. In an analysis of the potential taphonomic processes influencing Tui chub (*Gila bicolor*) skeletal abundance in lakeside archaeological sites located within the Great Basin, Butler (1996) presented bone density values for the Largescale sucker (*Catostomus macrocheilus*) and used these density data to examine the role of bone density in structuring Tui chub body part representation. Since the Largescale sucker bone density data were collected using the same methods as those from the Chinook salmon (*Oncorhynchus tshawytscha*) (Butler and Chatters 1994), it is possible to make inter-taxonomic comparisons using bone density. For instance, while salmon vertebrae are relatively denser than their cranial elements, sucker vertebrae are less dense than most cranial elements.

Measures of skeletal element abundance in archaeological or paleontological faunas may be differentially affected by inter-taxonomic differences in bone density. For instance, if the elements from one taxon exhibit bone densities that are consistently lower than another taxon, and these taxa are subjected to the same destructive processes, elements from the taxon with low bone density will be less likely to survive than high-density elements from the other taxon. Therefore, when comparing the element abundance values of multiple taxa, it is useful to consider whether inter-taxonomic differences in bone density may be biasing the characteristics of the assemblage. However, persistent use of non-standardized methods by some researchers and a proliferation of new approaches to measuring bone density and other skeletal element properties (i.e. Farquharson and Speller 1997; Robinson et al. 2003) have discouraged inter-taxonomic comparisons between bone density data sets produced by multiple researchers.

Nevertheless, data derived from bone density studies have been used productively to predict the effects of density-mediated destructive processes on bone and examine archaeofaunal assemblages for signatures of density-mediated element attrition. Archaeologists assess the role of bone density in accounting for element representation by comparing the density values of specific elements to their abundance in archaeofaunal assemblages. Assuming the ubiquity of destructive processes, a significant positive correlation between bone density and skeletal element representation (%MAU) suggests that density-mediated element attrition [i.e. the loss of skeletal parts due to their structural density (see Lyman 1994:252)] is responsible for the presence and absence of certain elements in the assemblage and may affect the abundance of certain taxa whose skeletal structures are predominantly composed of low-density elements. Taphonomic processes that differentially affect element representation by acting upon low-density elements include physical forces such as chewing or gnawing, post-depositional crushing or compaction or chemical processes involved in digestion or dissolution in acidic soil conditions (Brain 1981; Butler and Schroeder 1998; Jones 1984, 1986; Jordan 1997; Nicholson 1996, 1998). Bone density data allow researchers to test for the potential effects of density-mediated destruction in archaeofaunal assemblages. Once density-mediated attrition has been eliminated as a causal agent responsible for structuring an archaeofaunal assemblage, element representation may be used to infer past human behavior. In the North Pacific region the presence, absence and changes in the relative abundance of certain salmon skeletal elements through time are used to infer the processing, preservation and storage of salmon and, salmon bone density data are used to test for the effects of density-mediated bone destruction in some archaeological assemblages.

Identifying Archaeological Measures of Salmon Storage along the North Pacific Coast

Prehistoric storage behavior can be documented by identifying the archaeological correlates of surplus production, processing in preparation for storage, and the delayed consumption of stored resources. Three lines of evidence are used to infer storage from the archaeological record: indications of labor organization, the existence of specialized technologies and the remains of processed resources. For example, labor organization is commonly inferred from the construction and use of facilities such as weirs, traps or large nets designed to produce a surplus catch. Technological developments, such as specialized tools and facilities, are needed to efficiently process the surplus and prepare it for storage (Rowley-Conwy and Zvelebil 1989). Finally, direct evidence of storage may be obtained from the characteristics of archaeological floral and faunal assemblages. For instance, the remains of some taxa may be transported outside of their natural ranges (Chatters 1987). While use in tool manufacturing may be the impetus for transporting some bones, most are transported in association with consumable soft tissues (Lyman 1984:283) and the presence or absence of specific remains may be evidence of processing or preparation involved in the storage and consumption of the resource (Sauvage 1875). Specific skeletal remains may also be associated with storage features or activity areas (Kent 1999). Along the North Pacific coast archaeologists have studied these lines of evidence to document changes in subsistence strategies associated with the development of complex hunter-gatherers (Fitzhugh 2003a, 2003b; Kopperl 2003; Maschner 1997; Partlow 2000). However, these efforts have tended to primarily focus on the intensive use and storage of salmon.

Ethnohistoric accounts of the abundance of salmon and intensive strategies for procuring, processing and storing salmon inspired many researchers to document the prehistoric development of salmon fisheries along the North Pacific coast. Researchers have sought evidence of hierarchical social organization and the ability to direct a large labor force that may have enabled the large-scale procurement and storage of salmon (Ames 1981, 1985). Archaeological investigations have identified technologies, such as nets, traps and slate knives, utilized in salmon procurement, processing and storage. Several studies have examined North Pacific faunal assemblages for evidence of salmon intensification (Butler and Campbell

2004; Kopperl 2003; Partlow 2000). Finally, some researchers have sought direct evidence of salmon storage from analyses of remains associated with storage features and patterns of body part representation from numerous sites along the Northwest Coast (Bernick 1983; Boehm 1973; Coupland et al. 2003; Croes 2003; Grier 2003; Matson 1992; Matson and Coupland 1995; Wigen 2003, 2005).

A simple behavioral model to explain salmon element representation in terms of human behavior was originally proposed by Sauvage (1875) in France:

> It is an interesting fact that among the numerous salmon remains from the caves, which we have examined, we have not met with an entire skeleton, having seen only portions of the vertebral column, as if only the edible portions were taken home to the caves. The bones of the head of the salmon, had they been there, would have been as well preserved as those of the small cyprinoids [chub, bream] which we find in the same deposits. These cyprinoids, on the contrary, which constituted what we may call the every-day fishing of the Aborigines, are recognised (sic) in all parts of their skeleton. They were evidently caught near the abode, and furnished fresh food; whilst the salmon went to form a food reserve (Sauvage 1875:223).

In this passage Sauvage assumes that salmon and cyprinoids should be equally well preserved in these cave deposits and uses the disproportionate abundance of salmon post-cranial remains to make several inferences. First, that salmon were being processed in a manner different from the cyprinoids. Second, that processing resulted in salmon cranial and postcranial remains being deposited in separate locations. Finally, that the pattern of salmon element representation was indicative of the use of stored salmon at these sites.

Nearly one hundred years later a similar model was independently developed by Boehm (1973) to explain the disproportionate representation of salmon post-cranial remains at the St. Mungo Cannery site in British Columbia. Based on ethnographic accounts of Upper Stalo salmon processing, Boehm (1973:95) proposed that if salmon heads were removed before being preserved, archaeologists could expect to find increasingly disproportionate percentages of salmon post-cranial and cranial remains as the preparation and consumption of dried or smoked salmon increased through time. Boehm (1973:95) further proposed that disproportionate abundance of salmon post-cranial remains could be a seasonal indicator of winter occupation of archaeological sites. Other researchers subsequently used Boehm’s model to infer prehistoric salmon storage, site seasonality and site function from the relative abundance of salmon post-cranial remains at archaeological sites along the Northeast Pacific coast (e.g. Bernick 1983; Coupland et al. 2003; Croes 2003; Grier 2003; Matson 1992; Matson and Coupland 1995; Wigen 2003; 2005).

As researchers focusing on mammalian fauna have pointed out, archaeologists must consider the “monitoring perspective” (the location of the site in the context of the subsistence and settlement system) when interpreting patterns in archaeofaunal samples (Thomas and Mayer 1983). Since the attributes of a faunal assemblage are the product of the processing, transport and disposal activities conducted at a location within the subsistence system, inferences based on the archaeofaunal assemblage from one site, or one type of site, may not be representative of the whole subsistence system (Binford 1978; Lyman 1994; Thomas and Mayer 1983:368-369). Boehm's model is often used to infer that sites containing disproportionately high numbers of vertebrae represent base-residential sites where preserved and stored salmon were consumed. If this inference were accurate, one would expect that head parts should dominate faunal samples from contemporaneous logistical camps if, in fact, heads were cut off and deposited at these field-processing locations (Butler 1990). While differences in the proportions of cranial and post-cranial remains have been documented at different functional locations in late prehistoric salmon processing camps and village sites in the Aleutian Islands (Hoffman et al. 2000), little effort has been taken to systematically document variation in salmon body part representation between different types of contemporaneous sites along the North Pacific coast. When salmon cranial or post-cranial remains are disproportionately represented in North Pacific faunal assemblages this pattern is often uncritically viewed as evidence of specific processing activities. However, other taphonomic processes have also been shown to affect body part representation.

Butler and Chatters (1994) measured salmon structural bone density and compared the density data with element representation data from three archaeological sites in northwestern North America. They found that the bone density values of most salmon cranial elements were lower than vertebrae and reasoned that vertebrae should resist destruction better than cranial remains when exposed to destructive processes. Their analysis revealed that significant correlations were present between salmon element survivorship and ranked salmon bone density values suggesting that density-mediated bone attrition accounted for cranial element representation at two of the three sites in their study, while processing behavior could account for the relative abundance of post-cranial remains at the third site. This study demonstrated that the density of salmon bones can affect patterns of body part representation that are used to infer the operation of prehistoric butchering, transport and storage practices.

The commonly employed assumption that high numbers of salmon vertebrae and relatively low numbers of cranial remains are indicative of salmon storage is: 1) overly simplistic, 2) narrowly focused on one component of the settlement system, and 3) does not consider variation between sites. While salmon bone density data have been available for over 10 years, and ethnohistoric sources contain descriptions of salmon head preservation methods (e.g. Drucker 1951:63; Emmons 1991:143), archaeologists continue to cite the simple behavioral model and infer salmon storage from body part representation without using salmon bone density data to test for the effects of density-mediated bone destruction in North Pacific archaeological sites (e.g. Croes et al. 2005; Coupland et al. 2003; Wigen 2003).

The preoccupation with documenting salmon utilization along the North Pacific coast has affected archaeologists' perception of the value of other fish resources (Ames 1991:941). Analyses of the ethnographic and archaeological records from the North Pacific region demonstrate that a diverse range of plant and animal resources were included in the local subsistence economies of native peoples. Although salmon may have been a critical resource for groups with access to productive salmon procurement areas, non-salmonid fishes were important sources of protein, oils and fats (Ames 1994). Additional research is needed to better document the changing use of all fishes by native peoples across the North Pacific region through time. Fishes such as Pacific halibut, which can grow to be very large, and Pacific cod, which could be taken in large numbers using relatively simple fishing technologies, were important resources that could be processed and stored for long periods of time. The importance of these fishes is visible in historic accounts of Native American subsistence practices and archaeofaunal assemblages along the North Pacific coast.

Ethnohistoric Uses of Pacific Cod and Halibut and their Taphonomic Implications

The ethnohistoric record from the North Pacific region contains descriptions of cod and halibut procurement, butchering, storage practices and the decision-making processes that guided these strategies. These descriptions provide a starting point for archaeologists to formulate hypotheses regarding the effects of human behavior on fish faunal remains incorporated into the archaeological record and the types of patterns that may be produced by certain procurement or processing activities. In reviewing ethnohistoric accounts from the North Pacific coast I attempted to address the following questions regarding the use of cod and halibut by native peoples.

- Where and when were cod and halibut obtained?
- How and where were fresh cod and halibut prepared for immediate consumption?
- Where and how did cod and halibut processing occur?
- How and where were preserved cod and halibut stored?
- When and where were preserved cod and halibut consumed?
- How were they prepared?
- And finally, how were fish remains disposed of?

Cod and Halibut Seasonality

While the availability and abundance of fish such as salmon varied dramatically throughout the year, Pacific cod and halibut could be obtained in nearly every season. Ethnographic accounts of Native American subsistence fisheries describe native peoples from southwest, southcentral and southeast Alaska obtaining halibut throughout the year (Table 2).

Table 2: Seasonality of North Pacific Ethnohistoric Halibut Fishing

Area	**Group**	**Season**				**Reference**
		Spring	**Summer**	**Fall**	**Winter**	
Southwest Alaska	Unalaska Island	X	X	X	X	Jochelson 1933
	Akutan Island	X	X	X	X	Spaulding 1955
	Kodiak	X	X			Clark 1984
Southcentral Alaska	Chugach	X	X	X	X	Clark 1984
	Eyak		X		X	Birket-Smith and de Laguna 1938; de Laguna 1990
Southeast Alaska	Tlingit	X	X	X	X	de Laguna 1972; Oberg 1973
British Columbia	Haida	X	X	X	X	Blackman 1982, 1990 Dawson 1880:109B
	Kwakiutl	X		X		Boas 1921
	Nootka	X	X			Jewitt 1988
Washington	Makah	X	X	X		Swan 1870
	Coast Salish		X			Suttles 1974

Further south along the British Columbia and Washington coasts, halibut fishing was primarily a spring and summer subsistence activity. Young Pacific halibut typically inhabit shallow nearshore waters. As they age, Pacific halibut begin to migrate into deeper waters along the edge of the continental shelf during the winters and return to shallower nearshore waters in the summers (OCSEAP 1987:424-425). However, many mature halibut do not spawn every year. Along the North Pacific coast Pacific cod were most commonly caught in the spring and early summer although two native groups in southwest Alaska and British Columbia also obtained cod in the winter (Table 3). The seasonal pattern of Pacific cod use may have resulted from fluctuations in the accessibility of cod as they migrate into deeper offshore waters to spawn during the winter (Ketchen 1961).

Table 3: Seasonality of North Pacific Ethnohistoric Cod Fishing

		Season				
Area	**Group**	**Spring**	**Summer**	**Fall**	**Winter**	**Reference**
Southwest Alaska	Unalaska Island		X		X	Jochelson 1933
	Akutan Island	X				Spaulding 1955
Southcentral Alaska	Chugach		X			Clark 1984
	Eyak	X	X			de Laguna 1990
Southeast Alaska	Tlingit	X	X			de Laguna 1972; Oberg 1973
British Columbia	Kwakiutl	X	X			Boas 1921
	Nootka	X	X		X	Drucker 1951; Jewitt 1988

Along the North Pacific coast, the seasonal movements of native peoples within traditional territories were tied to changes in resource availability. In addition to access to fresh water and sheltered beaches, the locations of winter villages were partially determined by access to resources during the late winter and early spring when stored foods ran low. In Southeast Alaska, Tlingit and Haida winter settlements on the islands of the Alexander Archipelago were located in sheltered bays with convenient access to deep-water halibut and cod fishing grounds (Acheson 1995:284; Blackman 1990:241; de Laguna 1972:52, 1990:206; Langdon 1979:116). Ethnohistoric accounts from southeast Alaska, British Columbia and western Washington also describe the seasonal movement of native peoples to spring and summer camps where halibut were fished and dried for use in the fall and winter. For example, in April and May the Yakutat Tlingit moved to spring camps in Yakutat Bay where they fished and dried halibut for use in the mid summer at seal hunting camps located near seal birthing areas at the head of Yakutat Bay (de Laguna 1972). In the early 1900s, Haida families from Masset lived at halibut fishing camps between the end of February and early May (Blackman 1982:55-56). Similarly, Jewitt (1988) reports that at the end of February the Nuu-chah-nulth (historically referred to as the “Nootka”) moved their plank houses from sheltered winter village locations to summer settlements situated closer to the ocean coast and deep-water fishing areas where halibut and cod were caught. In the summer, Coast Salish families moved from the mainland and established temporary camps on the islands in Puget Sound where halibut were processed and preserved (Suttles 1974:115). In addition to established fish camps, the initial butchery of cod or halibut may have taken place at locations immediately accessible from the fishing grounds. For instance, along the west coast of Vancouver Island Lord (1866:147:150) reported that if a large halibut was caught but could not be brought into the canoe, the halibut was towed to shore where it was cleaned, portions of the halibut were cooked and consumed, and the rest of the halibut was cut up and loaded into the canoe for the trip back to the settlement.

Preparation and Consumption of Fresh Cod and Halibut

Spring could be the leanest season for many native groups along the North Pacific coast (Drucker 1951:37; Jewitt 1988). Aside from the dried provisions that had been put away the year before, few fresh foods were available. However, in many coastal areas cod and halibut were the exception; they were often the first fresh fish caught and consumed in the early spring (Davydov 1977; Oberg 1973).

Boas (1921), Emmons (1991), Katasse (in Newton and Moss 1984) and Swan (1870) provide detailed descriptions of halibut and cod butchery. With the exception of especially large halibut (e.g. Lord 1866:149-150), halibut and cod likely arrived whole at residential villages or camps. Cleaning and butchering of the fish took place on beaches adjacent to these sites. Viscera were removed and discarded and the carcass was disarticulated to some degree. All or portions of the carcass were transported to secondary processing stations such as the household hearth where the carcass was prepared for immediate consumption or the drying racks or smokehouse where the carcass was preserved and prepared for storage.

According to Boas (1921:382), the Kwakiutl (now referred to as the Kwakwaka’wakw) never left the viscera in cod and halibut overnight. Halibut gills and viscera were removed by cutting open the abdominal cavity along the ventral margin between the anal vent and the base of the pectoral girdle and along the top of the gills near the base of the neurocranium (Boas 1921:242).

The gills and viscera were then removed in one piece. While the gills and viscera were discarded, the Kwakiutl sometimes set aside the stomach to be boiled or dried and eaten (Boas 1921:244). To remove the cod gills and viscera, a cut was made behind the pectoral fins and along the ventral surface of the cervical vertebrae allowing the pectoral girdle and gills to be removed in one piece (Boas 1921:379-380). The viscera were then pulled out of the body cavity, the stomach and gills were saved and the intestines were discarded on the beach. The cod stomach and gills were then boiled and consumed within a day of the cod being caught (Boas 1921:383).

Pacific cod were sometimes prepared for consumption by roasting and boiling. The Kwakiutl roasted whole cod carcasses by placing them alongside a fire and turning them to expose each side of the fish to the heat. The meat was stripped from the trunk and the head was not eaten. At the conclusion of the meal, the carcass, including the head, was thrown into the fire (Boas 1921:391-392). When many cod were caught and processed, the cod were filleted in a manner similar to salmon. Cuts were made behind the head and pectoral girdle and along both sides of the dorsal fins down the length of the body close to the backbone (Boas 1921:382-383). The meat fillets from both side of the body, connected by the belly and the pelvic girdle, were then removed in one piece from the head, pectoral girdle and vertebrae. The fresh cod fillets were then boiled or roasted (Boas 1921:384-386, 390-391). However, while Boas describes the boiling and roasting of fresh cod fillets in great detail, he does not describe how the fresh heads or vertebrae were treated after the fillets were removed.

Although Boas describes four methods of preparing fresh cod, he reports that the Kwakiutl preferred to consume what he referred to as “tainted” cod that had been kept in the corner of a house for a long (but unspecified) period of time, until they were ripe (Boas 1921:386). Both whole cod carcasses and cod heads were prepared and consumed in this manner. Whole tainted cod were placed in warm water to remove the scales, then removed from the water and beaten with a wedge until the body was softened. Vertical cuts were then made along both sides of the body and the whole fish was boiled until the bones separated easily from the meat. The post-cranial bones were then removed from the boiling water and thrown into the fire and the head was left in the boiling water (Boas 1921:387). The cooked head was broken apart and the meat and fat contained in the head was consumed. Tainted cod heads were prepared by being boiled for a very long time. The meat and fat on the cranial bones was eaten, the bones were sucked clean and then thrown into the fire (Boas 1921:389).

Halibut heads, along with portions of the backbone and fins were roasted or boiled and consumed fresh by the Kwakiutl (Boas 1921:247), Haida (Blackman 1982:84) and Tlingit (Oberg 1973:66) during the spring and summer halibut fishing season. Boas (1921:357-359) provides a particularly detailed account of the processing and consumption of fresh halibut heads and backbones among the Kwakiutl. The halibut head was first chopped into large pieces, placed in a kettle and then boiled for a long time. The chopped and boiled halibut heads were distributed to the guests who consumed the adhering meat and separated the bones. The bones were then chewed and sucked to remove all of the fat and juices within the bones. According to Boas' informants, halibut heads were not consumed in the morning because they contained too much fat and too much fat makes a person sleepy (Boas 1921:358-359). Blackman (1982:84) reports that the Masset Haida often consumed fresh halibut heads, vertebrae and tails while they processed and dried halibut at their spring halibut fishing camps. If numerous halibut were caught and processed, the stomachs were not saved and the viscera, heads and fins were thrown back into the water after the meat fillets were removed from the trunk (Boas 1921:247). While a portion of the cod and halibut caught in the spring were prepared and consumed fresh, the remainder was often preserved and stored for use in later seasons.

Cod and Halibut Processing and Storage Methods

Halibut fillets obtained during the late spring and early summer were preserved and stored (Boas 1921:241-252; Drucker 1951; Emmons 1991; Swan 1870). Native groups such as the Kwakiutl believed that halibut were fattest in the autumn, and so in addition to their spring halibut fishing season, the Kwakiutl would fish halibut again in the fall to preserve for winter (Boas

1921:248). In preparation for storage, halibut were filleted, the carcasses were disarticulated and nearly every part was dried over fires and in the sun (Boas 1921). Prior to filleting, the pectoral fins were cut off. The skin was then cut along the dorsal and anal fin. Finally, a cut was made along the lateral line to the vertebrae and along the dorsal and ventral vertebral spines in order to remove halibut meat fillets from the trunk (Boas 1921:243). The head was removed and the tail and vertebrae were separated from the dorsal and anal fins. The dorsal and anal fins were tied together and suspended over a fire to dry (Boas 1921:244). The lower jaw was removed from the halibut heads and each side of the head was cut from the neurocranium. The neurocranium was then discarded on the beach, and the sides of the head were spread out over the fire to dry (Boas 1921:248). The vertebral column and attached caudal fin were also hung over the fire to dry. Meat fillets were hung over the fire for four days (Boas 1921:249). On the fifth day they were brought outside to dry in the sun. Additional cuts were made into the meat to produce pieces of a desired length and thickness and the fillets were hung out on a drying rack for at least four more days until sufficiently dry to be packed away in baskets in a dry part of the house (Boas 1921:250-252). Among the Tlingit, the preserved head, fins and tail were highly valued (Emmons 1991:145) and the Makah and Tlingit stockpiled dried halibut fillets for consumption during the winter season (Emmons 1991; Swan 1870).

In some parts of Southeast Alaska and British Columbia, cod caught in the late spring and early summer were also filleted, dried and stored (Boas 1921; de Laguna 1972:402; Drucker 1951; Oberg 1973). According to Boas (1921:253) dried cod fillets were prepared and treated in a similar manner as halibut. With the exception of tainted cod Boas (1921) does not describe the preservation of other cod body parts. Once the bones were removed from the cod fillets, the skin was removed and the fillet was cut into long thin strips. The cod fillets were then dried outside in the open air or, during bad weather, inside the house behind the fire (Boas 1921:253). Boas' informant reported that dried cod did not keep as well as dried halibut although it is unclear whether the informant was referring to sun-dried cod, smoke-dried cod or cod in general (Boas 1921:253).

In areas where locally available spring resources such as eulachon and halibut could be preserved and stored, these resources were often used to supplement the diet at summer and fall resource procurement camps or were traded to groups that lacked access to such resources. For example, among the Tlingit, some cod and halibut caught and preserved in the spring was consumed in the late summer and early fall when the Tlingit caught and processed salmon (de Laguna 1972:401). The Haida often traded dried halibut with groups on the mainland. In return for dried halibut, they received eulachon grease, dried eulachon and soapberries (Blackman 1990:246). The Makah traded dried halibut fillets along with blubber and whale oil with tribes on Vancouver Island and with the Chinook near the mouth of the Columbia River (Swan 1870:31). Among the North and Central Nootkan tribes, Drucker (1951:65) notes that families stockpiled dried cod for use by women during their menstrual periods and after childbirth but provides no further explanation.

Preparation and Consumption of Preserved Cod and Halibut

The fat content of salmon, cod and halibut body parts appears to have affected their retention or disposal, how they were preserved, how long they could be stored, and the methods employed in preparing different body parts for consumption. In all three taxa, the head appears to contain the most fatty tissue (Boas 1921:359, 390), followed by the fins and belly region, and finally the meat fillets.

In the case of salmon, body parts with a high fat content require more time, care and attention during processing, preservation and storage to ensure that fats and oils do not become rancid and to prevent the decomposition of tissues by bacteria, yeasts, and molds that could cause sickness when consumed. Halibut and cod body parts such as the head and fins have higher fat content than meat fillets from the trunk and could not be stored for long periods of time (Isabell Ides in Croes 1992:348). Salmon and halibut fillets with lower fat content were not as susceptible to spoilage once they were dried and could be kept for longer periods of time (Boas 1921:361; Romanoff 1985:131-138). For instance, dried halibut meat was only regularly consumed once the Kwakiutl had exhausted their stores of dried salmon (Boas 1921:360). There is little specific ethnohistoric data on the maximum length of time that cod, halibut or salmon could be stored before they were no longer considered edible. For instance, if the salmon fillets became damp and mold developed, the Quileute believed that the mold could be washed off without affecting the edibility of the meat (Pettit 1950:6). In some cases, the practice of aging certain fish (i.e. preparing tainted cod, rendering eulachon and salmon oils, or burying salmon heads in the intertidal zone) suggests that a certain amount of spoilage was tolerated or encouraged. The ethnohistoric records also suggest that there was a relationship between the fat content of preserved body parts the amount of cooking time required prior consumption. Dried salmon and halibut fillets were consumed in their dried state without any additional preparation. Dried cod was tenderized with a club before cooking (Drucker 1951). Dried halibut heads, fins and vertebral columns were commonly soaked in water and boiled over high heat for long periods of time in preparation for consumption (Boas 1921:371; Swan 1870:24).

Disposal of Cod and Halibut Remains

Ethnohistoric sources contain few references to how native peoples along the North Pacific coast disposed of halibut and cod remains. Emmons (1991:117) reports that the Tlingit ceremonially burned halibut remains after a meal to ensure that they would take the form of another halibut and Boas

(1921:372, 387, 389, 391-392) describes several instances when the Kwakiutl would burn cod and halibut bones at the conclusion of a meal.

Behavioral Summary of Ethnohistoric Pacific Cod and Halibut Processing and Consumption

According to ethnohistoric descriptions of native subsistence, Pacific cod and halibut were highly regarded resources in native communities from the Aleutian Islands to the coast of Washington (Dawson 1880:44 in Blackman 1990:244; de Laguna 1972:52; Drucker 1951; Emmons 1991; Fladmark 1975:51 in Langdon 1979:116; Jochelson 1933:51; Swan 1870:19). Their importance was due to their consistent seasonal availability (i.e. cod and halibut were available in the winter and early spring when other food sources were scarce), their oil and fat content and the length of time that they could be stored in dried or smoked form.

Where, when and how cod and halibut were processed, how different body parts were prepared and where skeletal parts were discarded were influenced by the season of procurement, the distance between procurement and ultimate consumption locations, whether intermediate processing sites were used, the size of individual fish carcasses, the number of fish that were caught, and the fat content of certain fish or body parts. The distance between the procurement site and where the majority of the fish was ultimately consumed affected where initial processing activities (i.e. viscera removal and disarticulation) occurred. In all cases, processing began as soon as halibut and cod were brought to land and according to Boas (1921) viscera were never left in a fish carcass overnight. If the fishermen were more than a day's journey away from the residential base, the fishermen cleaned their catch at their first landfall. The initial processing site may have been a predetermined location such as a seasonally occupied logistical camp, or an opportunistic landfall in close proximity to a procurement site. At the initial processing site, the viscera would be removed and if the carcass was especially large and difficult to handle, the carcass was disarticulated to facilitate transportation. If an established logistical camp was used, activities such as butchering, filleting and drying occurred at this location and preserved portions of fish carcasses were later transported to a primary residential site where they were consumed. Choice portions of the carcass were also prepared and consumed at the initial processing site (Blackman 1982; Lord 1866). Any unconsumed portions of prepared meals were discarded at this site and the remaining portions of the carcass were transported to the residential base site where final processing and consumption took place. If fish were caught within one day's journey of the residential base, and the whole carcass could be transported, then whole carcasses were conveyed to the residential base.

Zooarchaeological Implications of Behavioral Analysis: Expectations for Archaeological Patterning

Differences in the sizes of Pacific cod and halibut carcasses appear to have affected how carcasses were processed and transported. Large-bodied halibut were more likely to be disarticulated and transported in pieces while cod were commonly transported whole. Disarticulation increases the possibility that entire halibut carcasses were not transported from the procurement site to the final consumption location. In addition, the size difference between halibut and cod suggests that halibut were more likely to be divided into more pieces, increasing the potential for body parts to be separated and deposited in different contexts across a site area. In comparing cod and halibut body part representation from an archaeological assemblage, it is therefore more likely that cod cranial and post-cranial remains will be represented in equal proportions, while halibut may be disproportionately represented by either cranial or post-cranial remains.

Physiological differences in the accessibility of meat and fats in cod and halibut carcasses affected butchering and transport decision-making. Ethnohistoric accounts of cod processing suggest that cod filleting required the disarticulation or cutting of certain bones to separate body parts. In the process, certain elements were left attached to cod meat fillets. Partlow and Kopperl (2007, 2008) postulate that faunal assemblages at sites where cod were stored and consumed (i.e. residential sites) should be dominated by post-cranial elements, particularly those from the pectoral girdle (e.g. cleithra), and that assemblages from cod processing sites (i.e. logistical camps) should be dominated by cranial elements and exhibit significantly fewer post-cranial remains.

While no previous studies explicitly described how halibut body part representation would be expected to differ between logistical sites where halibut were prepared for storage and residential sites where preserved halibut were consumed, ethnohistoric accounts of halibut processing provide a starting point for generating hypotheses regarding the effects of halibut butchering, and the selective transport of preserved halibut remains on halibut element representation in logistical and residential sites. Unlike cod, halibut meat fillets can effectively be removed from the post-cranial region of a halibut carcass without cutting any bones and leaving all of the skeletal elements articulated. Given the relative ease of separating halibut meat from skeletal remains, if dried halibut meat was the only portion of the halibut carcass preserved and transported from logistical camps to residential sites, then both cranial and post-cranial portions of halibut carcasses were disposed of at logistical camp sites. If additional body parts, such as dried vertebrae, heads or fins were also transported to and consumed at residential sites, then elements associated with these body parts should be present in residential site assemblages.

Based on ethnographic descriptions of cod and halibut processing there appears to be a relationship between the fat content of certain cod and halibut body parts and the intensity of processing prior to, and during consumption. In general, halibut cranial bone and vertebral columns reportedly contain high fat concentrations and these body parts were selectively prepared and preferentially consumed, often in a manner that broke up the bony structure to release the fatty tissues. Ethnographic studies of human mammal bone processing have demonstrated that humans will spend more time opening bones with high marrow content and that the level of fragmentation exhibited in the resulting bone assemblages increased in proportion to the increased processing intensity (Munro and Bar-Oz 2005).

Stored halibut and cod body parts with high fat content were boiled for long periods of time. Roberts et al.'s (2002) experimental studies of the effects of different cooking processes on bone showed that boiling significantly weakens the bone structure by removing flexible proteins and increasing the porosity and crystallinity of bone minerals. This decreases the mechanical strength of the bone and its resilience to physical stresses. Their experiments also demonstrated that these effects increased with boiling time. In contrast, roasting and baking had relatively little effect on bone due to the insulating effects of adhering soft tissues (Roberts et al. 2002:488-489). Ultimately, Robertson et al. (2002) concluded that boiling bone for long periods of time decreases its preservation potential by rendering it more susceptible to physical stresses and microbial damage. Finally, if the North Pacific ethnohistoric descriptions are representative of disposal behavior, we should expect to see a large proportion of carbonized or calcined fish remains associated with hearth features or hearth-cleaning deposits of mixed ash and charcoal.

According to my analysis of ethnohistoric descriptions of cod and halibut processing, faunal assemblages from logistical camps and residential bases should differ both in terms of whether whole or partial carcasses are represented in the assemblage and the probability that density-mediated attrition has affected element representation. Activities involved in preparing portions of fish carcasses for storage and consumption have different effects on the survival or destruction of fish skeletal elements. For instance, the most intense processing events, such as boiling for long periods of time, took place at residential sites, inside of houses; low-temperature processing methods, including smoking and air-drying, were more commonly used to preserve portions of halibut, cod and salmon carcasses for storage. Therefore, the effects of density-mediated element attrition are more likely to be identified in faunal assemblages from residential sites than from logistical camps.

Archaeological Evidence of Cod and Halibut Use

In numerous coastal archaeological assemblages, comparisons of salmon and so-called secondary resources reveal that the latter comprise a larger proportion of recovered fish fauna (Bowers and Moss 2001; Butler and

Campbell 2004; Croes 1992; Huelsbeck 1994; McKechnie 2005:39). In some sites Pacific cod and halibut make up a sizable fraction of the fish assemblage. For example, based on his analysis of faunal remains recovered from one of the houses at the Ozette village complex (45CA24) Huelsbeck (1994:78) calculated that halibut contributed the most to the household's food supply. Like salmon, variations in cod and halibut cranial/postcranial body part representation identified in prehistoric and historic archaeological deposits along the North Atlantic and North Pacific coasts have also been used to argue that specific processing, preservation and transport strategies were used by the inhabitants of these sites. For example, Atlantic cod skeletal element representation from medieval sites along the North Atlantic coast in the Orkney and Shetland Isles and at Caithness has been used to argue for the intensive use of cod and the development of surplus cod production for export and trade (Barrett 1997; Barrett et al. 1999; Barrett et al. 2004; Colley 1984:127). However, as with salmon, few studies have directly addressed the potential influence of density-mediated element attrition on marine fish element representation in archaeological sites (see Chapter 3), therefore ambiguity persists as to whether archaeological patterns of fish body part representation resulted from human behavior or natural processes. This is particularly apparent at archaeological sites along the North Pacific coast where some researchers have sought to infer prehistoric butchering and selective transport behavior from Pacific cod and halibut body part representation.

In the archaeofaunal assemblage recovered from the North Point site (49SUM25), located in Southeast Alaska, Bowers and Moss (2001) found that Pacific cod vertebrae were far more abundant than cranial remains. Citing ethnographic accounts of Tlingit and Kwakiutl cod butchering and cooking, Bowers and Moss (2001:172) proposed three possible explanations to account for the disproportionate ratio of cod cranial to postcranial elements: 1) The cod were butchered offsite and their heads were discarded offsite; 2) Processing (e.g. boiling, steaming or roasting) resulted in the differential destruction of cranial elements; 3) The cod were butchered at North Point, the cod heads were removed from the site for further processing and the remains were discarded offsite. In the end, Bowers and Moss concluded that Pacific cod bone density data were needed to test for the effects of density-mediated bone destruction in the North Point cod faunal assemblage.

Wigen and Stucki (1988:108-109) and Croes (1992:348-351) made similar inferences when they analyzed the fish faunal assemblages from the Hoko River site complex (45CA21/213) on the Olympic Peninsula in Washington State. When compared to the total number of identified halibut specimens (NISP) recovered inside the Hoko River rockshelter (45CA21), halibut vertebrae were disproportionately abundant. In an effort to account for the relative absence of many halibut cranial remains, Wigen and Stucki hypothesized that structural differences in halibut cranial and post-cranial skeletal elements made cranial elements more susceptible to destruction than halibut vertebrae. Although no empirical data were available to test this hypothesis, Wigen and Stucki (1988:108) proposed that the bone structure of smaller flatfishes such as flounder or sole were similar enough to halibut that their vertebrae to NISP ratio should be similar if the flatfish cranial remains were less resistant to destruction. When they compared the number of flatfish vertebrae to the total flatfish NISP they found that the ratio was consistently lower than halibut. Therefore, Wigen and Stucki (1988:109) concluded that the low number of halibut cranial remains was not due to the differential destruction of halibut cranial remains. Instead, citing ethnohistoric descriptions of Makah halibut processing, Wigen and Stucki (1988:109) and Croes (1992:348-351) asserted that the disproportionate representation of halibut post-cranial remains found in the Hoko River rockshelter was the result of butchering and disposal practices. Specifically, they contended that native peoples removed the halibut heads and discarded them outside of the rockshelter (Wigen and Stucki 1988:109).

While differential processing and disposal of cod and halibut may have produced the discrepancies in the ratios of cod and halibut cranial and post-cranial remains identified at sites like North Point and Hoko River, the role of density-mediated element attrition must be ruled out before behavioral explanations can be tested. Both cultural and natural processes of element attrition affect the constituents of archaeological faunal assemblages. Whole or partial carcasses may be brought to a site, some pieces may be processed more intensively than others, and the effects of post-depositional processes may vary between different depositional contexts. Ultimately denser bones may be present in archaeological sites because the less dense bones have been transported away or because they have been broken down (either physically or chemically) beyond recognition. The lack of quantifiable data describing the biomechanical properties of Pacific cod and halibut skeletal elements have prevented previous researchers from adequately testing for the effects of taphonomic processes such as density-mediated attrition.

CHAPTER 3: BONE DENSITY ANALYSIS METHODS, MATERIALS AND RESULTS

Few researchers have measured the density of fish skeletal elements and even fewer studies have directly examined inter-taxonomic variation in bone density between fish taxa. When compared with other vertebrate taxa, fish exhibit diverse arrays of physical morphologies developed through evolutionary adaptations to specific habitats and ecological niches; therefore it is not unexpected that considerable variation should also be present between their skeletal bone densities. Pacific cod and halibut exhibit different morphologies and occupy different habitats, suggesting that corresponding differences may be present in their respective skeletal structures. Halibut are adapted to benthic habitats in which they use a combination of ambush attack and active searching to obtain their prey. When swimming, halibut use dynamic lift (requiring forward momentum) to move vertically through the water column. If a halibut stops swimming its negative buoyancy will cause it to sink. Pacific cod are pelagic fishes that use a gas-filled swim bladder to generate static lift (Bone et al. 1995:78-80). A cod's swim bladder may allow it to support a denser, heavier skeletal structure (Brix 2002).

In this chapter I present the methods used to measure Pacific cod and halibut bone density and the results of this analysis. I then use the differences in bone density to make predictions regarding the potential effects of density-mediated element attrition on Pacific cod and halibut element representation in archaeological assemblages.

Methods

Five Pacific cod (*Gadus macrocephalus*) and seven Pacific halibut (*Hippoglossus stenolepis*) specimens representing a range of size and age classes were caught in Icy Straits in northern Southeast Alaska and processed for this study (Table 4). Skeletons were defleshed using room temperature water maceration and degreased using a dilute (5%) ammonia solution. A total of 12 Pacific cod elements and 14 halibut elements were selected for this study (Table 5). In selecting these elements my objectives were to include both robust and slight elements from each anatomical region, to maximize comparability with existing bone density data sets [e.g. Butler and Chatters (1994)] and to study elements that were commonly and rarely identified in North Pacific archaeofaunal assemblages (See Appendix A Table A-1). Elements from the left side were included from paired elements. However, in one case, a right side element was used. During its capture, the left opercle from halibut specimen H-21 was damaged. Halibut are a member of the right-eyed flounders (Family Pleuronectidae), meaning that both eyes are located on the right side of the head. Halibut, therefore, exhibit bilateral asymmetry in the size and shape of some of their cranial and post-cranial elements, including the opercle. While the right and left opercle differ in size, I assumed that that the size difference would not affect the bone mineral density of these elements and I proceeded with the analysis using the right side opercle from specimen H-21.

Table 4: Pacific Cod and Halibut Specimens Measured

Common Name (*Genus species*)	**Catalog no.**	**Sex**	**Standard Length (mm)**
Pacific Cod (*Gadus macrocephalus*)	C-1	-	438
	C-2	F	575
	C-3	F	760
	C-4	-	715
	C-5	-	693
Pacific Halibut (*Hippoglossus stenolepis*)	H-1	-	540
	H-2	M	610
	H-4	-	750
	H-5	M	920
	H-20	-	1194
	H-21	F	1397
	H-22	F	1308

Table 5: Pacific Cod and Halibut Elements Included in Bone Density Study

Body Region **Element (Abbreviation)**	**Pacific Cod**	**Pacific Halibut**
Cranial Region		
Vomer (Vom)	X	X
Hyomandibula (Hyo)	X	X
Quadrate (Quad)	X	X
Articular (Artic)	X	X
Dentary (Dent)	X	X
Ceratohyal (Cerat)	X	X
Pectoral Girdle		
Cleithrum (Cleith)	X	X
Coracoid (Corac)	-	X
Pelvic Girdle		
Basipterygium (Basipt)	X	X
Vertebral Column		
Atlas Vertebra (Atlas Vert)	X	X
First Caudal Vertebra (1st Caudal Vert)	X	X
Caudal Fin		
Penultimate Vertebra (Penult Vert)	-	X

The volume (cm^3) and mass (g) of an object are required in order to calculate its density. To determine the density of selected Pacific cod and halibut elements I measured the bone mineral content (mass of the bone minerals) in each element and its corresponding volume. Bone mineral content (BMC) was measured using a Dual Energy X-ray Absorptiometry (DEXA) instrument [Hologic model QDR 4500 Discovery A (S/N45036)] housed at the Oregon Health and Science University (OHSU), Bone and Mineral Unit. Although this instrument is primarily used to measure the bone density of human patients, researchers at the OHSU Bone Mineral Unit also use it to conduct non-human bone density studies. Rats are the most common lab animals analyzed in these studies and a software program is available to analyze rat and other small mammal skeletal elements. Since the size of the smallest fish elements were closer to those of small mammals than humans, all of the fish elements were scanned using the Small Animal – Subregion Hi-Resolution (software V12.5) scanning protocol and analyzed using a global region of interest in which the BMC was measured within the entire scan area. This scanning protocol restricted the scan area to 2.9 by 2.0 inches.

Ideally, I wanted bone density data for Pacific cod and halibut to be comparable to the Chinook salmon (*Oncorhynchus tshawytscha*) elements analyzed by Butler and Chatters (1994) so that I could undertake inter-taxonomic comparisons. Following Lyman (1994:238), I sought to use the same measurement techniques as Butler and Chatters (1994). However, the DEXA instrument (a Nordland XR-26) used by Butler and Chatters was different from the OHSU system. Therefore, before I analyzed the cod and halibut specimens I needed to test whether the two instruments would produce comparable BMC measurements. A sample of nine Chinook salmon (*Oncorhynchus tshawytscha*) atlas vertebrae originally analyzed by Butler and Chatters (1994) were rescanned in 2006 using the OHSU DEXA instrument and the 1994 and 2006 BMC values were compared by calculating the Spearman's Rank Order Correlation Coefficient (r_s). While small differences were present between the 1991 and 2006 scan results (Table 6), there is a significant correlation between the two data sets (r_s=0.954, P<0.001) indicating that the BMC measurements produced by the OHSU DEXA instrument are comparable to those produced by the DEXA instrument used by Butler and Chatters (1994).

Table 6: Comparison of Chinook Salmon (*Oncorhynchus tshawytscha*) Atlas Vertebrae Bone Mineral Content (BMC) Measured in 1991 and 2006

	1991		**2006**	
Specimen	**Rank**	**BMC**	**Rank**	**BMC**
92-6-11	1	0.199	1	0.22
92-6-2a	2	0.109	2	0.10
92-6-5	3	0.084	3.5	0.08
92-6-9	4	0.077	3.5	0.08
92-6-8	5	0.072	5.5	0.07
92-6-4	6	0.071	5.5	0.07
92-6-3	7	0.067	8	0.05
86-40-1	8	0.054	7	0.06
92-6-6	9	0.044	9	0.04

Both whole elements and portions of Pacific cod and halibut elements were then scanned (Figures 1 and 2). To maximize comparability with salmon bone density data produced by Butler and Chatters (1994), only specific portions of some elements were scanned. Elements that were not scanned in their entirety by Butler and Chatters or that exceeded the scan area were cut into sections and each section was scanned individually. This included the Pacific cod cleithra and the cleithra, dentaries, hyomandibula and opercles from the largest halibut specimens. To maximize the precision of BMC measurements taken from different individual specimens, all of the elements or element sections were oriented in a consistent manner during the scanning process (Appendix A Table A-2).

I then measured the volumes of Pacific cod and halibut elements using the hydrostatic weighing method previously described by Butler and Chatters (1994:423-424 Appendix). In preparation for hydrostatic weighing, I tied a 6 inch length of sewing thread to the element and coated each of the scanned elements with a thin layer of paraffin wax by quickly dipping them into a container of hot liquefied wax and allowing them to cool while suspended in the air. This wax coating sealed the porous structure of the individual cod and halibut elements and increased the precision of the bone volume measurements and ensured that the resulting cod and halibut volume measures would be comparable to those from the salmon elements.

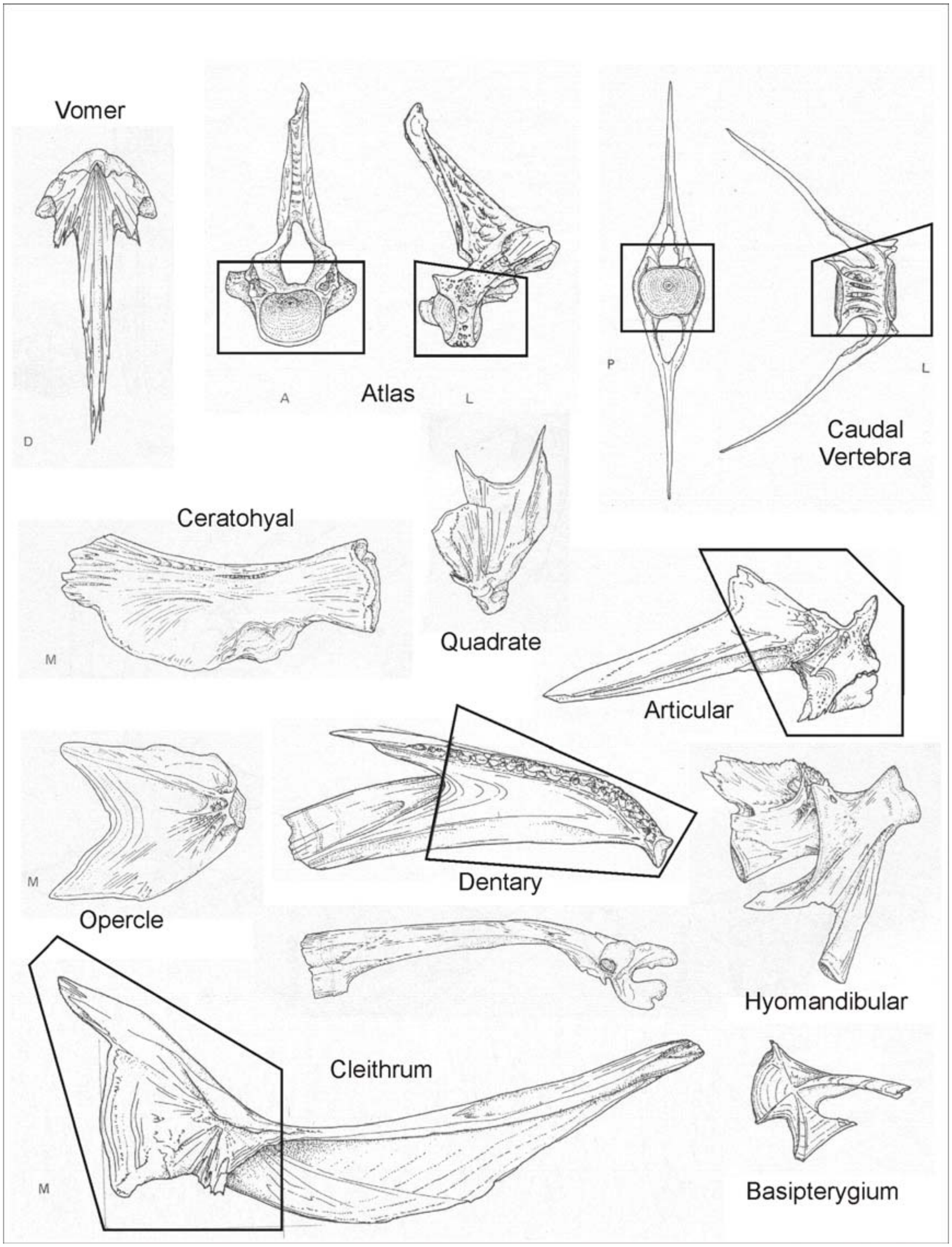

Figure 1. Cod elements and scanned portions. Images modified from Cannon (1987:47-71).

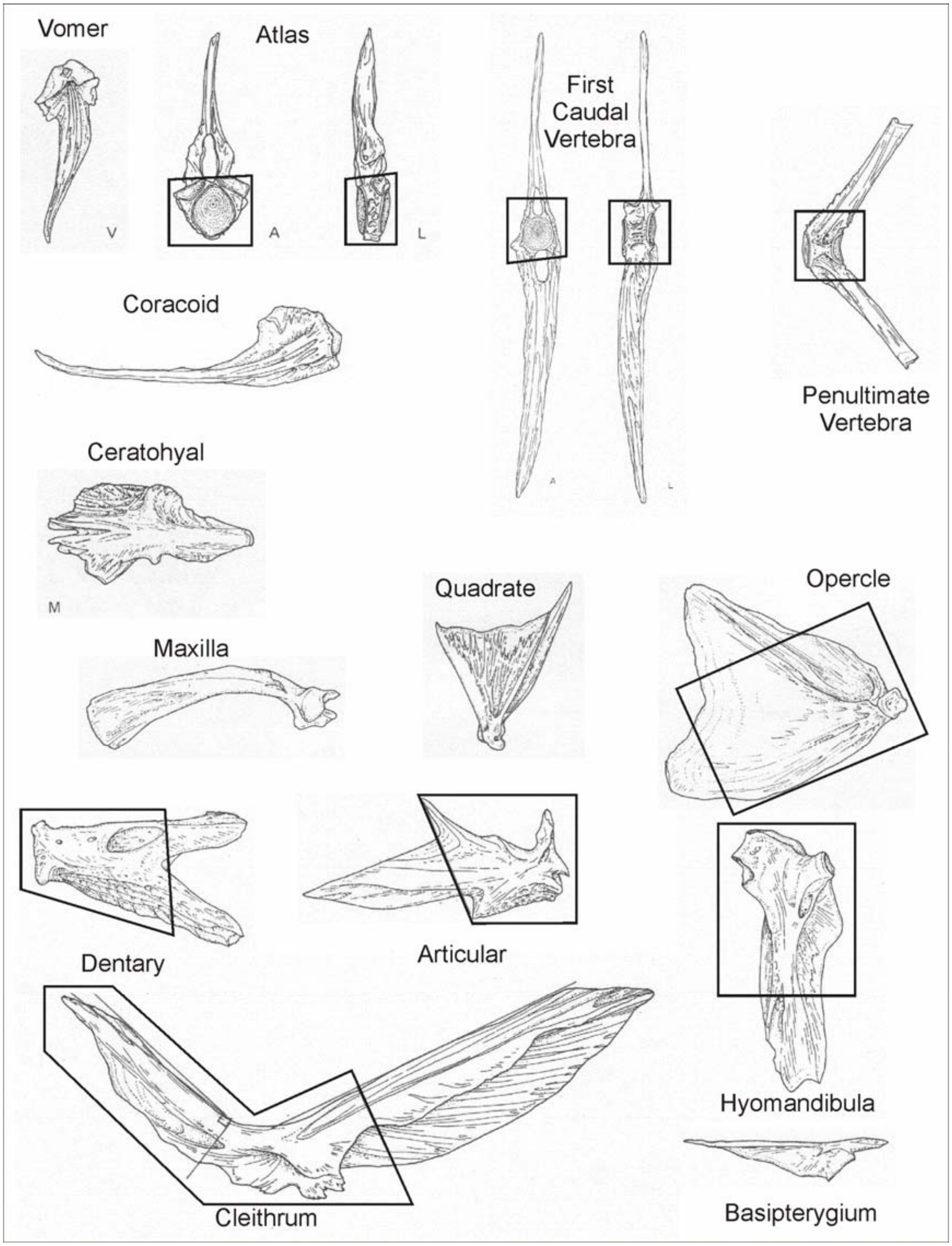

Figure 2. Halibut elements and scanned portions. Images modified from Cannon (1987:97-122)

Hydrostatic weighing was conducted by placing a water-filled container on an analytic balance, measuring the temperature of the water, suspending the bone from a ring stand over the container, completely immersing the bone in the water, making sure that the bone was oriented so that it was not touching the sides or bottom of the container and reweighing the container. The weight of the water displaced by the submerged bone was determined by subtracting the original weight of the water-filled container from the weight of the water-filled container with the submerged bone. This process was repeated 10 times and the average weight difference was calculated.

Since the density of water is constant (approximately1 g/cm^3) at temperatures between 18° and 30°C, I used the measured water temperature to determine the corresponding density value (SImetric 2007) and calculated the volume of the submerged element using the following equation:

$$V_o = M / D_w$$

where: V_o = volume of the object, M = mass of the submerged object and D_w = density of water

If the element to be measured was positively buoyant, I added ballast (in this case a 2g calibration weight tied to a fishing swivel) to the suspended element in order to completely submerge the element below the water surface. The volume of the ballast was measured 20 times using the hydrostatic weighing method described above and the average volume value was then subtracted from the combined bone and ballast volume measurements. I then used the bone volume measurements generated through hydrostatic displacement to calculate the bone volume density (g/cm^3) of the cod and halibut elements by dividing the BMC by the volume of the element.

When I completed calculating the Pacific cod and halibut bone volume densities (BVD), I analyzed the degree of bone density variation both within and between individuals from each taxon using interval level statistics. To begin, I visually examined the overall range of BVD values exhibited by each taxon and how high and low BVD values were distributed between elements from their different body regions using box-and-whisker plots. To determine if the significant variations in bone density were present between individuals from the same taxon I calculated Pearson's r values for each possible pair-wise comparison between individuals of like-taxon. The Peason's r values measured whether significant linear correlations were present between the BVD values of different elements between individuals. Finally, to determine if a relationship was present between element BVD values and the size of the Pacific cod or halibut specimen, I calculated Pearson's r for the standard length of each specimen versus the BVD values for each set of analyzed elements.

To examine the amount of bone density variation between taxa, I generated scatter-plots to illustrate the distribution of BVD mean and standard deviation values associated with elements from each taxon. Following Ioannidou (2003), I then calculated independent sample t-tests of difference to determine if significance differences were present between BVD values of different taxa. Previous analyses [e.g. Elkin (1995:30) and Lyman (1984:281)] used interval/ratio statistics, such as Pearson's r, to conduct inter-taxonomic pair-wise comparisons using bone density data from individuals from different taxa. Since the use of ordinal statistics tend to obscure individual variation in bone density (Symmons 2005:89) I also calculated Pearson's r to examine the amount of interval level bone density variation between individual cod and halibut specimens and the mean salmon BVD values in pair-wise comparisons.

To place my data in the context of existing published bone density data sets I examined inter-taxonomic variation in bone density between Pacific cod, halibut and published Pacific salmon data sets. Since differences between Pacific cod, halibut and salmon BVD may differentially affect taxonomic representation in archaeofaunal assemblages I sought to explore the role that differences in BVD might play in structuring cod, halibut and salmon bone assemblages by examining ordinal and interval scale variation between Pacific salmon, cod and halibut BVD. Using all available Pacific cod, halibut and salmon bone density data, I described the general characteristics of the density distributions. Then I analyzed the skeletal elements shared in common between the Pacific cod, halibut and salmon bone density data sets using Pearson's r. Finally, I described the taphonomic implications of the differences in bone density identified both within and between the taxa and predicted the characteristics of faunal assemblages in which cod, halibut and salmon remains have been affected by density-mediated element destruction.

Results

Pacific Cod and Halibut Bone Density

Among the analyzed Pacific cod elements (Table 7, Figure 3) four out of five dentary specimens exhibit the highest density values while the lowest density values are always associated with the basipterygium. Overall, a majority of the BVD values from both cranial and post-cranial Pacific cod elements fall within a range from 0.50 to 1.00 g/cm^3. Low-density outliers associated with the vomer, hyomandibular, opercle, articular, and dentary were all derived from elements from the smallest cod specimen (C-1). Within the Pacific halibut bone density data set (Table 8), the halibut maxilla exhibits the highest average bone density value (Figure 4), which is only slightly higher than the quadrate, articular, cleithrum, and the three vertebrae whose average densities are all greater than 0.25 g/cm^3. The halibut basipterygium exhibits the lowest average density (0.01 g/cm^3), followed closely by the coracoid and the opercle. Overall, the bone density values of all of the halibut elements analyzed in this study were less than 0.50 g/cm^3.

Table 7. Element Bone Volume Density (g/cm^3) from Pacific Cod Individuals

Individual	**1**		**2**		**3**		**4**		**5**	
Element	**BVD**	**Rank**	**BVD**	**Rank**	**BVD**	**Rank**	**BVD**	**Rank**	**BVD**	**Rank**
Vomer	0.79	3	0.85	3	0.89	4	0.88	3	0.86	3
Maxilla	0.87	1	0.93	2	0.95	3	0.95	2	0.91	2
Hyomandibula	0.37	11	0.48	11	0.52	11	0.50	11	0.47	11
Opercle	0.38	10	0.60	9.5	0.70	9	0.63	10	0.55	10
Quadrate	0.74	6	0.78	6.5	0.75	6	0.78	7	0.74	7
Articular	0.72	7	0.82	5.0	0.99	2	0.83	4	0.80	4
Dentary	0.80	2	1.31	1	1.42	1	1.41	1	1.19	1
Ceratohyal	0.46	9	0.60	9.5	0.71	8	0.79	5.5	0.69	8
Cleithrum	0.76	4	0.83	4	0.80	5	0.79	5.5	0.77	6
Basipterygium	0.00	12	0.06	12	0.18	12	0.13	12	0.17	12
Atlas	0.75	5	0.78	6.5	0.74	7	0.77	8.5	0.78	5
First Caudal	0.67	8	0.73	8	0.67	10	0.77	8.5	0.66	9

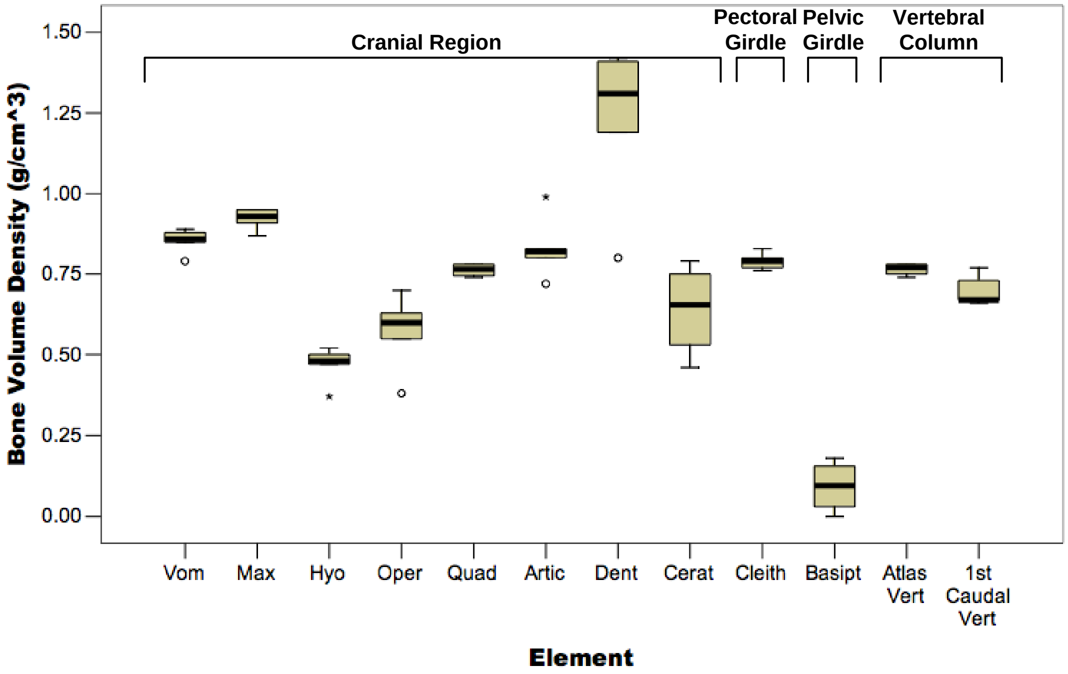

Figure 3. Pacific cod bone volume density (g/cm3). This box plot illustrates the distribution of BVD values associated with each element. The bold line represents median BVD value, the inter-quartile range containing 50% of the measured values defines the box, and the whiskers represent the minimum and maximum measured values. Outliers are illustrated by a * or a ° depending on distance from the inter-quartile range.

Table 8. Element Bone Volume Density (BVD) from Pacific Halibut Individuals

Individual	**1**		**2**		**4**		**5**		**20**		**21**		**22**	
Element	**BVD**	**Rank**	**BVD**	**Rank**	**BVD**	**Rank**	**BVD**	**Rank**	**BVD**	**Rank**	**BVD**	**Rank**	**BVD**	**Rank**
Vomer	0.16	9	0.15	9	0.17	8	0.16	9	0.22	9	0.22	9.5	0.22	9
Maxilla	0.32	1	0.27	2	0.32	1	0.30	1.5	0.38	1.5	0.42	1	0.42	1.5
Hyomandibula	0.06	10.5	0.06	11	0.10	10	0.14	10	0.16	10.5	0.22	9.5	0.18	10.5
Opercle	0.02	12.5	0.02	12	0.01	12	0.03	12	0.05	12	0.07	13	0.07	12
Quadrate	0.28	4	0.22	7	0.26	5	0.30	1.5	0.36	4	0.41	2	0.42	1.5
Articular	0.30	2.5	0.25	5	0.30	3	0.29	3.5	0.38	1.5	0.37	5	0.32	7
Dentary	0.26	6.0	0.25	5	0.22	7	0.26	7.5	0.34	6.5	0.35	7	0.30	8
Ceratohyal	0.06	10.5	0.07	10	0.08	11	0.11	11	0.16	10.5	0.16	11	0.18	10.5
Cleithrum	0.20	8	0.16	8	0.16	9	0.26	7.5	0.32	8	0.33	8	0.35	5.5
Coracoid	0.02	12.5	0.01	13	0.00	13	0.00	13.5	0.04	13	0.13	12	0.05	13
Basipterygium	0.00	14	0.00	14	0.00	14	0.00	13.5	0.00	14	0.04	14	0.01	14
Atlas	0.27	5	0.30	1	0.31	2	0.28	5	0.35	5	0.39	3.5	0.36	3.5
First Caudal	0.23	7	0.25	5	0.26	5	0.27	6	0.34	6.5	0.36	6	0.35	5.5
Penult. Vert.	0.30	2.5	0.26	3	0.26	5	0.29	3.5	0.37	3	0.39	3.5	0.36	3.5

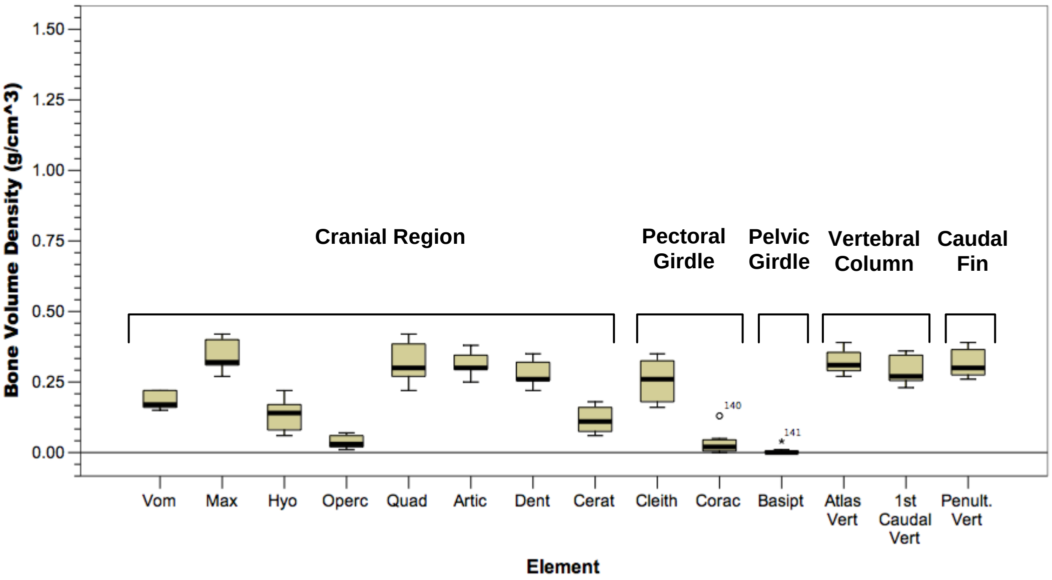

Figure 4. Pacific halibut bone volume density (g/cm^3).

Differences are also present between elements from different body regions. Among the 8 elements measured within the halibut cranial region, the bones of the jaws (maxilla, dentary and articular) and mandibular arch (quadrate) exhibit higher BVD values (i.e. in excess of 0.25 g/cm^3) than elements found in the opercular, olfactory and hyoid regions (e.g. the vomer, hyomandibula, opercle, and ceratohyal) (Figure 4). A similar pattern is present in the Pacific cod cranial region (Figure 3) where jaw elements generally exhibit density values greater than 0.75 g/cm^3. However, unlike halibut cranial elements, BVD values from the Pacific cod vomer exceed those of the articular and quadrate. Within the halibut pectoral girdle (Figure 4), the bone density values associated with the cleithrum are consistently higher than those from the coracoid. Bone volume density values associated with the three types of halibut vertebrae consistently fall between 0.20 and 0.40 g/cm^3 (Figure 4). Pacific cod atlas and first caudal vertebrae exhibit similar densities with BVD values clustering around 0.75 g/cm^3 (Figure 3).

To determine how much the bone density values from each specimen differed from those of other individuals within the same taxon, I used interval level statistics (Pearson's r) to compare the BVD values from each specimen in pair-wise comparisons. The Pearson's analysis revealed that BVD values associated with each Pacific cod specimen exhibited strong positive linear correlations (Pearson's r values ranged from 0.792 to 0.986, $P=0.002$ and $P<0.001$ respectively) in pair-wise comparisons (Table 9). The Pearson's r values from the Pacific halibut ranged from 0.925 to 0.995 ($P<0.001$) (Table 10) suggesting that very strong positive linear correlations exists between the BVD values from the different Pacific halibut specimens. The results of the pair-wise Pearson's analyses between different specimens within each taxon confirmed that the bone density values associated with each individual were not radically different from those measured in other specimens within the specific taxon.

Table 9: Results of Pacific Cod Pair-wise BVD Correlation Analyses (Pearson’s r)

			Pacific Cod Specimen				
			C-1	C-2	C-3	C-4	C-5
Pacific Cod Specimen	C-1	Pearson Correlation	-	.893	.792	.823	.893
		Sig. (2-tailed)		.000	.002	.001	.000
	C-2	Pearson Correlation		-	.967	.979	.986
		Sig. (2-tailed)			.000	.000	.000
	C-3	Pearson Correlation			-	.973	.966
		Sig. (2-tailed)				.000	.000
	C-4	Pearson Correlation				-	.983
		Sig. (2-tailed)					.000
	C-5	Pearson Correlation					-
		Sig. (2-tailed)					

All correlations are significant at the 0.01 level (2-tailed).

Table 10: Results of Pacific Halibut Pair-wise BVD Correlation Analyses (Pearson’s r)

			Pacific Halibut Specimen						
			H-1	H-2	H-4	H-5	H-20	H-21	H-22
Pacific Halibut Specimen	H-1	Pearson Correlation	-	.974	.973	.966	.976	.967	.945
		Sig. (2-tailed)		.000	.000	.000	.000	.000	.000
	H-2	Pearson Correlation		-	.980	.952	.963	.951	.925
		Sig. (2-tailed)			.000	.000	.000	.000	.000
	H-4	Pearson Correlation			-	.960	.964	.958	.939
		Sig. (2-tailed)				.000	.000	.000	.000
	H-5	Pearson Correlation				-	.995	.981	.983
		Sig. (2-tailed)					.000	.000	.000
	H-20	Pearson Correlation					-	.982	.976
		Sig. (2-tailed)						.000	.000
	H-21	Pearson Correlation						-	.977
		Sig. (2-tailed)							.000
	H-22	Pearson Correlation							-
		Sig. (2-tailed)							

All correlations are significant at the 0.01 level (2-tailed).

Pearson's correlation coefficient was also used to identify potential relationships between the length of individual Pacific cod and halibut specimens and the BVD values from their respective elements. Significant correlations were found between Pacific cod specimen length and the BVD values from the vomer, hyomandibula, opercle, ceratohyal, and basipterygium (Table 11) indicating that body size affects the bone density of these elements. However, variation in the density of Pacific cod maxillae, quadrates, articulars, dentaries, atlas and first caudal vertebrae were unrelated to the lengths of the cod specimens from which they were removed. In contrast, of the fourteen Pacific halibut elements analyzed, only the halibut basipterygium did not exhibit significant positive correlations between specimen length and BVD (Table 11); this is likely the result of the low BMC (less than 0.01 g) exhibited by several of the halibut basipterygia. These results demonstrate that the density of nearly all measured halibut skeletal elements increase as they mature. In contrast, little relationship exists between the size of cod specimens and the density of elements from their jaw (i.e. the maxilla, articular, and dentary), pectoral girdle and vertebral column.

Table 11. Pearson's Correlation Analyses Results for Pacific Cod and Halibut Specimen Standard Length (mm):Element BVD

	Pacific Cod	**Pacific Halibut**
Element	**Pearson's r Sig. (2-tailed)**	**Pearson's r Sig. (2-tailed)**
Vomer	.971(**)	.929(**)
	.006	.002
Maxilla	.850	.900(**)
	.068	.006
Hyomandibula	.918(*)	.981(**)
	.028	.000
Opercle	.886(*)	.937(**)
	.045	.002
Quadrate	.182	.938(**)
	.770	.002
Articular	.791	.784(*)
	.111	.037
Dentary	.870	.836(*)
	.055	.019
Ceratohyal	.937(*)	.975(**)
	.019	.000
Cleithrum	.252	.932(**)
	.682	.002
Coracoid	-	.758(*)
	-	.048
Basipterygium	.965(**)	.678
	.008	.094
Atlas Vertebra	.022	.903(**)
	.972	.005
First Caudal Vertebra	.146	.985(**)
	.815	.000
Penultimate Vertebra	-	.891(**)
	-	.007

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

The results of the Pearson's correlation analyses between halibut body size and element BVD show that halibut preservation potential is affected by body size; elements from large halibut exhibit higher bone densities than those from small halibut, therefore the remains of large halibut specimens are more likely to resist destructive processes and be identified in the course of subsequent zooarchaeological analyses. While correlations were identified between Pacific cod specimen length and the BVD values of some elements, BVD variation in the majority of the analyzed cod elements was not related to specimen length. This suggests that the size of the cod specimen may not affect the density of its skeletal elements and their ability to resist destructive taphonomic processes; the remains of small cod are just as likely to preserve as those from larger individuals.

Taphonomic Implications of Pacific Cod and Halibut Bone Density

Jaw elements such as the maxilla and dentary exhibited the highest average BVD values for both the Pacific cod and halibut and the lowest average BVD values for both the Pacific cod and halibut were found in the basipterygium (Figures 3 and 4, Tables 7 and 8). All things being equal, halibut elements from the cranial, pectoral, vertebral and caudal regions should resist destruction better than elements from the pelvic girdle (Figure 4). Within specific body regions, halibut jaw elements should be more resistant to density-mediated attrition than elements such as the ceratohyal, hyomandibula, vomer, and opercle found in the hyoid arch, olfactory and opercular regions; the halibut cleithrum should be more persistent than the coracoid. Pacific cod cranial, pectoral, and vertebral elements should be more resistant to density-mediated destruction than the elements from the pelvic region (Figure 3). Within the Pacific cod cranial region, jaw elements and portions of the mandibular arch and olfactory region should survive destructive forces better than elements from the hyoid arch and opercular region. Vertebral and pectoral girdle elements exhibited BVD values similar to the majority of cranial elements, suggesting that the majority of cod cranial and post-cranial remains are similarly resistant to destructive processes.

Inter-taxonomic Bone Volume Density Comparisons

Differences in bone density between taxa may affect their overall preservation potential and derived measures of taxonomic abundance used to describe how frequently different taxa occur in archaeological assemblages. Therefore, in addition to examining BVD variation within individuals of a given taxon, it is important to determine if consistent differences or similarities are present between BVD values from different taxa. To determine whether Pacific cod, halibut and salmon bone densities are similar or different, I compared the BVD values from each of these taxa using ordinal and interval level analyses. The results of these analyses were then used to determine how taphonomic processes might affect Pacific cod, halibut and salmon element representation in faunal assemblages containing these taxa.

In the previous section, my intra-taxonomic analysis demonstrated that the BVD of Pacific cod and halibut elements varied in a consistent manner between specimens in like-taxon, pair-wise comparisons (see Tables 9 and 10). However, the BVD values of nearly all of the halibut elements and some Pacific cod elements were influenced by the length of the halibut or cod specimen from which they were collected (Table 11). Since my sample of Pacific cod and halibut specimens included individuals representing a range of size and age classes, it is reasonable to conclude that a measure of central tendency (i.e. the mean BVD) derived from this sample should accurately represent the variation present within the sample. Therefore, I calculated the BVD mean and standard deviation values for each of the analyzed Pacific cod and halibut elements (Table 12) to generate a BVD profile for Pacific cod and halibut. To examine the degree of inter-taxonomic variation in bone density between Pacific cod, halibut and salmon I compared the BVD mean and standard deviation values of Pacific cod and halibut elements to mean salmon BVD values published by Butler and Chatters (1994:417 Table 5).

Inter-taxonomic differences and similarities in the BVD profiles of cod, halibut and salmon were particularly apparent in a scatter-plot of the cod halibut and salmon current BVD mean and standard deviation values (Figure 5). The majority of cod elements exhibited BVD values greater than 0.40 g/cm^3 while all halibut and salmon elements measured less than 0.40 g/cm^3. The three lowest BVD values from the cod hyomandibula, opercle and the ceratohyal were still greater than one standard deviation away from the density values of corresponding halibut and salmon elements. The Pacific cod basipterygium was a notable exception; it exhibited density values similar to halibut and salmon basipterygia.

Table 12: Pacific Cod and Halibut Element BVD Mean, Standard Deviation (S.D.) and Rank Order

		Pacific cod			**Pacific Halibut**		
Body Region	**Element**	**N**	**BVD (g/cm^3) S.D.**	**BVD Rank**	**N**	**BVD (g/cm^3) S.D.**	**BVD Rank**
Cranial	Articular (Section)	5	0.83 0.10	4	7	0.32 0.05	3.5
	Ceratohyal	5	0.65 0.13	9	7	0.12 0.05	11
	Dentary (Section)	5	1.23 0.26	1	7	0.28 0.05	7
	Hyomandibula	5	0.47 0.06	11	7	0.13 0.06	10
	Maxilla	5	0.92 0.03	2	7	0.35 0.06	1
	Opercle	5	0.57 0.12	10	7	0.04 0.02	12.5
	Quadrate	5	0.76 0.02	7	7	0.32 0.08	3.5
	Vomer	5	0.85 0.04	3	7	0.19 0.03	9
Pectoral Girdle	Cleithrum	5	0.79 0.03	5	7	0.25 0.08	8
	Coracoid	-	-	-	7	0.04 0.04	12.5
Pelvic Girdle	Basipterygium	5	0.11 0.07	12	7	0.01 0.01	14
Vertebral Column	Atlas Vertebra	5	0.76 0.02	6	7	0.32 0.04	3.5
	First Caudal Vertebra	5	0.70 0.05	8	7	0.29 0.05	6
Caudal Fin	Penultimate Vertebra	-	-	-	7	0.32 0.05	3.5

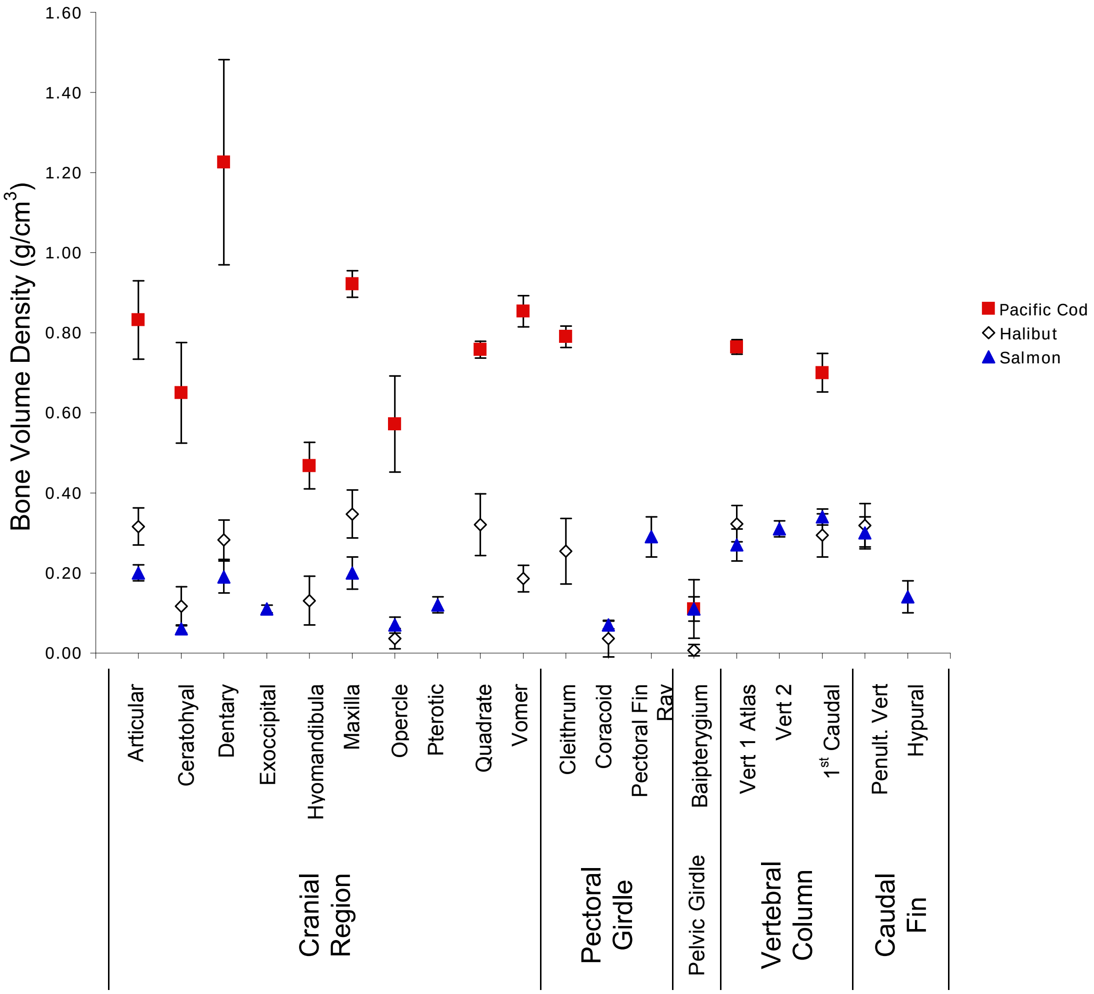

Figure 5. Pacific salmon, cod and halibut element BVD mean and standard deviation.

To further explore how bone density variation between taxa may differentially affect the susceptibility of skeletal elements to destructive processes, I used interval level statistics to compare Pacific cod, halibut and salmon BVD values. When the cod, halibut and salmon data sets were compared, a total of eight elements were analyzed in common (Table 13). Comparison of the cod and halibut BVD values using independent t-tests of difference revealed significant differences in every element comparison (Table 14).

Table 13. Pacific Halibut, Cod, and Salmon Element BVD Mean and Standard Deviation (S.D.)

	Halibut BVD (g/cm^3)		**Cod BVD (g/cm^3)**		**Salmon* BVD (g/cm^3)**	
Element	**Mean**	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
Articular (Section)	0.32	0.05	0.83	0.10	0.20	0.02
Ceratohyal	0.12	0.05	0.65	0.13	0.06	0.01
Dentary (Section)	0.28	0.05	1.23	0.26	0.19	0.04
Maxilla	0.35	0.05	0.92	0.03	0.20	0.04
Opercle	0.04	0.02	0.57	0.12	0.07	0.02
Basipterygium	0.01	0.01	0.11	0.07	0.11	0.03
Atlas Vertebra	0.32	0.04	0.76	0.02	0.27	0.04
Caudal Vertebra	0.29	0.05	0.70	0.05	0.34	0.02

*Salmon data from Butler and Chatters (1994:417 Table 5).

Table 14. Pacific Cod, Halibut and Salmon Element BVD Independent Sample T-tests of Difference Results*

Body Region	**Element**	**Cod:Halibut**	**Halibut:Salmon**	**Cod:Salmon**
Cranial	Maxilla	**t=21.25** **_P_<0.001**	t=2.31 *P*=0.060	**t=19.69** **_P_<0.001**
	Opercle	**t=9.77** **_P_<0.001**	t=-1.19 *P*=0.280	**t=3.81** **_P_=0.019**
	Articular	**t=10.93** **_P_<0.001**	t=2.37 *P*=0.056	**t=5.87** **_P_=0.004**
	Dentary	**t=8.15** **_P_=0.001**	t=1.79 *P*=0.124	**t=3.70** **_P_=0.021**
	Ceratohyal	**t=8.99** **_P_<0.001**	t=1.09 *P*=0.319	**t=4.28** **_P_=0.013**
Pelvic Girdle	Basipterygium	**t=3.10** **_P_=0.034**	**t=-6.43** **_P_<0.001**	t=0.000 *P*=1.000
Vertebral Column	Atlas	**t=23.57** **_P_<0.001**	t=1.11 *P*=0.310	**t=24.82** **_P_<0.001**
	First Caudal	**t=13.73** **_P_<0.001**	t=-0.80 *P*=0.457	**t=6.85** **_P_=0.002**

* Bold values are significant at *P*<0.05

While, no significant differences were present between the BVD values from halibut and salmon cranial and vertebral elements, halibut and salmon basipterygia BVD values were significantly different (t=-6.43, P<0.001). These results contrast with the t-test results of cod and salmon element BVD comparisons which showed significant differences present between all cranial and vertebral elements, and no significant difference between the average cod and salmon baispterygia BVD values (Table 14). The data show that the bone density of the Pacific cod basipterygium is relatively lower than all of the other cod elements, whereas in salmon and halibut the basipterygia are relatively higher when compared to the densities of all other salmon and halibut elements.

The results of the intra- and inter-taxonomic correlation analyses are useful for determining the amount of similarity or difference between the bone density values associated with individuals within and between different taxa. As was noted above, the results of the pair-wise correlation analyses conducted between specimens from the same taxon demonstrated that the measurements taken from each specimen were statistically similar to one another. However, the range of Pearson's r values produced for halibut (0.925 to 0.995, $P<0.001$ for all values) is less than that found between the Pacific cod specimens (0.792 to 0.986, $P=0.002$ and $P<0.001$ respectively), suggesting that less variation in BVD is present between halibut specimens than cod. Inter-taxonomic comparisons between individual cod and halibut BVD profiles revealed strong associations [i.e. Pearson's r values ranging from 0.548 to 0.902 ($P=0.065$ and $P<0.001$ respectively)] in nearly every comparison (Appendix A Table A-3). However, the range of Pearson's r values produced by comparisons between cod and halibut specimens was greater than the range of values produced by comparing individuals within a specific taxon (i.e. between halibut individuals). When Pacific halibut BVD values were compared with the mean BVD values available for salmon (Butler and Chatters 1994), the resulting Pearson's r values ranged from 0.803 (*P*=0.005) to 0.855 (*P*=0.002) (See Appendix A Table A-4), illustrating a strong association is present between the halibut and salmon bone density data sets. In this comparison, the range of Pearson's r values for halibut and salmon is narrower than that produced in pair-wise comparisons between halibut and cod, suggesting that the relationship between halibut and salmon bone density is stronger than the association between halibut and cod bone density. Additional pair-wise comparisons between Pacific cod specimens and mean salmon BVD values reveal no significant associations between the bone density values of cod and salmon [i.e. Pearson's r values ranged from 0.218 (*P*=0.605) to 0.603 (*P*=0.114)] (See Appendix A Table A-5).

When taken together, the results of Pearson's r analyses between taxa revealed that more variation was present between the analyzed fish taxa than between individuals within a specific taxon. However, both the results of the independent sample t-tests and Pearson's r analyses suggest that the halibut and salmon bone density profiles were more similar to one another than they were to cod. In the majority of the analyzed elements, cod elements consistently exhibited higher BVD values than halibut and salmon.

Taphonomic Implications of Inter-taxonomic Bone Density Comparisons

When a strong correlation is present between the BVD values of two taxa and processes of density-mediated element attrition affect assemblages containing the remains of these taxa, the resulting patterns of element representation for the two taxa should be similar (Elkin 1995:31). Using the BVD data described above we can predict the characteristics of a faunal assemblage in which density-mediated element attrition has occurred and use these predictions to evaluate the characteristics of archaeological assemblages to determine if they have been affected by density-mediated element attrition. The inter-taxonomic differences and similarities noted between Pacific cod, halibut and salmon bone densities suggest that the cod cranial and vertebral remains analyzed in this study should generally be more resilient than equivalent salmon and halibut cranial and vertebral remains when exposed to destructive agents. The slight differences identified between halibut and salmon cranial and vertebral remains suggest that there is little difference in their preservation potential. However, halibut pelvic elements are less dense, and therefore should be less resilient to density-mediated destruction than cod or salmon pelvic elements.

CHAPTER 4: TESTING FOR THE EFFECTS OF DENSITY-MEDIATED ELEMENT ATTRITION USING PUBLISHED NORTH PACIFIC ARCHAEOFAUNAL ASSEMBLAGES

In this chapter my goals are: 1) to illustrate how density-mediated element attrition can affect skeletal element representation and the inferences subsequently derived from body part representation; and 2) to demonstrate how considering cod, halibut and salmon bone density will improve our understanding of the prehistoric use of fish and our ability to identify storage behavior in subsistence practices. In order to illustrate the usefulness of bone density data in understanding site formation and taphonomic histories, I examined published faunal data from five North Pacific archaeological sites (Figure 6) for the effects of density-mediated element attrition. To determine if density-mediated element attrition had affected Pacific cod, halibut and salmon element representation at these sites, I compared the BVD profiles from each taxon with their corresponding element representation in each of the aggregate site assemblages, and the assemblages from different depositional contexts present within each site.

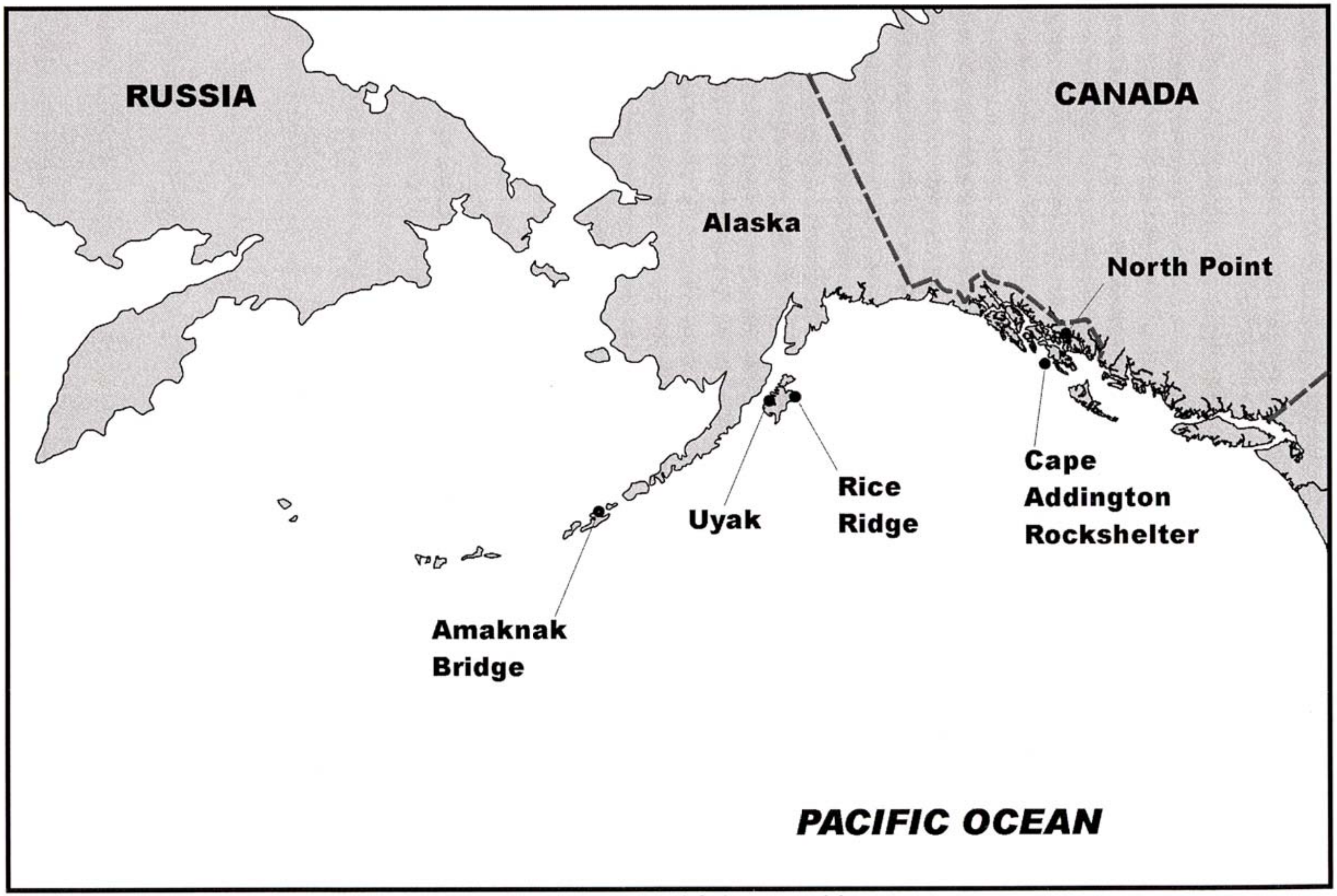

Figure 6. North Pacific archaeological sites with analyzed fish assemblages.

Methods

Faunal data from five North Pacific archaeological assemblages were drawn from both published and unpublished sources prepared by multiple researchers. The criteria for selection were: 1) taxonomic representation, specifically whether Pacific cod, halibut and salmon remains were identified in the assemblages, 2) whether detailed element descriptions were presented in the publication, 3) the geographic and temporal distribution of the assemblages and 4) that sufficient contextual data was presented to allow the inference of activities relating to fish processing and consumption. Data from the North Point and Cape Addington faunal assemblages were summarized from published in-text abundance tables (Bowers and Moss 2001:167-169; Moss 2004:161-170) and Susan Crockford and Robert Kopperl generously shared spreadsheets containing the detailed descriptions of fish fauna from the Amaknak Bridge, Rice Ridge and Uyak sites. Each of these assemblages was recovered using at least ¼ inch (6.4 mm) mesh; considering the large body sizes of halibut, cod and salmon and the size of elements for which BVD data were available, this screen size was sufficient to recover the elements considered in this study. To standardize the faunal data for further analysis, I recoded the original data sets using a paradigmatic classification (See Appendix B) and entered the coded data into an SPSS database. When available, detailed information for each analyzed specimen, such as the degree of completeness, the presence or absence of non-repetitive skeletal landmarks and associated provenience data were recorded in the SPSS database. When information regarding the completeness of an element was not presented I used the presence or absence of keywords, such as “fragment”, in the description when deciding whether to code elements as whole or fragmentary.

For each faunal assemblage, I tabulated the frequency of Pacific cod, halibut and salmon skeletal elements for which corresponding BVD data were available. Complete elements or element fragments with non-repetitive landmarks were used to calculate the minimum number of skeletal elements (MNE) present in the assemblage and the minimum number of animal units (MAU) necessary to account for the number of observed specimens. The MAU was calculated by dividing the MNE by the number of times that an element occurs in an individual skeleton. Since element side was not consistently presented in the data sets, element side was not considered in calculating the MNE and MAU values. Cod, halibut and salmon vertebrae were also not consistently described for these assemblages. To compensate I grouped all of the cod, halibut and salmon vertebrae and recoded them as “indeterminate”. Pacific cod and halibut taxonomic descriptions presented by Mecklenburg et al. (2002) contain the average number of vertebrae observed in individual Pacific cod and halibut. These vertebrae frequencies were used to calculate MAU from the number of indeterminate Pacific cod and halibut vertebrae reported at each of the sites. Salmon MAU was calculated using the average number of vertebrae reported for the pink (*Oncorhynchus gorbuscha*), coho (*Oncorhynchus kisutch*), Chinook (*Oncorhynchus tshawytscha*), chum (*Oncorhynchus keta*), and sockeye (*Oncorhynchus nerka*) salmon by Mecklenburg et al. (2002). When atlas vertebrae were reported in faunal assemblages, they were separated from the indeterminate class and considered independently.

The MAU for each element was then used to calculate the representation of skeletal parts within the assemblages. Element representation (%MAU), a ratio derived from the number of observed and expected skeletal elements, was determined for each element type by dividing the element MAU by the highest MAU value within the assemblage. Elements were then ranked according to their %MAU values. Rank order %MAU values were then compared with rank order BVD values to determine if correlations were present between bone density and skeletal element representation within an assemblage. Since my sample of cod and halibut specimens included a range of size and age classes, it is reasonable to conclude that the average BVD of Pacific cod and halibut elements and their associated rank orders (Table 12) can be used to test for the effects of density-mediated element attrition on Pacific cod and halibut element representation from North Pacific archaeological sites. The Pacific cod and halibut mean BVD values represent an ordinal scale measure. Therefore, I used an ordinal statistic, Spearman's rho, to measure the relationship between Pacific cod, halibut and salmon BVD and the rank order element representation (%MAU) of cod, halibut and salmon remains. If ties in the rank order of bone densities or element representation were present, I calculated the Spearman's correlation coefficient corrected for rank order ties using formulae presented by Drennan (1996:228-231).

For this analysis, my null hypothesis was that Pacific cod, halibut and salmon element representation were influenced by density-mediated element attrition; the test implication being that correlations would be present between element representation (%MAU) and BVD. Based on the results of the bone density analysis described in Chapter 3, I identified the following characteristics of cod, halibut and salmon assemblages affected by density-mediated element attrition. Pacific cod assemblage affected by density-mediated element attrition should exhibit the following pattern of element representation: 1) Elements with the highest BVD values, such as the dentaries in the cranial region and the cleithra and vertebrae in the post-cranial region, should be relatively well represented (i.e. exhibit the highest %MAU), 2) Low density elements such as the opercle and hyomandibula from the cranial regions and basipterygium in the pelvic region should be poorly represented. In halibut and salmon assemblages affected by density-mediated element attrition, the highest %MAU values should be associated with the halibut maxilla (cranial region) and the salmon caudal vertebra (post-cranial vertebral column); low-density elements such as the halibut basipterygium (pelvic region) and salmon ceratohyal (cranial region) should exhibit the lowest %MAU values.

I began by examining the relationship between Pacific cod, halibut and salmon %MAU and BVD in the aggregate site assemblage. If the sample size (N) from a particular taxon was less than 30 or if approximately half of the element types were not represented, Spearman's rho was not used to measure the association between %MAU and BVD in that assemblage. Since the characteristics of an aggregate site assemblage may not accurately represent patterns of element abundance within different depositional contexts present within the site (Colley 1984:121-123), when detailed provenience data were available in the published sources I used the finest analytic unit available to explore intra-site variability in cod, halibut, and salmon element representation. Specifically, I sought to determine if correlations, or lack of correlations, identified between %MAU and BVD at the aggregate site level were consistently found in the fish assemblages from different depositional contexts, such as between interior house floors and exterior midden deposits, or between stratigraphic levels.

North Pacific Archaeofaunal Assemblages, Taphonomic Expectations and Results

North Point (49-SUM-25)

The North Point site is located in Southeast Alaska on the mainland north of Petersburg at the confluence of Stephens Passage and Frederick Sound. A diverse array of terrestrial fauna, resident shorebirds and numerous remains of Pacific cod led Bowers and Moss (2001:170) to conclude that North Point was a residential base for subsistence procurement activities in the local terrestrial uplands and nearshore environments during the late winter and early spring. Excavated sediments were passed through ¼ inch mesh and the majority of fish faunal remains were recovered from midden deposits (Bowers and Moss 2001:166 Table 3).

In their analysis, Bowers and Moss (2001:167) noted that the number of cod crania (represented by 20 cod basioccipitals) was considerably lower than the reconstructed number of cod individuals (MNI=35) derived from the number of vertebrae. They asserted that cod heads were treated differently than postcranial body parts; cod heads had either been processed more intensively in a manner that reduced the preservation potential of their cranial remains, or cod heads were disposed of off-site (Bowers and Moss 2001:172). If the effects of density-mediated element attrition are not identified in the cod faunal assemblage from North Point then the pattern of body part representation would suggest that cod post-cranial carcasses were being preferentially processed and consumed at the North Point site and that cod crania were being discarded at a location outside of the sampled areas (Table 15).

Table 15. Expected Body Part Representation in North Pacific Sites

Area	**Site**	**Season of Occupation**	**Site Function**	**Expected Body Part Representation***		
				Cod	**Halibut**	**Salmon**
Southeast Alaska	North Point Wet Site	Late Winter – Early Spring	Residential	Pc	W	Pc
	Cape Addington	Late Winter – Early Spring	Logistical	Cr	W	Cr
Kodiak Archipelago	Uyak	-	Residential	W	W	Pc
	Rice Ridge	Multi-season	Residential	W	W	W
Aleutian Islands	Amaknak Bridge	Multi-season	Residential	W	W	W

* Assuming that density-mediated destruction has not affected element representation.
W=Whole (Approximately Equal Proportions of Cranial and Post-cranial Elements Present), Cr=Cranial, Pc=Post-cranial

Comparing the abundances of elements for which bone density data are available, Pacific cod (NISP=1970) make up the largest proportion of the North Point assemblage (Table 16), followed by salmon (NISP=135) and halibut (NISP=5) (Tables 17 and 18). A minimum of 35 Pacific cod, one halibut and three salmon individuals are represented in the North Point faunal assemblage. Halibut and salmon were not considered in the Spearman's correlation analysis because the total number of halibut elements was less than 30 and because less than half of the salmon element types were represented in the North Point faunal assemblage. No significant correlation was identified between Pacific cod BVD and %MAU (r_s=0.529, $0.10<P<0.20$) in the North Point faunal assemblage (Table 19). In this case, bone density did not appear to have affected Pacific cod element representation;

moderately dense elements such as the vertebrae were well represented while high-density cod elements (i.e. the dentary and maxilla) exhibited moderate to low abundance (40% and 24.29% respectively). Cod skeletal element representation in the North Point assemblage does not appear to have been influenced by density-mediated attrition, therefore the under-representation of Pacific cod cranial remains in the North Point assemblage was likely the result of differential off-site disposal of cod crania. The characteristics of the cod assemblage (e.g. body part representation) from the North Point site are consistent with an assemblage composed of the remains of stored cod.

Table 16: Pacific Cod Abundance in North Pacific Assemblages

	NISP		**MNE**		
Element	**North Point**	**Cape Addington**	**Rice Ridge**	**Uyak**	**Amaknak Bridge**
Dentary	28	26	85	10	356
Maxilla	17	8	44	21	358
Vomer	11	2	29	3	130
Articular	35	18	108	24	296
Cleithrum	5	10	2	27	19
Atlas Vertebra*	-	-	40	4	55
Quadrate	26	7	59	13	208
Vertebrae	1819	383	1886	289	2197
Ceratohyal	18	3	44	46	21
Opercle	0	2	3	23	5
Hyomandibular	11	3	32	25	16
Basipterygium	0	1	0	7	0
Total	**1970**	**463**	**2332**	**492**	**3661**

* Atlas Vertebrae were not differentiated from other cod vertebrae in the North Point or Cape Addington assemblages.

Table 17: Pacific Halibut Abundance in North Pacific Assemblages

	NISP		**MNE**		
Element	**North Point**	**Cape Addington**	**Rice Ridge**	**Uyak**	**Amaknak Bridge**
Maxilla	0	5	0	0	3
Atlas Vertebra*	-	-	-	-	2
Quadrate	0	4	1	0	7
Articular	0	6	3	1	3
Indeterminate Vertebrae	5	552	18	10	101
Dentary	0	2	0	0	1
Cleithrum	0	6	0	0	0
Vomer	0	1	1	0	0
Hyomandibula	0	2	0	0	0
Ceratohyal	0	1	0	0	0
Opercle	0	2	0	0	0
Coracoid	0	2	0	0	0
Basipterygium	0	2	0	0	0
Total	**5**	**585**	**23**	**11**	**117**

* Atlas Vertebrae were not differentiated from other halibut vertebrae in the North Point, Cape Addington, Rice Ridge, Uyak and Crag Point Assemblages

Table 18: Pacific Salmon Abundance in North Pacific Assemblages

	NISP		**MNE**		
Element	**North Point**	**Cape Addington**	**Rice Ridge**	**Uyak**	**Amaknak Bridge**
Indeterminate Vertebrae*	134	711	1461	181	165
Pectoral Fin Ray	0	0	0	0	0
Angular	0	1	0	4	0
Maxilla	1	2	0	2	0
Dentary	0	1	0	2	0
Hypural	0	2	0	4	0
Pterortic	0	2	0	0	0
Exoccipital	0	1	0	0	0
Basipterygium	0	26	2	91	1
Opercle	0	0	0	2	0
Coracoid	0	8	0	39	0
Ceratohyal	0	0	0	1	0
Total	**135**	**723**	**1463**	**326**	**166**

*****All reported types of salmon vertebrae were grouped together in order to ensure comparability between assemblages.

Table 19. Pacific Cod Ranked BVD and Element Representation (%MAU)

Pacific cod	VD	Element Representation									
		North Point		Cape Addington		Rice Ridge		Uyak		Amaknak Bridge	
Element	Rank	%MAU	Rank	%MAU	Rank	%MAU	Rank	%MAU	Rank	%MAU	Rank
Dentary	1	40.00	3	100.00	1	78.70	2	21.74	9	99.44	2
Maxilla	2	24.29	7	30.77	5	40.74	7.5	45.65	6	100.00	1
Vomer	3	31.43	5	15.38	7	53.70	6	13.04	12	72.63	4
Articular	4	50.00	2	69.23	2	100.00	1	52.17	4	82.68	3
Cleithrum	5	7.14	9	38.46	4	1.85	11	58.70	2	5.31	9
Atlas Vertebra*	6	-	-	-	-	74.07	3	17.39	10	30.73	6
Quadrate	7	37.14	4	26.92	6	54.63	5	28.26	7	58.10	5
Vertebrae**	8	100.00	1	55.59	3	67.17	4	24.16	8	23.60	7
Ceratohyal	9	25.71	6	11.54	8.5	40.74	7.5	100.00	1	5.87	8
Opercle	10	0	10.5	7.69	10	2.78	10	50.00	5	1.40	11
Hyomandibular	11	15.71	8	11.54	8.5	29.63	9	54.35	3	4.47	10
Basipterygium	12	0	10.5	3.85	11	0	12	15.22	11	0	12
Summary Statistics		MNE=1970 MAU=35 r_s=0.567 0.05<P<0.10		MNE=463 MAU=13 r_s=0.793 0.005<P<0.01		MNE=2332 MAU=54 r_s=0.577 0.05<P<0.10		MNE=492 MAU=23 r_s= - 0.189 P>0.50		MNE=3661 MAU=179 r_s=0.902 P<0.01	

* Atlas Vertebrae were not differentiated from other cod vertebrae in the North Point or Cape Addington assemblages.

**Average of Atlas and First Caudal Vertebrae VD values.

Cape Addington Rockshelter (49-CRG-188)

The Cape Addington Rockshelter is located on Noyes Island, along the outer coastline of the Prince of Wales Archipelago in Southeast Alaska. Dr. Madonna Moss, assisted by a team of archaeologists, worked with the U.S. Forest Service to test this site in 1996 and 1997 (Moss 2004). Archaeological deposits within the rockshelter were excavated using arbitrary levels and following natural stratigraphic boundaries. Faunal remains were recovered in the field using ¼ inch mesh and bulk samples were screened using ¼ and ⅛ inch mesh during lab processing. Moss (2004) presents detailed descriptions of faunal data from both screened and bulk samples with their associated provenience information.

The dry environment and ample air circulation within the rockshelter led Moss to conclude that the rockshelter provided an ideal environment for preserving fish for long-term storage (Moss 2004:160). Numerous small streams supporting runs of coho, chum and pink salmon are present along the coast of Noyes Island between 10 and 20 km from the Cape Addington rockshelter site (ADF&G 2008; Langdon 1977:48). In addition, Moss (2004:160) noted that commercial and sport salmon fishermen congregate near the site to fish for at least five species of salmon that migrate through the marine waters to the west of Cape Addington during the summer months. The local availability of salmon in the marine waters surrounding Cape Addington, suggested that the salmon represented in the Cape Addington rockshelter were likely obtained during the summer months (Moss 2004:160). Ethnohistoric sources from this region suggest that cod and halibut were also fished during the spring and summer and that these fish were processed for long-term storage (Emmons 1991; Harrison 1925; Langdon 1977, 1979; Newton and Moss 2005; Oberg 1973). Based on the relative abundances and diversity of taxa represented in the Cape Addington faunal assemblage, Moss (2004:211) concluded that the rockshelter was a seasonally occupied logistical camp where locally procured resources were processed and likely preserved. If cod were being processed at the Cape Addington Rockshelter site and preserved portions of the carcass were transported elsewhere, then I expected that cod cranial remains should dominate the cod assemblage. If salmon were processed for storage at Cape Addington, I expected that salmon post-cranial remains should be underrepresented in the assemblage. If halibut meat was preferentially processed and transported from the site then halibut cranial and post-cranial body parts should be equally well representation. However, if halibut cranial or post-cranial parts are disproportionately represented, then this would suggest that portions of the carcass were discarded outside of the sampled site area, or that certain parts may have been processed with meat fillets, removed to the residential base and consumed at that location.

Compared to open-air archaeological deposits, the dry depositional environment present within the Cape Addington Rockshelter may have reduced the influence of post-depositional density-mediated destructive processes. Therefore, I expected that correlations between bone density and element representation were less likely to be observed in the faunal assemblage from the Cape Addington Rockshelter than those from open-air sites such as North Point.

Among the salmon, halibut and cod remains recovered from the Cape Addington Rockshelter, vertebrae were the most abundant elements (Tables 16-18). However, the number of different types of halibut and salmon elements recovered at Cape Addington was greater than at any of the other sites considered in this analysis (Tables 17 and 18). When Pacific cod, halibut and salmon element representation were compared with their corresponding bone density profiles, a significant correlation was identified between Pacific cod BVD and element representation while no significant correlations were present for halibut or salmon (Tables 19-21).

High-density Pacific cod jaw elements, such as the dentary and articular, are abundant while low-density elements such as the basipterygium and opercle are poorly represented in the Cape Addington assemblage. In addition to the numerous salmon vertebrae, elements from the salmon neurocranium, jaws, and pectoral and pelvic girdles were also recovered at Cape Addington (Table 20). High-density halibut elements such as the maxilla and quadrate are less well represented in the Cape Addington assemblage than the vertebrae and cleithrum which exhibit relatively low density values

(Table 21). While a significant correlation was present between cod element representation and bone density, there was no evidence of density-mediated element attrition in the halibut and salmon assemblages from Cape Addington.

Table 20. Pacific Salmon Ranked BVD and Element Representation (%MAU)

Pacific salmon Element	**VD Rank**	**Element Representation**			
		Cape Addington		**Uyak**	
		%MAU	**Rank**	**%MAU**	**Rank**
Indeterminate Vertebrae*	1	79.25	2	6.03	4
Pectoral Fin Ray	2	0	11.5	0	11.5
Angular	3.5	3.85	7	4.40	5
Maxilla	3.5	7.69	5.5	2.20	7
Dentary	5	3.85	7	2.20	7
Hypural	6	15.38	4	8.79	3
Pterortic	7	7.69	5.5	0	11.5
Exoccipital	8.5	3.85	7	0	11.5
Basipterygium	8.5	100.00	1	100.00	1
Opercle	10.5	0	11.5	2.20	7
Coracoid	10.5	30.77	3	42.86	2
Ceratohyal	12	0	11.5	1.10	9
Summary Statistics		MNE=723 MAU=13 r_s=0.128 *P* >0.50		MNE=326 MAU=46 r_s= -0.167 *P* >0.50	

* Atlas, precaudal, and caudal vertebrae were grouped to increase comparability between assemblages and an average of the vertebrae VD values reported by Bulter and Chatters (1994:417) was used to establish the Indeterminate Vertebrae VD rank.

Table 21. Pacific Halibut Ranked BVD and Element Representation (%MAU)

Pacific halibut Element	VD Rank	Element Representation			
		Cape Addington		Amaknak Bridge	
		%MAU	Rank	%MAU	Rank
Maxilla	1	22.64	4	42.86	4.5
Atlas Vertebra*	2	-	-	57.14	3
Quadrate	3	18.12	5	100.00	1
Articular	4	27.17	2.5	42.86	4.5
Indeterminate Vertebrae**	5	100.00	1	57.71	2
Dentary	6	9.06	9	14.29	6
Cleithrum	7	27.17	2.5	0	10
Vomer	8	9.06	9	0	10
Hyomandibula	9	9.06	9	0	10
Ceratohyal	10	9.06	9	0	10
Opercle	11	9.06	9	0	10
Coracoid	12	9.06	9	0	10
Basipterygium	13	9.06	9	0	10
Summary Statistics		MNE=585 MAU=11 $r_s=0.08$ $P>0.50$		MNE=117 MAU=4 $r_s=0.602$ $0.02<P<0.05$	

* Atlas Vertebrae were not differentiated from other halibut vertebrae in the Cape Addington assemblage

**Average of Atlas, First Caudal and Penultimate Vertebrae VD values.

Since a portion of the Cape Addington site was excavated by natural strata I was also able to examine within-site variation in density-mediated element attrition. To determine if correlations identified in the aggregate assemblage were present within, or absent from, assemblages obtained different strata within the Cape Addington Rockshelter, I calculated the Spearman’s correlation coefficient for bone density and element representation from each stratum identified in Units 1, 2 and 3 (Table 22). Given the small number of salmon elements recovered from the majority of strata and that less than half of the salmon element types were represented in Stratum III, salmon was not include in this analysis. Pacific cod elements were sufficiently abundant (MNE>30) in Strata IV and V for me to calculate

Spearman's correlation coefficient. The resulting values from Stratum IV illustrated a significant correlation between cod BVD and element representation (Table 22); however, no significant correlation was present in Stratum V. These results did not conform to my expectation that density-mediated attrition was more likely to be found in lower, relatively older deposits. For halibut, Spearman's results from Strata V and VI suggest that there is not a significant relationship between halibut bone density and element representation in these strata (Table 22).

Table 22. Cape Addington (Units 1-3) Pacific Cod, Halibut and Salmon Spearman's Analysis Results by Stratum

	Spearman's Correlation Results								
	Cod			**Halibut**			**Salmon**		
Stratum	**MNE**	r_s	***P***	**MNE**	r_s	***P***	**MNE**	r_s	***P***
I	3	-	-	0	-	-	12	-	-
II	18	-	-	10	-	-	23	-	-
III	17	-	-	7	-	-	41*	-	-
IV	62	0.621	$0.02<P<0.05$	10	-	-	19	-	-
V	341	0.448	$0.10<P<0.20$	89	0.354	$0.20<P<0.50$	5	-	-
VI	13	-	-	89	0.474	$0.10<P<0.20$	0	-	-

***** Less than half of the elements types were represented.

Analysis of the aggregate faunal assemblage from the Cape Addington Rockshelter suggested that Pacific cod element representation was influenced by density-mediated element attrition, while halibut and salmon element representation were not. However, the effects of density-mediated destructive processes were not uniformly distributed between depositional contexts. The cod assemblage from Stratum V (containing the majority of cod remains recovered from the Cape Addington site) differed from the pattern observed in the aggregate assemblage in that it was not affected by density-mediated element attrition.

The results of the Spearman's analysis suggested that Pacific cod element representation from Stratum V and the halibut element representation from Strata V and VI were not influenced by density-mediated element attrition; therefore body part representation from these strata should most accurately represent the results of processing and transport activities carried out at the Cape Addington Rockshelter. The remains of 11 Pacific cod crania and 5 post-cranial carcasses are present in the assemblage from Stratum V. The over-representation of cod heads at Cape Addington is consistent with the expected pattern of body part representation produced by processing for storage (Table 15); cod crania were separated from the post-cranial carcass and left at the Cape Addington Rockshelter while the post-cranial carcasses was removed for storage and consumed at a separate residential base site. Unlike cod, halibut remains recovered from Stratum V suggest that the number of halibut cranial and post-cranial body parts is approximately equal (i.e. at least 2 halibut crania and post-cranial carcasses are represented in the assemblage from Stratum V). In Stratum VI, the remains of 1 halibut cranium and at least 2 post-cranial carcasses are represented. While the number of halibut body parts represented in Strata V and VI are small, they suggest that whole halibut carcasses were disposed of at the Cape Addington Rockshelter and that certain portions of the skeletal structure were not consistently transported away from the site; the disposal of whole halibut carcasses at the Cape Addington Rockshelter is consistent with processing of halibut meat fillets for storage.

Kodiak Island Archaeological Sites

Faunal data from two sites, Rice Ridge and Uyak, were analyzed by Robert Kopperl as part of his dissertation research (Kopperl 2003). Extensive shell midden deposits, semi-subterranean house structures and residential surfaces are present at these sites. The presence of seasonal indicator species, such as juvenile harbor seals, the extent of midden deposits, and the presence of semi-subterranean structures suggested that these were semi-permanent residential sites occupied for multiple seasons (Kopperl 2003:95-96). Previous analyses of these archaeological assemblages demonstrate that site occupations spanned the range of cultural historical phases identified for the Kodiak Archipelago extending from the colonization of the Kodiak Archipelago over 7500 years ago (Ocean Bay I) to the contact period beginning in the mid-eighteenth century (Table 23). Between the Ocean Bay and Koniag periods, archaeologists have inferred that subsistence practices changed from a central place foraging strategy characterized by high residential mobility and use of a broad range of marine taxa, to a logistical procurement strategy characterized by low residential mobility, increased use of seasonally-occupied logistical camps and subsistence focused primarily on seasonally abundant, spatially concentrated resources such as salmon

(Fitzhugh 2002, 2003a, 2003b; Kopperl 2003; Partlow 2000). Therefore, if density-mediated element attrition has not affected the cod, halibut and faunal assemblages from these sites, I expect that differences in the patterns of body part representation should be present between the early and late prehistoric periods. Cod and halibut cranial and post-cranial body part representation should be approximately equal in earlier sites, indicating that whole carcasses were being brought to the sites and consumed, while faunal assemblages from later periods should exhibit disproportionate body part representation (Table 15).

Table 23. Kodiak Cultural Historic Phases, Archaeological Sites and Associated Radiocarbon Ages*

Approx. Dates	**Phase**	**Kodiak Archaeological Sites Range of Radiocarbon Dates**	
400 BP – Contact	Late Koniag		
1000/800 – 400 BP	Early Koniaq		
2500 – 1000/800 BP	Late Kachemak		**Uyak** 1130±70 BP 1320±70 BP
3500 – 2500 BP	Early Kachemak		
4500 – 3500 BP	Ocean Bay II	**Rice Ridge** 3850±80 BP	
>6600 – 4500 BP	Ocean Bay I	6180±305 BP	

* Modified from Kopperl (2003:25, 117-118 Table 1.1, 4.1 and 4.2)

Rice Ridge (49-KOD-363)

The archaeological deposits excavated by Hausler-Knecht (1991, cited in Kopperl 2003) between 1988 and 1990 consisted of a series of superimposed house floor and midden deposits spanning the Ocean Bay I and II phases (Kopperl 2003:97-105). Artifacts and fauna were recovered from these deposits using ¼ inch screen. Kopperl's analysis of the stratigraphy and associated radiocarbon dates suggests that three distinct periods of rapid deposition, separated by two occupational hiatuses, occurred between approximately 7000 and 4400 BP (Kopperl 2003:102). Kopperl (2003:105) concluded that Rice Ridge represented a semi-permanent campsite occupied during multiple seasons. Based on the occupation dates and the current availability of rocky/sandy nearshore marine habitats and salmon-bearing streams within a 5 km radius of the site (ADF&G 2008), the faunal assemblage likely contains the remains of locally-procured fish taxa. Cod, salmon and halibut likely arrived whole at the Rice Ridge site, where they were subsequently processed and consumed. Therefore, I expected cod, halibut and salmon to be represented by approximately equal proportions of cranial and post-cranial body parts in the Rice Ridge faunal assemblage (Table 15).

Pacific cod remains dominate the Rice Ridge fish assemblage (MNE=2332), salmon are the second most abundant taxon (MNE=1463) and halibut make up a very small part of the fish assemblage (MNE=23). Halibut and salmon were not considered in the Spearman's correlation analysis because the total number of halibut specimens was less than 30 (Table 17) and because less than half of the salmon element types were represented in the Rice Ridge faunal assemblage (Table 18). Spearman's analysis revealed that Pacific cod element representation was not significantly correlated with bone density at the aggregate site level (Tables 19). However, when the cod assemblage was analyzed by level, significant correlations were present in levels 2 and 8; level 2 contains the majority of the cod elements recovered at Rice Ridge (Table 24). When the fish faunal assemblage was grouped by context and reanalyzed, significant correlations were identified between cod BVD and element representation in both the floor and midden samples (Table 24).

Table 24. Rice Ridge Pacific Cod Spearman's Correlation Results and Body Part Representation by Stratigraphic Level and Depositional Context

			Pacific Cod				
			Spearman's Correlation Results			**Body Part Representation**	
Level	**Context**	**Age (rcBP)***	**MNE**	r_s	P	**Cranial MAU**	**Post-Cranial MAU**
1	Midden	3900±70 4310±80	243	0.306	$0.20<P<0.50$	5	4
2	Floor	-	1426	0.601	$0.02<P<0.05$	-	-
3	Midden	5070±40	487	0.544	$0.05<P<0.10$	12	8
4	Floor	5130±40	39	0.488	$0.10<P<0.20$	2	1
5	Midden	-	30**	-	-	-	-
6	Floor	-	9	-	-	-	-
7	Midden	-	14	-	-	-	-
8	Midden	-	34	0.649	$0.02<P<0.05$	-	-
9	Floor	-	2	-	-	-	-
10	Midden	5970±50 6580±220	38	0.336	$0.20<P<0.50$	2	1
11	Floor	-	10	-	-	-	-
-	All Midden	-	878	0.694	$0.01<P<0.02$	-	-
-	All Floor	-	1486	0.607	$0.02<P<0.05$	-	-

* From Kopperl (2003:119 Table 4.3)

** Less than half of the cod element types were represented.

The correlations identified between cod element representation and bone density in the assemblages from levels 2 and 8 suggest that density-mediated element attrition has affected cod element representation in levels containing a large proportion of the cod assemblage from Rice Ridge. However, Pacific cod element representation in the assemblages from levels 1, 3, 4 and 10 do not appear to have been influenced by density-mediated element attrition. Therefore, the body part representation from these levels were examined to determine if cod usage could be characterized, whether use of cod changed over the course of site occupation, or if differences were present between element representation in midden versus floor depositional contexts. In each level, the reconstructed number of cod crania is greater than the number of cod post-cranial carcasses (Table 24). While the relative proportions of cranial and post-cranial body parts do not vary widely between levels 1, 3, 4 and 10, suggesting that the use of cod did not shift during the occupation of the Rice Ridge site, in all cases post-cranial portions of the Pacific cod carcass are consistently under-represented. These results do not conform to the expectation that whole cod carcasses would be identified in the Rice Ridge assemblage. The under representation of Pacific cod post-cranial remains in levels 1, 3, 4, and 10 may suggest that post-cranial portions of cod carcasses were removed from this site for storage, or that post-cranial remains were disposed-of in a manner different from cranial remains. In either case, the ability to detect the signature of density-mediated element attrition in the

Rice Ridge assemblage was affected by the level of analysis; at the aggregate level cod element representation did not appear to be affected by density-mediated element attrition, however, analysis by level and depositional context revealed that cod element representation from particular levels and contexts had been influenced by density-mediated element attrition.

Uyak (49-KOD-145)

The Uyak site contains extensive midden deposits and the remains of numerous structures. Alex Hrdlicka excavated portions of the Uyak site in the 1930s and in 1987 and 1988 Amy Steffian conducted additional excavations at the site (Steffian 1992). Steffian's excavations uncovered midden deposits and three house floors (Floors 7, 10 and 11). Charcoal samples collected from these floors produced radiocarbon dates ranging from 1130±70 to 1320±70 BP (Kopperl 2003:111). The faunal assemblages from house floors 7, 10 and 11 were analyzed and reported by Kopperl (2003:108-111). Based on the diversity of tools and ceremonial artifacts recovered during excavation, the presence of semi-subterranean house structures and the thickness of the midden deposits, Kopperl suggested that the site was occupied for multiple seasons. Both cod and halibut are currently available in the near-shore and deepwater marine habitats located in close proximity to the Uyak site; therefore they likely arrived whole at the Uyak site and both cranial and post-cranial remains should be present in equal proportions in the faunal assemblage. While small runs of pink and chum salmon are currently available in the streams in the local vicinity of the Uyak site (ADF&G 2008), the Karluk River drainage, which has supported runs of salmon for over 1000 years (Finney et al. 2000; Finney et al. 2002), is located approximately 10 km west of the Uyak site via an overland portage at the head of Larsen Bay (Clapsadl 2002). While some locally caught salmon may have been transported whole to the Uyak site, salmon harvested at a distance from the Uyak site were likely processed prior to transport and the salmon heads were likely left at the processing site. In the absence of density-mediated salmon element attrition, I expected that salmon post-cranial remains should dominate the Uyak salmon faunal assemblage.

Pacific cod (MNE=492) make up the largest proportion of the analyzed fish assemblage, followed by salmon (MNE=326) and halibut (MNE=11) (Tables 16-18). Unlike Rice Ridge, in addition to salmon vertebrae, a relatively large number of elements from the pectoral and pelvic girdles, and some cranial elements were also identified in the Uyak assemblage (Table 18). Halibut element representation was not considered in the Spearman’s correlation analysis because the total number of halibut elements was less than 30. No significant correlations were identified between Pacific cod or salmon BVD and element representation in the aggregate Uyak faunal assemblage (Tables 19 and 20). In addition, no significant correlations were identified between cod and salmon BVD and element representation in any of the strata in the Uyak assemblage (Table 25).

Table 25. Uyak Pacific Cod and Salmon Spearman's Results by Stratum

			Spearman's Correlation Results					
			Cod			Salmon		
Stratum	Context	Age (rcBP)*	MNE	r_s	*P*	MNE	r_s	*P*
7	House Floor	1270±100	268	0.086	>0.50	120**	-	-
10	House Floor	1130±70	113	-0.259	$0.20<P<0.50$	96	0.017	>0.50
11	House Floor	1320±70	111	-0.525	$0.05<P<0.10$	110*	-	-

* From Kopperl (2003:118 Table 4.2)

** Less than half the salmon element types were represented.

Although all of the faunal samples analyzed from the Uyak site were derived from interior house floor deposits and associated features, the Spearman's results suggest that the depositional environment located inside the residential structures may have facilitated the preservation of these low-density salmon and cod elements. For instance, the abundance of low-density salmon and cod elements recovered from floor deposits do not support the expectation that density-mediated element attrition is more commonly associated with activity areas where fresh and dried fish carcasses were prepared for consumption. However, analysis of the faunal remains associated with discrete areas within house structures suggests that the effects of processing and preparation activities may have localized effects on skeletal element representation within activity areas or disposal areas. For example, while cod and salmon element representation in floor samples exhibited no evidence of density-mediated element attrition, Pacific cod element representation in samples recovered from within pit features exhibited a strong negative correlation with bone density (Table 26). In this case, the inverse correlation suggests that low-density elements were selectively discarded in pit features located within the structures identified at Uyak.

Table 26. Uyak Pacific Cod and Salmon Spearman's Results by Depositional Context

Depositional Context	**Spearman's Correlation Results**					
	Cod			**Salmon**		
	MNE	**r_s**	***P***	**MNE**	**r_s**	***P***
Pit Feature	67	-0.59	$0.02<P<0.05$	0	-	-
House Floor	425	-0.107	>0.50	326	-0.068	>0.50

Pacific cod and salmon body part representation from each of the analyzed assemblages at Uyak also suggests selective use and disposal of certain portions of the cod and salmon carcass. In each of the assemblages from the Uyak house floors, the reconstructed number of Pacific cod crania exceeds the number of post-cranial body parts (Table 27). In contrast, salmon crania are underrepresented in assemblages from all analyzed contexts (Table 27). Salmon body part representation at Uyak matches the prediction in Table 15 that was derived from the inferred use of this site and its inferred relation to the location of salmon procurement and processing activities.

Table 27. Uyak Pacific Cod and Salmon Body Part Representation by Stratum and Depositional Context

Stratum	**Context**	**Cod**			**Salmon**		
		MNE	**Cranial MAU**	**Post-Cranial MAU**	**MNE**	**Cranial MAU**	**Post-Cranial MAU**
7	Floor	268	13	8	120	1	12
10	Floor	113	8	4	96	2	16
11	Floor	111	4	2	110	0	18
	Pit Samples	67	4	1	326	2	46
	Floor Sample	425	20	13	0	-	-

Amaknak Bridge (49-UNL-50)

Excavated by the Museum of the Aleutians in 2000, the Amaknak Bridge site is located on a small island near Unalaska Island at the eastern end of the Aleutian Island chain (Knecht and Davis 2001). Semi-subterranean pithouse features and midden deposits dating between 3310±110 and 2540±60 BP were identified and sampled during the excavation; a subsample of the faunal assemblage was subsequently analyzed and described by Crockford et al. (2004). Based on their analysis of mammal and bird remains, Crockford et al. (2004:74-77) concluded that this site was a multi-season residential base from which its inhabitants made use of marine and marine foreshore environments in close proximity to the site.

The proximity of inshore and offshore habitats where Pacific cod and halibut could be caught suggests that whole carcasses were transported to the Amaknak Bridge site. In addition, the presence of multiple salmon bearing streams within a 5 km radius of the site (ADF&G 2008) suggests that whole salmon may also have been transported to the site area. I therefore expected that salmon, cod and halibut body part representation should reflect the presence of whole carcasses in the Amaknak Bridge faunal assemblage, if density-mediated element attrition was limited.

The remains of Pacific cod (MNE=3661) made up the largest component of the fish faunal assemblage, followed by salmon (MNE=166) and halibut (MNE=117) (Tables 16-18). While post-cranial elements comprised the majority of the identified Pacific cod remains, cod cranial remains were also well represented (Table 16). Vertebrae made up the largest proportion of both the salmon and halibut remains recovered at Amaknak Bridge (Tables 17 and 18). Both cod and halibut element representation in the aggregate assemblage were significantly correlated with bone density (Tables 19 and 21). The salmon assemblage was not included in the correlation analysis because too few element types were represented in the samples.

While the halibut assemblages from the different strata were too small or lacked sufficient element representation for inclusion in correlation analyses, analysis of Pacific cod element representation from different depositional contexts revealed significant correlations between Pacific cod BVD and element representation in midden and fill deposits (Table 28). However, no evidence of density-mediated element attrition was identified in samples recovered from house floors.

Table 28. Amaknak Bridge Pacific Cod and Halibut Spearman's Results by Depositional Context

Stratum	**Spearman's Correlation Results**					
	Cod			**Halibut**		
	MNE	**r_s**	***P***	**MNE**	**r_s**	***P***
Pit Feature	14	-	-	9	-	-
House Floor	886	0.355	$0.20<P<0.50$	69*	-	-
Midden	0	-	-	19	-	-
Capping Midden	828	0.719	$0.01<P<0.02$	9	-	-
House Fill	962	0.776	<0.01	0	-	-
Non-midden Fill	0	-	-	11	-	-
Basal Midden	971*	-	-	0	-	-

* This sample was not analyzed because less than half the element types were represented.

At the aggregate level, cod and halibut skeletal element representation were affected by density-mediated element attrition. However, at finer levels of analysis, cod element representation in floor deposits was not correlated with bone density, while cod element representation from midden and fill deposits continued to exhibit the signature of density-mediated element attrition.

Analysis of the 886 Pacific cod remains recovered from the house floor deposits at the Amaknak Bridge site revealed that at least 14 Pacific cod crania and 18 cod trunks were represented in the house floor assemblage. The abundance of cod post-cranial remains associated with the Amaknak Bridge house floors suggests that whole cod were processed and consumed at this site and that a small number of the cod crania were selectively disposed of outside of the houses. Although cod cranial remains are under-represented in the Amaknak Bridge assemblage, the local proximity of the cod fishing grounds suggests that whole cod were processed and consumed at this site.

Discussion

Based on my review of ethnohistoric records and the intra- and inter-taxonomic bone density analysis, I expected that Pacific cod assemblages were the least likely to exhibit the effects of density-mediated element attrition. Barring the effects of density-mediated element attrition, I expected significant differences to be present between cod and halibut body part representation at logistical and residential sites and that the late prehistoric use of logistical camps would alter the patterns of fish body part representation found in residential assemblages. Analysis results from the five North Pacific fish assemblages suggest that the effects of natural and cultural processes of density-mediated element attrition are far more complex than I had originally suspected. However, in some cases, expectations drawn from ethnohistoric data were confirmed by analyses of the North Pacific archaeofaunal assemblages.

Inter-taxonomic BVD comparisons between Pacific cod, halibut and salmon demonstrated that Pacific cod elements are denser than elements from either halibut or salmon. Therefore, I expected that Pacific cod element representation was the least likely to be affected by density-mediated element attrition. However, in the Cape Addington assemblage, the only assemblage in which all three taxa were represented in sufficient numbers to compare the effects of density-mediated element attrition between the three taxa, analysis of the aggregate assemblage revealed that Pacific cod element representation had been affected by density mediated element attrition while no evidence of density-mediated element attrition was present in the halibut and salmon assemblages from Cape Addington. Further analyses of the assemblages recovered from different strata within the Cape Addington site revealed that cod element representation in the stratum containing the majority of the cod remains recovered at Cape Addington exhibited no evidence of density-mediated element attrition. Although the low numbers of cod remains recovered from many strata limited the number of possible comparisons, the differential distribution of the effects of density-mediated element attrition between strata suggest that the use of cod changed through time (i.e. cod carcasses deposited in Stratum IV were processed more intensively than those deposited the underlying stratum) or that post-depositional processes, such as trampling, were more pervasive during the deposition of Stratum IV.

Based on the descriptions of Pacific cod and halibut butchering and cooking techniques presented in North Pacific ethnohistoric accounts, and the results of experimental taphonomic studies, I also expected that differences should be present between the Pacific cod, halibut and salmon element representation from logistical camps and residential bases if portions of these fishes were being preserved at logistical camps and transported to residential bases for storage and consumption. Faunal assemblages from logistical camps and residential bases should differ both in terms of which portions of fish carcasses were deposited at these different locations and the probability that density-mediated attrition has affected element representation. Activities involved in preserving portions of fish carcasses for storage and preparing stored fish for consumption have different effects on the survival or destruction of fish skeletal elements; low-temperature processing methods (e.g. smoking and air-drying) employed at logistical processing sites to preserve portions of fish carcasses for storage likely did not significantly degrade bone or contribute to density-mediated element attrition. In contrast the most intense processing events (e.g. boiling for long periods of time) took place at residential sites, inside of houses. Therefore, I expected that the effects of density-mediated element attrition were more likely to be identified in faunal assemblages from residential sites than from logistical camps.

Comparison of the aggregate assemblages at the four residential base sites (North Point, Rice Ridge, Uyak and Amaknak Bridge) and the single logistical camp (Cape Addington) revealed that density-mediated element attrition had not influenced the element representation of taxa represented in three out of the four residential sites, and that density-mediated element attrition had only affected the element representation of Pacific cod at the logistical camp (Table 29).

Table 29. Results of Spearman's Analysis of Aggregate North Pacific Assemblages

		Significant Correlation BVD:%MAU?					
		Cod		**Halibut**		**Salmon**	
Site	**Function**	**Exp.**	**Obs.**	**Exp.**	**Obs.**	**Exp.**	**Obs.**
North Point	Residential	Yes	No	-	-	-	-
Cape Addington	Logistical Camp	No	Yes	No	No	No	No
Rice Ridge	Residential	Yes	No	-	-	-	-
Uyak	Residential	Yes	No	-	-	Yes	No
Amaknak Bridge	Residential	Yes	Yes	Yes	Yes	-	-

Where sample size allowed, closer inspection of the depositional contexts from four of the sites revealed that the effects of density-mediated destructive processes were not uniformly distributed between depositional contexts. For instance, among the stratified deposits identified at Cape Addington, Pacific cod element representation in the stratum containing the majority of the Pacific cod remains collected at this site exhibited no evidence of the effects of density-mediated element attrition. In contrast, no significant correlation was identified between Pacific cod element representation and bone density in the aggregate assemblage from Rice Ridge; however, significant correlations were present in the assemblages from two of the stratigraphic levels containing the majority of the cod remains recovered from Rice Ridge. These results suggest that the characteristics of the aggregate assemblages at Cape Addington and Rice Ridge did not accurately describe the pattern of element representation identified in the different deposits at these sites. In these cases, the fact that strata containing the majority of remains yielded results that differ from those found in the aggregate assemblage suggest that testing for the effects of density-mediated element attrition at finer-scales, below the level of the aggregate assemblage, may generate productive results. In my analysis of the Cape Addington assemblage, the apparent discrepancy between my expectations and the observed effects of density-mediated element attrition identified in the analysis of the aggregate Pacific cod assemblage were resolved by finer-scale consideration of element representation between different depositional strata. The lack of evidence indicating that density-mediated element attrition affected Pacific cod, halibut and salmon element representation at the Cape Addington site, combined with the pattern of Pacific cod body part representation supports the interpretation that this site was used as a logistical camp for the purposes of processing cod for storage. These results demonstrate that analyses of aggregate site assemblages were insufficient to identify the localized effects of density-mediated element attrition in archaeological assemblages. Additional analyses of the fish remains recovered from different depositional contexts within the sample of North Pacific sites revealed differences between some interior and exterior depositional contexts.

Contrary to my expectation that the effects of density-mediated element attrition were more likely to be identified in assemblages recovered within house structures, comparisons between the element representation in the house floor assemblages from Uyak and the Amaknak Bridge sites, and exterior depositional contexts at Amaknak Bridge, suggest that density-mediated element attrition had not affected cod element representation in the Uyak and Amaknak house floor assemblages, and that salmon element representation in one of the Uyak house assemblages also was not affected by processes of density-mediated destruction.

To examine whether density-mediated element attrition had affected element representation in different activity areas identified within the Uyak households I compared the Pacific cod and salmon element representation from assemblages recovered from pit features found within the houses with the assemblages obtained from the house floors. In this case, the correlation analysis revealed that the pattern of disposal within house structures varied between the house floor and associated pit features. When taken together, the results of the analyses from interior and exterior deposits at Uyak and Amaknak Bridge and the activity areas within the Uyak households, suggest that the effects of density-mediated element attrition may vary significantly depending on the localized conditions and the types of taphonomic processes that occur in these contexts.

The use of logistical processing camps may represent a relatively recent development in the subsistence practices of native peoples along the North Pacific coast (Ames and Maschner 1999:93, 143-144; Kopperl 2003; Partlow 2000). However, it is unclear where and when cod and halibut were stored by North Pacific native peoples prior to contact. Having ruled out the effects of density-mediated element attrition in some assemblages, I sought to determine if any evidence of cod or halibut storage was visible by comparing the pattern of Pacific cod use between the deposits from Rice Ridge and the Uyak site. Specifically, I examined the cod assemblages to determine if cod body part representation shifted between the Ocean Bay and Late Kachemak phases (Table 23). Prior to 4,000 BP, archaeological sites found in the Kodiak archipelago are interpreted as residential bases used by highly mobile hunter-gatherers. After 4,000 BP, functionally-specific logistical camps appear to have been used to process fishes such as salmon. If the cod consumed at the Uyak site had been processed at a logistical camp, I expected that the pattern of Pacific cod body part representation should differ from that observed at Rice Ridge.

In comparing Pacific cod body part representation at Rice Ridge and Uyak, it appears that cod cranial remains are slightly over-represented in all of the depositional contexts in which the effects of density-mediated element attrition were not identified (Tables 24 and 27). To place these numbers in context, it is useful to consider the ratio of cod crania and post-cranial carcasses identified at the Cape Addington site. The reconstructed number of cod crania (MAU=11) at Cape Addington was more than twice as large as the number of cod post-cranial carcasses (MAU=5). Considering the monitoring perspective of the Cape Addington site, the observed ratio of cod cranial to post-cranial carcasses most likely represents the results of cod processing for storage. When the cranial and post-cranial MAU values from each depositional level or stratum from the Uyak and Rice Ridge sites are analyzed independently or are combined, the reconstructed number of cod crania is less than two times the number of post-cranial carcasses in assemblages from both sites. Based on the results from the Rice Ridge and Uyak site, there does not appear to have been a shift in Pacific procurement and processing strategies between the Ocean Bay and Late Kachemak phases.

At sites like Rice Ridge that were occupied or reoccupied over long time periods, I suspected that the effects of density-mediated element attrition may be differentially distributed through the stratified deposits, particularly if butchering, transport and processing strategies remain constant. Therefore, at Rice Ridge and Uyak I expected to find that effects of density-mediated element attrition were common in assemblages recovered from relatively older deposits in which post-depositional destructive processes have had more time to break down low-density skeletal elements. Comparisons between the results of bone density analysis from distinct stratigraphic levels or strata at Rice Ridge, demonstrated that there was no relationship between the depth or relative age of the deposits and whether or not the effects of density-mediated element attrition were identified.

The remains of Pacific cod dominated the assemblages from all but one of the analyzed assemblages. Salmon were the second most commonly occurring taxa in these assemblages, and with the exception of the Cape Addington assemblage, Pacific halibut remains were poorly represented in the

North Pacific faunal assemblages. Although this pattern of taxonomic abundance may reflect prey selection or the availability of these fishes, inter-taxonomic differences in bone density and differences in the methods used to process cod, halibut and salmon may contribute to the under-representation of halibut remains in some of the North Pacific assemblages.

The relatively large size and low bone densities found in halibut skeletal elements may render halibut remains more susceptible to destruction or degradation. When combined with the selective butchery and transport of halibut meat fillets, and the intensive processing of fat-rich body parts, the combination of natural and cultural taphonomic processes may differentially reduce the visibility of halibut in the archaeological record. If this were the case, the results of inter-taxonomic comparisons of halibut element abundance with those from other fish taxa would not accurately depict the relative subsistence contributions of the different taxa.

Although my analysis of published North Pacific faunal assemblages demonstrated that density-mediated element attrition had influenced cod, halibut and salmon element representation in some assemblages, I was also able to identify assemblages or depositional contexts where element representation had not been influenced by density-mediated element attrition. This allowed me to focus my attention on assemblages where patterns of Pacific cod, halibut and salmon element representation more accurately reflect the results of past human behavior. The results of this analysis demonstrate that cod and halibut element representation can be used to examine the role of these taxa in past human subsistence, but that care must be taken to ensure that patterns of element representation were not produced by taphonomic processes such as density-mediated element attrition.

CHAPTER 5: CONCLUSIONS

In the course of my research I generated and used bone density data to determine whether Pacific cod and halibut element representation in North Pacific archaeological assemblages were influenced by taphonomic processes such as density-mediated element attrition and whether Pacific cod and halibut element representation could be used to infer whether these fishes were preserved and stored in a manner similar to salmon.

Bone density data allow archaeologists to differentiate the effects of taphonomic processes that affect element representation through density-mediated element attrition from the effects of human decision-making that do not act upon bone density in structuring element representation within archaeological assemblages. Based on my review of ethnohistoric accounts of Pacific cod and halibut use and the results of intra- and inter-taxonomic bone density comparisons between Pacific cod, halibut and salmon I developed specific predictions regarding the effects of density-mediated element attrition, butchering, selective transportation, storage, consumption and disposal and evaluated these expectations using Pacific cod, halibut and salmon element representation in North Pacific archaeological assemblages. My analysis of the fish faunal data from the North Point, Cape Addington, Rice Ridge, Uyak and Amaknak Bridge sites revealed that density-mediated taphonomic processes affected Pacific cod, halibut and salmon element representation in these archaeological assemblages; however, in assemblages where density-mediated element attrition had not affected element representation, Pacific cod and halibut body part representation were used to examine the effects of human decision-making in the procurement, processing, consumption and disposal of these fishes.

My analysis results demonstrated that differences were present between cod body part representation from logistical and residential sites at Cape Addington and North Point. However, in other cases, my findings were inconclusive. My failure to consistently identify differences between body part representation in logistical and residential sites likely stems from my inability to clearly distinguish the remains of fresh and preserved fish consumed at these locations and the simplicity of my expectations regarding the characteristics of faunal assemblages at logistical camps and residential assemblages derived from stored resources. The presence, absence and relative abundances of cranial versus post-cranial fish body parts are not sufficient to consistently identify the storage of different fish taxa, particularly when anatomical differences between the taxa affected how they were butchered and which parts were preserved.

Historically, Pacific halibut, cod and salmon were butchered and processed in different ways at different times of the year in different locations along the North Pacific coast. In future analyses, if the effects of density-mediated element attrition are not identified in an assemblage, analyses of cod, halibut and salmon element representation should consider changes in the abundances of elements associated with the pectoral and pelvic girdles, and caudal fin, as well as differentiating between different portions of the vertebral column to identify which specific body parts are present in, or absent from, archaeofaunal assemblages and how these patterns relate to those found in other sites.

The results of this analysis suggest that inter-taxonomic bone density differences may also affect the abundance of certain taxa in archaeological assemblages. Cod remains consistently exhibit the highest bone volume densities and with the exception of the Cape Addington assemblage their remains are consistently the most common constituents of the sites considered in this analysis. This raises the question of the degree to which relative taxonomic abundance may be governed by inter-taxonomic differences in BVD, or whether differences in taxonomic abundances reflects prey choice or resource availability and how we should interpret changes in relative abundance over time. The data and analyses presented in this thesis unfortunately are not sufficient to address these questions; more work should be done to determine the extent to which taphonomic processes affect the relative abundances of different fish taxa.

Future inter-taxonomic research should also examine the role of body size in structuring fish faunal assemblages. In particular, when compared to cod and salmon, the relatively large size of most halibut elements and the positive correlation identified between halibut body size and bone density suggest that the remains of large and small-bodied halibut specimens may differ in their resilience to taphonomic processes.

The results of this research highlights the uncertainties involved in the uncritical use of element representation to infer past processing, transport, and disposal decision-making and the difficulties of using simple comparisons of cranial and post-cranial body part representation to examine differences in the use of fish between sites. My results also suggest that the relative frequencies of different fish taxa may be influenced by differential density-mediated element attrition. However, the data that I have presented in this thesis offers archaeologists a means of differentiating the patterns of cod and halibut element representation produced by density-mediated element attrition from the results of human processing behavior. The application of Pacific cod and halibut bone density data in future analyses will ultimately improve our understanding of past human behavior and resource use along the North Pacific coast.

REFERENCES CITED

Acheson, S. R.

1995 In the Wake of the Iron People: A Case for Changing Settlement Strategies Among the Kunghit Haida. *The Journal of the Royal Anthropological Institute* 1(2):273-299.

Alaska Department of Fish and Game (ADF&G)

2008 ADF&G Fish Distribution GIS MAP Layers. Accessed February 2008 at: http://gis.sf.adfg.state.ak.us/AWC_IMS/viewer.htm

Ames, K. M.

1981 The Evolution of Social Ranking on the Northwest Coast of North America. *American Antiquity* 46:789-805.

1985 Hierarchies, Stress, and Logistical Strategies Among Hunter-gatherers in Northwest North America. In *Prehistoric Hunter-Gatherers: The Emergence of Cultural Complexity*, edited by T. D. Price and J. A. Brown, pp. 155-180. Academic Press, New York.

1991 The Archaeology of the Longue Duree: Temporal and Spatial Scale in the Evolution of Social Complexity on the Southern Northwest Coast. *Antiquity* 65:935-945.

1994 The Northwest Coast: Complex Hunter-gatherers, Ecology, and Social Evolution. *Annual Review of Anthropology* 23:209-229.

2005 Intensification of Food Production on the Northwest Coast and Elsewhere. In *Keeping It Living*, edited by D. Duer and N. J. Turner, pp. 67-100. University of Washington Press, Seattle.

Ames, K. M. and H. D. G. Maschner

1999 *Peoples of the Northwest Coast: Their Archaeology and Prehistory*. Thames and Hudson, London.

Barrett, J. H.

1997 Fish trade in Norse Orkney and Caithness: A Zooarchaeological Approach. *Antiquity* 71:616-638.

Barrett, J. H., A. M. Locker and C. M. Roberts

2004 The Origins of Intensive Marine Fishing in Medieval Europe: The English Evidence. *Proceedings of the Royal Society of London, Series B.* 271:2417-2421.

Barrett, J. H., R. A. Nicholson and R. Ceron-Carrasco

1999 Archaeo-ichthyological Evidence for Long-term Socioeconomic Trends in Northern Scotland: 3500 BC to AD 1500. *Journal of Archaeological Science* 26:353-388.

Behrensmeyer, A. K.

1975 The Taphonomy and Paleoecology of Plio-Pleistocene Vertebrate Assemblages East of Lake Rudolf, Kenya. *Bulletin of the Museum of Comparative Zoology* 146:473-578.

Bernick, K. M.

1983 *A Site Catchment Analysis of the Little Qualicum River Site, DiScl: A Wet Site on the East Coast of Vancouver Island, B.C.* National Museum of Man Mercury Series 118.

Binford, L. R.

1978 *Nunamiut Ethnoarchaeology*. Academic Press, New York.

Birket-Smith, K. and F. de Laguna

1938 *The Eyak Indians of the Copper River Delta, Alaska*, Copenhagen, Denmark.

Blackman, M. B.

1982 *During My Life: Florence Edenshaw Davidson, A Haida Woman.* University of Washington Press, Seattle.

1990 Haida: Traditional Culture. In *Northwest Coast*, edited by W. P. Suttles, pp. 240-260. Handbook of North American Indians. vol. 7, W. C. Sturtevant, general editor, Smithsonian Institution, Washington, D.C.

Boas, F.

1921 *Ethnology of the Kwakiutl*. 35th Annual Report of the Bureau of American Ethnology, 1913-194, Part I. U.S. Government Printing Office, Washington D.C.

Boehm, S. G.

1973 *Cultural and Non-cultural Variation in the Artifact and Faunal Samples from the St. Mungo Cannery Site, B.C. (DgRr2).* Master's thesis, University of Victoria, Victoria, British Columbia.

Bone, Q., N. B. Marshall and J. H. S. Blaxter

1995 *Biology of Fishes*. 2nd Edition ed. Tertiary Level Biology. Chapman & Hall, London.

Bowers, P. M. and M. L. Moss

2001 The North Point Wet Site and the Subsistence Importance of Pacific Cod on the Northern Northwest Coast. In *People and Wildlife in Northern North America: Essays in honor of R. Dale Guthrie*, edited by

C. S. Gerlach and M. S. Murray, pp. 159-177. BAR International Series. Archaeopress, Oxford.

Brain, C. K.
1981 *The Hunters of the Hunted? An Introduction to African Cave Taphonomy*. University of Chicago Press, Chicago.

Brix, O.
2002 The Physiology of Living in Water. In *Handbook of Fish Biology and Fisheries*, edited by P. J. B. Hart and J. D. Reynolds, pp. 71-92. Blackwell Publishing, Malden, Massachusetts.

Burley, D. V.
1980 *Marpole: Anthropological Reconstructions of a Prehistoric Culture Type*. Department of Archaeology Publications, No. 8. Simon Fraser University, Burnaby, British Columbia.

Butler, V. L.
1990 *Distinguishing Natural from Cultural Salmonid Deposits in Pacific Northwest North America.* Ph.D. dissertation, University of Washington, Seattle.
1996 Tui Chub Taphonomy and the Importance of Marsh Resources in the Western Great Basin of North America. *American Antiquity* 61(4):699-717.

Butler, V. L. and S. K. Campbell
2004 Resource Intensification and Resource Depression in the Pacific Northwest of North America: A Zooarchaeological Review. *Journal of World Prehistory* 18(4):327-405.

Butler, V. L. and J. C. Chatters
1994 The Role of Bone Density in Structuring Prehistoric Salmon Bone Assemblages. *Journal of Archaeological Science* 21:413-424.

Butler, V. L. and R. A. Schroeder
1998 Do Digestive Processes Leave Diagnostic Traces on Fish Bones? *Journal of Archaeological Science* 25:957-971.

Cannon, A.
2001 Was Salmon Important in Northwest Coast Prehistory? In *People and Wildlife in Northern North America: Essays in Honor of R. Dale Guthrie*, edited by S. C. Gerlach and M. S. Murray, pp. 159-177. BAR International Series 944, Oxford, England.

Cannon, A. and D. Y. Yang
2006 Early Storage and Sedentism on the Pacific Northwest Coast: Ancient DNA Analysis of Salmon Remains from Namu, British Columbia. *American Antiquity* 71(1):123-140.

Cannon, D. Y.
1987 *Marine Fish Osteology: A Manual for Archaeologists*. Department of Archaeology Publication no. 18. Simon Fraser University, Burnaby, B.C.

Cannon, M. D.
1999 A Mathematical Model of the Effects of Screen Size on Zooarchaeological Relative Abundance Measures. *Journal of Archaeological Science* 26:205-214.

Carlson, K. J. and T. R. Pickering
2004 Shape-adjusted Bone Mineral Density Measurements in Baboons: Other Factors Explain Primate Skeletal Representation at Swartkrans. *Journal of Archaeological Science* 31:577-583.

Chatters, J. C.
1987 Hunter-gatherer Adaptations and Assemblage Structure. *Journal of Anthropological Archaeology* 6(336-375).

Clapsadl, M.
2002 *Age Composition and Spawning Escapement of Chinook Salmon in the Karluk, Ayakulik, and Chignik Rivers, Alaska 1997 and 1998*. Alaska Department of Fish and Game, Division of Sport Fish, Research and Technical Services.

Clark, D. W.
1984 Pacific Eskimo: Historical Ethnography. In *Arctic*, edited by D. Damas pp. 185-197. Handbook of North American Indians, vol. 5, W. C. Sturtevant, general editor, Smithsonian Institution, Washington, D.C.

Colley, S. M.
1983 *The Role of Fish Bone Studies in Economic Archaeology: With Special Reference to the Orkney Isles.* Ph.D. dissertation, University of Southampton.
1984 Some Methodological Problems in the Interpretation of Fish Remains from Archaeological Sites in Orkney. In *2nd Fish Osteoarchaeology Meeting*, edited by N. Desse-Berset, pp. 117-131. Notes et Monographies Techniques 16. Centre de la Recherche Scientifique, Paris.

Coupland, G.
1985 Restricted Access, Resource Control, and the Evolution of Status Inequality among Hunter-Gatherers. In *Status, Structure, and Stratification: Current Archaeological Reconstructions*, edited by M. Thompson, M. T. Garcia and F. J. Kense, pp. 217-226. Archaeological Association, University of Calgary, Calgary, Alberta.

Coupland, G., R. H. Colten and R. Case
2003 Preliminary Analysis of Socioeconomic Organization at the McNichol Creek Site, British Columbia. In *Emerging from the Mist: Studies in Northwest Coast Culture History*, edited by R. G. Matson and Q. Mackie. UBC Press, Vancouver, British Columbia.

Crockford, S., G. Frederick, R. Wigen and I. McKechnie
2004 *Analysis of the Vertebrate Fauna from Amaknak Bridge UNL-50 Unalaska, AK*. Pacific Identifications Inc., Victoria, British Columbia.

Croes, D. R.
1992 Exploring Prehistoric Subsistence Change on the Northwest Coast. In *Long Term Subsistence Change in Prehistoric North America*, edited by D. R. Croes, R. A. Hawkins and B. L. Isaac. Research in Economic Anthropology, Supplement 6. JAI Press, Inc., Greenwich, Connecticut.
2003 Northwest Coast Wet-Site Artifacts: A Key to Understanding Resource Procurement, Storage, Management and Exchange. In *Emerging from the Mist: Studies in Northwest Coast Culture History*, edited by R. G. Matson, G. Coupland and Q. Mackie. University of British Columbia Press, Vancouver, British Columbia.

Croes, D. R., B. Stucki and R. Wigen
2005 *The Hoko River Archaeological Site Complex: The Rockshelter (45CA21), 1,000-100 B.P., Olympic Peninsula, Washington*. Washington State University Press, Pullman, Washington.

Cruz, I. and D. Elkin
2003 Structural Bone Density of the Lesser Rhea (*Pterocnemia pennata*) (Aves: Rheidae): Taphonomic and Archaeological Implications. *Journal of Archaeological Science* 30:37-44.

Davydov, G. I.
1977 *Two Voyages to Russian America: 1802-1807*. Limestone Press, Kingston.

Dawson, G. M.

1880 Report on the Queen Charlotte Islands, 1878. *Geological Survey of Canada Report of Progress for 1878-1879, Vol. 4*. Geological Survey of Canada, Ottawa.

de Laguna, F.

1972 *Under Mount Saint Elias: The History and Culture of the Yakutat Tlingit*. Smithsonian Contributions to Anthropology. Smithsonian Institution Press, Washington, D.C.

1990 Eyak. In *Northwest Coast*, edited by W. P. Suttles, pp. 189-196. Handbook of North American Indians, vol. 7, W. C. Sturtevant, general editor, Smithsonian Institution, Washington, D.C.

Dirrigl, F. J. J.

2001 Bone Mineral Density of Wild Turkey (*Meleagris gallopavo*) Skeletal Elements and Its Effect on Differential Survivorship. *Journal of Archaeological Science* 28:817-832.

Drennan, R. D.

1996 *Statistics for Archaeologists*. Plenum Press, New York.

Drucker, P.

1951 *The North and Central Nootkan Tribes*. Smithsonian Institution Bureau of American Ethnology Bulletin 144. United States Government Printing Office, Washington, D.C.

Elkin, D. C.

1995 Volume Density of South American Camelid Skeletal Parts. *International Journal of Osteoarchaeology* 5:29-37.

Emmons, G. T.

1991 *The Tlingit Indians*. Anthropological Papers of the Museum of Natural History, No. 70. University of Washington Press, Seattle.

Fagan, B. M. and H. D. G. Maschner

1991 Hunter-gatherer Complexity on the West Coast of North America. *Antiquity* 65(249):921-923.

Farquharson, M. J. and R. D. Speller

1997 Measuring Bone Mineral Density in Archaeological Bone using Energy Dispersive Low Angle X-ray Scattering Techniques. *Journal of Archaeological Science* 24:765-772.

Finney, B. P., I. Gregory-Eaves, M. S. V. Douglas and J. P. Smol
2002 Fisheries Productivity in the Northeastern Pacific Ocean Over the Past 2,200 Years. *Nature* 416:729-733.

Finney, B. P., I. Gregory-Eaves, J. Sweetman, M. S. V. Douglas and J. P. Smol
2000 Impacts of Climatic Change and Fishing on Pacific Salmon Abundance Over the Past 300 Years. *Science* 290(27):795-799.

Fitzhugh, B.
2002 Residential and Logistical Strategies in the Evolution of Complex Hunter-Gatherers on the Kodiak Archipelago. In *Beyond Foraging and Collecting*, edited by B. Fitzhugh and J. Habu, pp. 257-304. Kluwer Academic/Plenum Publishers, New York.
2003a *The Evolution of Complex Hunter-Gatherers*. Interdisciplinary Contributions to Archaeology. Kluwer Academic/Plenum Publishers, New York.
2003b The Evolution of Complex Hunter-gatherers on the Kodiak Archipelago. *Senri Ethnological Studies* 63(13-48).

Fladmark, K. R.
1975 *A Paleoecological Model for Northwest Coast Prehistory*. Archaeological Survey of Canada Paper, Mercury Series. No. 43. National Museum of Civilization, Ottawa, Ontario.

Gifford, D. P.
1981 Taphonomy and Paleoecology: A Critical Review of Archaeology's Sister Disciplines. In *Advances in Archaeological Method and Theory*, edited by M. B. Schiffer, pp. 365-438. Academic Press, New York.

Grayson, D. K.
1979 On the Quantification of Vertebrate Archaeofaunas. *Advances in Archaeological Method and Theory* 2:199-237.

Grier, C.
2003 Dimensions of Regional Interaction in the Prehistoric Gulf of Georgia. In *Emerging from the Mist: Studies in Northwest Coast Culture History*, edited by R. G. Matson and Q. Mackie. UBC Press, Vancouver, British Columbia.

Hanson, D. K.
1991 *Late Prehistoric Subsistence in the Strait of Georgia Region of the Northwest Coast.* Ph.D. Dissertation, Simon Fraser University, Burnaby, British Columbia.

Harrison, C.
1925 *Ancient Warriors of the North Pacific: The Haidas, Their Laws, Customs and Legends, with some Historical Accounts of the Queen Charlotte Islands.* H. F. & G. Witherby, London.

Hoffman, B. W., J. M. C. Czederpiltz and M. A. Partlow
2000 Heads or Tails: The Zooarchaeology of Aleut Salmon Storage on Unimak Island, Alaska. *Journal of Archaeological Science* 27:699-708.

Holmberg, H. J.
1985 *1818-1864 Holmberg's Ethnographic Sketches*. The Rasmuson Library Historical Translation Series I. The University of Alaska Press, Fairbanks, Alaska.

Huelsbeck, D. R. and G. C. Wessen
1994 Mammals and Fish in the Subsistence Economy of Ozette. In *Ozette Archaeological Research Reports, Volume II: Fauna*, edited by S. R. Samuels. Reports of Investigations 66. Washington State University, Department of Anthropology and National Park Service, Pacific Northwest Regional Office, Pullman and Seattle Washington.

Ioannidou, E.
2003 Taphonomy of Animal Bones: Species, Sex, Age and Breed Variability of Sheep, Cattle, and Pig Bone Density. *Journal of Archaeological Science* 30:355-365.

James, S. R.
1997 Methodological Issues Concerning Screen Size Recovery Rates and Their Effects on Archaeofaunal Interpretations. *Journal of Archaeological Science* 24:385-397.

Jewitt, J. R.
1988 *A Journal Kept at Nootka Sound.* Ye Galleon Press, Fairfield, Washington.

Jochelson, W.
1933 *History, Ethnology and Anthropology of the Aleut*. Anthropology of Pacific North America. University of Utah Press, Salt Lake City, Utah.

Jones, A. K. G.
1984 Some Effects of the Mammalian Digestive Systems on Fish Bones. In *Second Fish Osteoarchaeolgy Meeting*, edited by N. Desse-Berset, pp.

61-65. Centre de recherches archeologiques, Notes et Monographies Techniques. vol. Vol. 16.

1986 Fish Bone Survival in the Digestive Systems of the Pig, Dog and Man: Some Experiments. In *Fish and Archaeology*, edited by D. C. Brinkhuizen and A. T. Clason, pp. 53-61. British Archaeological Reports International Series, 294.

Jones, K. T. and D. Metcalfe

1988 Bare Bones Archaeology: Bone Marrow Indices and Efficiency. *Journal of Archaeological Science* 15:415-423.

Jordan, C.

1997 No Bones About It: The Effects of Cooking and Human Digestion on Salmon bones. *Northwest Anthropological Research Notes* 31(1&2):1-4.

Kent, S.

1999 The Archaeological Visibility of Storage: Delineating Storage from Trash Areas. *American Antiquity* 64(1):79-94.

Ketchen, K. S.

1961 Observations on the Ecology of the Pacific Cod (Gadus macrocephalus) in Canadian Waters. *Journal of the Fisheries Research Board of Canada* 18(4):513-558.

Knecht, R. A. and R. S. Davis

2001 A Prehistoric Sequence for the Eastern Aleutians. *Archaeology in the Aleut Zone of Alaska*, edited by D. E. Dumond, University of Oregon Anthropological Papers No. 58. Department of Anthropology and Museum of Natural History, University of Oregon, Eugene.

Kopperl, R. E.

2003 *Cultural Complexity and Resource Intensification on Kodiak Island, Alaska.* Ph.D. Dissertation, University of Washington, Seattle.

Kreutzer, L. A.

1992 Bison and Deer Bone Mineral Densities: Comparisons and Implications for the Interpretation of Archaeological Faunas. *Journal of Archaeological Science* 19:271-294.

Lam, Y. M., X. Chen and O. M. Pearson

1999 Intertaxonomic Variability in Patterns of Bone Density and the Differential Representation of Bovid, Cervid, and Equid Elements in the Archaeological Record. *American Antiquity* 64(2):343-362.

Lam, Y. M. and O. M. Pearson
2005 Bone Density Studies and the Interpretation of the Faunal Record. *Evolutionary Anthropology* 14:99-108.

Langdon, S. J.
1977 *Technology, Ecology and Economy: Fishing Systems in Southeast Alaska*, Stanford University.
1979 Comparative Tlingit and Haida Adaptation to the West Coast of the Prince of Wales Archipelago. *Ethnology* 18(2):101-121.

Lantis, M.
1984 Aleut. In *Arctic*, edited by D. Damas, pp. 161-184. Handbook *of* North American Indians, vol. 5, W. C. Sturtevant, general editor, Smithsonian Institution, Washington, D.C.

Lord, J. K.
1866 *The Naturalist in Vancouver Island and British Columbia,* Vol. I. Richard Bentley, London.

Lubinski, P. M.
1996 Fish Heads, Fish Heads: An Experiment on Differential Bone Preservation in a Salmonid Fish. *Journal of Archaeological Science* 23:175-181.

Lyman, R. L.
1984 Bone Density and Differential Survivorship of Fossil Classes. *Journal of Anthropological Archaeology* 3:259-299.
1994 *Vertebrate Taphonomy*. Cambridge Manuals in Archaeology. Cambridge University Press, Cambridge.

Lyman, R. L., L. E. Houghton and A. L. Chambers
1992 The Effect of Structural Density on Marmot Skeletal Part Representation in Archaeological Sites. *Journal of Archaeological Science* 19:557-573.

Maschner, H. D. G.
1991 The Emergence of Cultural Complexity on the Northern Northwest Coast. *Antiquity* 65:924-934.
1997 Settlement and Subsistence in the Later Prehistory of Tebenkof Bay, Kuiu Island. *Arctic Anthropology* 18:74-99.

Matson, R. G.
1983 Intensification and the Development of Cultural Complexity: The Northwest Versus the Northeast Coast. In *The Evolution of Maritime Cultures of the Northeast and Northwest Coasts of America*, edited by R. J. Nash, pp. 125-148. Publication No. 11, Simon Fraser University, Burnaby, British Columbia.
1985 The Relationship between Sedentism and Status Inequalities Among Hunter-Gatherers. In *Status, Structure and Stratification: Current Archaeological Reconstructions*, edited by M. Thompson, M. T. Garcia and F. J. Kense, pp. 245-252. Archaeological Association, University of Calgary, Calgary, Alberta.
1992 The Evolution of Northwest Coast Subsistence. In *Long-term Subsistence Change in Prehistoric North America*, edited by D. Croes, R., R. A. Hawkins and B. L. Isaac, pp. 367-428. Research in Economic Anthropology, Supplement 6. JAI Press, Greenwich, Connecticut.

Matson, R. G. and G. Coupland
1995 *Prehistory of the Northwest Coast*. Academic Press, New York.

McKechnie, I.
2005 *Five Thousand Years of Fishing at a Shell Midden in the Broken Group Islands, Barkley Sound, British Columbia.* M.A. Thesis, Simon Fraser University.

Mecklenburg, C., W., T. A. Meckelnburg and L. K. Thorsteinson
2002 *Fishes of Alaska*. American Fisheries Society, Bethesda, Maryland.

Metcalfe, D. and K. T. Jones
1988 A Reconsideration of Animal Body-part Utility Indices. *American Antiquity* 53(3):486-504.

Monks, G.
1987 Prey as Bait: The Deep Bay Example. *Canadian Journal of Archaeology* 11:119-142.

Moss, M. L.
1993 Shellfish, Gender, and Status on the Northwest Coast: Reconciling Archaeological, Ethnographic, and Ethnohistorical Records of the Tlingit. *American Anthropologist* 95(3):631-652.
2004 *Archaeological Investigation of Cape Addington Rockshelter: Human Occupation of the Rugged Seacoast on the Outer Prince of Wales Archipelago, Alaska.* University of Oregon Archaeological Paper No. 63. Department of Anthropology and the Museum of Natural History, Eugene, Oregon.

Moss, M. L. and J. M. Erlandson
1995 Reflections on North American Pacific Coast Prehistory. *Journal of World Prehistory* 9(1):1-45.

Munro, N. D. and G. Bar-Oz
2005 Gazelle Bone Fat Processing in the Levantine Epipalaeolithic. *Journal of Archaeological Science* 32:223-239.

Newton, R. G. and M. L. Moss
1984 *The Subsistence Lifeway of the Tlingit People: Excerpts of Oral Interviews*. USDA Forest Service.
2005 *Haa Atxaayi Haa Kusteeyix Sitee, Our Food is Our Tlingit Way of Life, Excerpts from Oral Interviews*. United States Department of Agriculture, Forest Service, Alaska Region.

Niblack, A. P.
1890 *The Coast Indians of Southern Alaska and Northern British Columbia*. Manuscript on file, Pacific Northwest Special Collections, University of Washington Library, Seattle.

Nicholson, R. A.
1992 An Assessment of the Value of Bone Density Measurements to Archaeoichthyological Studies. *International Journal of Osteoarchaeology* 2:139-154.
1996 Bone Degradation, Burial Medium and Species Representation: Debunking the Myths, an Experiment-based Approach. *Journal of Archaeological Science* 23:513-533.
1998 Bone Degradation in a Compost Heap. *Journal of Archaeological Science* 25:393-403.

Novecosky, B. J. and P. R. W. Popkin
2005 Canidae Volume Bone Mineral Density Values: An Application to Sites in Western Canada. *Journal of Archaeological Science* 32:1677-1690.

Outer Continental Shelf Environmental Assessment Program (OCSEAP)
1987 Marine Fisheries: Resources and Environments. In *The Gulf of Alaska: Physical Environment and Biological Resources*, edited by D. W. Hood and S. T. Zimmerman. National Oceanic and Atmospheric Administration, National Ocean Service, Office of Oceanography and Marine Assessment, Ocean Assessments Division, Alaska Office, Anchorage, Alaska.

O'Connell, J. F., K. Hawkes and N. Blurton-Jones
1989 Reanalysis of Large Mammal Body Part Transport among the Hadza. *Journal of Archaeological Science* 17:301-316.

O'Leary, B. L.
1985 *Salmon and Storage: Southern Tutchone use of an "Abundant" Resource*. Ph.D. dissertation, University of New Mexico, Albuquerque.

Oberg, K.
1973 *The Social Economy of the Tlingit Indians.* The American Ethnological Society. University of Washington Press, Seattle.

Orchard, T. J.
2001 *The Role of Selected Fish Species in Aleut Paleodiet.* M.A. thesis, University of Victoria, Victoria, British Columbia.

Partlow, M. A.
2000 *Salmon Intensification and Changing Household Organization in the Kodiak Archipelago*, University of Wisconsin-Madison.

Partlow, M. A. and R. E. Kopperl
2007 *Exploring the Skeletal Evidence for Dried Cod in the North Pacific.* Poster presented at the 34th Annual Meeting of the Alaska Anthropological Association, Fairbanks, Alaska.
2008 *Processing the Patterns: Elusive Archaeofaunal Signatures of Cod Storage on the North Pacific Coast*. Paper presented at the 73rd Annual Meeting of the Society for American Archaeology, Vancouver, British Columbia, Canada.

Pavao, B. and P. W. Stahl
1999 Structural Density Assays of Leporid Skeletal Elements with Implications for Taphonomic, Actualistic and Archaeological Research. *Journal of Archaeological Science* 26:53-66.

Pettitt, G. A.
1950 *The Quileute of La Push, 1775-1945*. Anthropological Records 14(1). University of California Press, Berkeley, California.

Pickering, T. R. and K. J. Carlson
2002 Baboon Bone Mineral Densities: Implications for the Taphonomy of Primate Skeletons in South African Cave Sites. *Journal of Archaeological Science* 29:883-896.

Richter, J.
1986 Experimental Study of Heat Induced Morphological Changes in Fish Bone Collagen. *Journal of Archaeological Science* 13:477-481.

Roberts, S. J., C. I. Smith, A. Millard and M. J. Collins
2002 The Taphonomy of Cooked Bone: Characterizing Boiling and its Physico-chemical Effects. *Archaeometry* 44(3):485-494.

Robinson, S., R. A. Nicholson and A. M. Pollard
2003 An Evaluation of Nitrogen Porosimetry as a Technique for Predicting Taphonomic Durability in Animal Bone. *Journal of Archaeological Science* 30:391-403.

Romanoff, S.
1985 Fraser Lillooet Salmon Fishing. *Northwest Anthropological Research Notes* 19(2):119-160.

Rowley-Conwy, P. and M. Zvelebil
1989 Saving it for Later: Storage by Prehistoric Hunter-gatherers in Europe. In *Bad Year Economics: Cultural Responses to Risk and Uncertainty*, edited by P. Halstead and J. O'Shea, pp. 40-56. Cambridge University Press, New York.

Sassaman, K. E.
2004 Complex Hunter-gatherers in Evolution and History: A North American Perspective. *Journal of Archaeological Research* 12(3):227-280.

Sauvage, H. E.
1875 On Fishing in the Reindeer Period. In *Reliquiae Aquitanicae; Being Contributions to the Archaeology of Perigord and the Adjoining Provinces of Southern France*, edited by E. Lartet and H. Christy. Williams and Norgate, London.

Schalk, R. F.
1977 The Structure of an Anadromous Fish Resource. In *For Theory Building in Archaeology*, edited by L. R. Binford, pp. 207-249. Academic Press, Orlando, Florida.
1981 Land Use and Organizational Complexity among Foragers of Northwestern North America. In *Affluent Foragers, Pacific Coasts East and West*, edited by S. Koyama and D. H. Thomas, pp. 53-76. Senri Ethnological Studies 9, National Museum of Ethnology, Osaka, Japan.

Shaffer, B. S.
1992 Quarter-inch Screening: Understanding Biases in Recovery of Vertebrate Faunal Remains. *American Antiquity* 57(1):129-136.

Shaffer, B. S. and B. W. Baker
1999 Comments on James' Methodological Issues Concerning Analysis of Archaeofaunal Recovery and Screen Size Correction Factors. *Journal of Archaeological Science* 26:1181-1182.

Shaffer, B. S. and J. L. J. Sanchez
1994 Comparison of 1/8"- and 1/4"-mesh Recovery of Controlled Samples of Small-to-medium-sized Mammals. *American Antiquity* 59(3):525-530.

SImetric
2007 Density of Water (g/cm^3) at Temperatures from 0°C (liquid state) to 30.9°C by 0.1°C inc. Accessed June 2007 at: http://www.simetric.co.uk/si_water.htm

Skedros, J. G., S. C. Su and R. D. Bloebaum
1997 Biomechanical Implications of Mineral Content and Microstructural Variations in Cortical Bone of Horse, Elk and Sheep. *The Anatomical Record* 249:297-316.

Spaulding, P. T.
1955 *An Ethnohistorical Study of Akutan: An Aleut Community*. Unpublished Master’s thesis, Department of Anthropology, University of Oregon, Eugene.

Stahl, P. W.
1999 Structural Density of Domesticated South American Camelid Skeletal Elements and the Archaeological Investigation of Prehistoric Andean Ch'arki. *Journal of Archaeological Science* 26(11):1347-1368.

Steffian, A. F.
1992 Fifty Years after Hrdlicka: Further Investigations at the Uyak site, Kodiak Island, Alaska. In *Contributions to the Anthropology of Southcentral and Southwestern Alaska*, edited by R. H. Jordan, F. deLaguna and A. F. Steffian, pp. 141-164. Anthropological Papers of the University of Alaska 24(1-2).

Suttles, W. P.

1966 Coping with Abundance: Subsistence on the Northwest Coast. In *Man the Hunter*, edited by R. B. Lee and I. DeVore, pp. 56-68. Aldine, Chicago.

1974 *Economic Life of the Coast Salish of Haro and Rosario Straits*. Garland Publishing, Inc., New York.

Swan, J. G.

1869 *The Indians of Cape Flattery at the Entrance to the Strait of Fuca, Washington Territory*. Smithsonian Contributions to Knowledge. Collins, Philadelphia.

1870 *The Indians of Cape Flattery at the Entrance to the Strait of Fuca, Washington Territory*. Smithsonian Contributions to Knowledge. Collins Printer, Philadelphia.

Symmons, R.

2004 Digital Photodensitometry: A Reliable and Accessible Method for Measuring Bone Density. *Journal of Archaeological Science* 31:711-719.

2005 Bone Density Variation between Similar Animals and Density Variation in Early Life: Implications for Future Taphonomic Analysis. In *Biosphere to Lithosphere: New Studies in Vertebrate Taphonomy*, edited by T. O'Connor, pp. 86-93, Oxbow Books, Oxford.

Thomas, D. H. and D. Mayer

1983 Behavioral Faunal Analysis of Selected Horizons. In *The Archaeology of Monitor Valley 2: Gatecliff Shelter*, edited by D. H. Thomas, pp. 353-391. Anthropological Papers No. 59. American Museum of Natural History, New York.

Wigen, R. J.

2003 Fish Remains from Sites 45SJ165 and 45SJ169. In *Archaeological Investigations at Sites 45SJ165 and 45SJ169, Decatur Island, San Juan County, Washington*, edited by S. L. Walker, pp. 227-308. Eastern Washington University Reports in Archaeology and History 100-118. Archaeological and Historical Services, Eastern Washington University, Cheney, Washington.

2005 Vertebrate Fauna. In *The Hoko River Archaeological Site Complex: The Rockshelter (45CA21), 1,000-100 B.P., Olympic Peninsula, Washington.* edited by D. R. Croes Washington State University, Pullman.

Wigen, R. J. and B. R. Stucki
1988 Taphonomy and Stratigraphy in the Interpretation of Economic Patterns at Hoko River Rockshelter. *Research in Economic Anthropology, Supplement No. 3*:87-146.

Willey, P., A. Galloway and L. Snyder
1997 Bone Mineral Density and Survival of Elements and Element Portions in the Bones of the Crow Creek Massacre Victims. *American Journal of Physical Anthropology* 104:513-528.

APPENDIX A: SUMMARY TABLES

Table A-1. Relative Abundance of Pacific Cod and Halibut Elements in Published Assemblages

	G. macrocephalus*		***H. stenolepis****	
Element	**Common****	**Rare*****	**Common****	**Rare*****
Vomer	X			X
Hyomandibula		X		X
Quadrate	X		X	
Opercle		X		X
Articular	X		X	
Dentary	X		X	
Maxilla	X		X	
Ceratohyal	X			X
Cleithrum		X	X	
Coracoid		X		X
Basipterygium		X	X	
Atlas Vert.	X			X
First Caudal Vert.	X		X	
Penultimate Vert.			X	

* Taxon identified in assemblages from Amaknak Bridge (Crockford 2006 personal comm.); Cape Addington Rockshelter (Moss 2004); Crag Point, Rice Ridge and Uyak (Kopperl 2004); North Point (Bowers and Moss 2001).

** Greater than 1% of Identified Specimens

*** Less than 1% of Identified Specimens

Table A-2. Element Orientation Protocol for DEXA Scanning

Element	**View**
Vomer	Dorsal (Cod) Ventral (Halibut)
Hyomandibula	Lateral
Quadrate	Lateral
Opercle	Medial
Articular	Lateral
Dentary	Lateral
Maxilla	Dorsal
Ceratohyal	Medial
Cleithrum	Lateral
Coracoid	Lateral
Basipterygium	Dorsal
Atlas Vert.	Anterior
First Caudal Vert.	Posterior
Penultimate Vert.	Posterior

Table A-3. Results of Pacific Halibut and Cod Pair-wise BVD Correlation Analyses (Pearson’s r)

			Pacific Cod Specimen				
			C-1	C-2	C-3	C-4	C-5
Pacific Halibut Specimen	H-1	Pearson Correlation	.879(**)	.745(**)	.657(*)	.663(*)	.739(**)
		Sig. (2-tailed)	.000	.005	.020	.019	.006
	H-2	Pearson Correlation	.859(**)	.739(**)	.635(*)	.669(*)	.734(**)
		Sig. (2-tailed)	.000	.006	.026	.017	.007
	H-4	Pearson Correlation	.841(**)	.661(*)	.559	.582(*)	.663(*)
		Sig. (2-tailed)	.001	.019	.059	.047	.019
	H-5	Pearson Correlation	.879(**)	.728(**)	.609(*)	.642(*)	.709(**)
		Sig. (2-tailed)	.000	.007	.036	.024	.010
	H-20	Pearson Correlation	.902(**)	.764(**)	.658(*)	.687(*)	.752(**)
		Sig. (2-tailed)	.000	.004	.020	.013	.005
	H-21	Pearson Correlation	.861(**)	.708(**)	.582(*)	.621(*)	.689(*)
		Sig. (2-tailed)	.000	.010	.047	.031	.013
	H-22	Pearson Correlation	.883(**)	.694(*)	.548	.609(*)	.680(*)
		Sig. (2-tailed)	.000	.012	.065	.036	.015

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Table A-4. Results of Pacific Halibut and Salmon Pair-wise BVD Correlation Analyses (Pearson's r)

			Salmon Mean BVD
Pacific Halibut Specimen	H-1	Pearson Correlation	.803(**)
		Sig. (2-tailed)	.005
	H-2	Pearson Correlation	.855(**)
		Sig. (2-tailed)	.002
	H-4	Pearson Correlation	.823(**)
		Sig. (2-tailed)	.003
	H-5	Pearson Correlation	.829(**)
		Sig. (2-tailed)	.003
	H-20	Pearson Correlation	.808(**)
		Sig. (2-tailed)	.005
	H-21	Pearson Correlation	.824(**)
		Sig. (2-tailed)	.003
	H-22	Pearson Correlation	.810(**)
		Sig. (2-tailed)	.004

** Correlation is significant at the 0.01 level (2-tailed)

Table A-5. Results of Pacific Cod and Salmon Pair-wise BVD Correlation Analyses (Pearson's r)

			Salmon Mean BVD
Pacific Cod Specimen	C-1	Pearson Correlation	.603
		Sig. (2-tailed)	.114
	C-2	Pearson Correlation	.388
		Sig. (2-tailed)	.343
	C-3	Pearson Correlation	.218
		Sig. (2-tailed)	.605
	C-4	Pearson Correlation	.287
		Sig. (2-tailed)	.490
	C-5	Pearson Correlation	.334
		Sig. (2-tailed)	.418

APPENDIX B: FISH ELEMENT CLASSIFICATION PROTOCOL

Site		
Lot		
Specimen		
Unit		
Quad		
Level		
Begin_Depth		
End_Depth		
Feature		
Dimensions	**Modes**	**Codes**
Screen Size		
	¼”	1
	1/8”	2
	1/16”	3
Family		
Salmon and Trout	Salmonidae	1
Codfishes	Gadidae	2
Righteye Flounder	Pleuronectidae	10
	Unid. Fish	99
Finest Taxon		
Salmon and Trout	*Oncorhynchus* spp.	4
Pacific Cod	*Gadus macrocephalus*	11
Pacific Halibut	*Hippoglossus stenolepis*	69
	Unid. Fish	99
Element		
	Ethmoid (supraethmoid, mesethmoid)	1
	Prefrontal	2
	Vomer	3
	Alisphenoid	4
	Parasphenoid	5
	Orbitosphenoid	6
	Supraoccipital	7
	Exoccipital	8
	Basioccipital	9
	Epiotic	10

	Opisthotic	11
	Otolith	12
	Prootic	13
	Pterotic	14
	Sphenotic	15
	Frontal	16
	Nasal	17
	Parietal	18
	Supratemporal	19
	Angular	20
	Dentary	21
	Lachrymal	22
	Maxilla	23
	Premaxilla	24
	Preopercle	25
	Retroarticular	26
	Suborbital	27
	Supramaxilla	28
	Supraorbital	29
	Suprapreopercle	30
	Branchiostegal Ray	31
	Interopercle	32
	Opercle	33
	Subopercle	34
	Ectopterygoid	35
	Mesopterygoid	36
	Metapterygoid	37
	Palatine	38
	Quadrate	39
	Basihyal	40
	Ceratohyal	41
	Epihyal	42
	Hyomandibular	43
	Hypohyal	44
	Interhyal	45
	Symplectic	46
	Basibranchial	47
	Basibranchial Plate	48
	Ceratobranchial	49
	Epibranchial	50
	Hypobranchial	51

	Pharyngeal Plate	52
	Pharyngobranchial	53
	Urohyal	54
	Cleithrum	55
	Coracoid	56
	Mesocoracoid	57
	Postcleithrum	58
	Posttemporal	59
	Radials	60
	Scapula	61
	Supracleithrum	62
	Basipterygium	63
	Interhaemal Spine	64
	Vert. Type-1 Atlas	65
	Cervical Vertebrae	66
	Thoracic Vert.	67
	Abdominal Vert.	68
	Precaudal Vert	69
	Caudal Vert.	70
	Penultimate Vert	71
	Ultimate Vert	72
	Hypural	73
Portion		
	Mostly Whole	1
	Central Portion	2
	Fragment	3
	Articular Facet	4
Landmark		
	Present	1
	Absent	2
	Unknown	3
Side		
	Left	1
	Right	2
	Undetermined	3
	Not Specified	4
Modification		
	Burned	1
	Cut	2
Count		