EARLY STORAGE AND SEDENTISM ON THE PACIFIC NORTHWEST COAST: ANCIENT DNA ANALYSIS OF SALMON REMAINS FROM NAMU, BRITISH COLUMBIA

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Ancient DNA identification of salmon remains from the site of Namu on the central coast of British Columbia shows use of a variety of species and an emphasis on pink salmon over the course of the past 7,000 years. These results support arguments that Namu was a permanent village settlement dependent on a salmon storage economy throughout this time. This pattern of subsistence and settlement predates by several millennia the first substantial evidence for population expansion or social differentiation in the region. Periodic salmon shortages in the period after 2000 cal B.C., which are associated with local and regional disruptions in settlement and increased reliance on more marginal resources, appear to be the result of failures in the pink salmon fishery.

La identificación del ADN antiguo en remanentes de salmón obtenidos en el sitio Namu en la costa central de la Columbia Británica, constituye evidencia de la utilización de una variedad de especies, con preferencia por el salmón rosado, a través de los últimos 7000 años. Dichos resultados vendrían a apoyar la hipótesis de que Namu sería un asentamiento permanente, que dependería económicamente del almacenamiento de salmón. Este patrón de subsistencia y de asentamiento vendría a ser más temprano, por varios milenios, que la importante primera evidencia de una expansión poblacional o de una diferenciación social en esta región. La escasez periódica del salmón en el período posterior al 2000 cal B.C., asociada con trastornos en los asentamientos locales y regionales y con un incremento de la dependencia sobre recursos más marginales, vendrían a ser producto del fracaso en la pesca del salmón rosado.

Archaeologists debate when sedentary settlement and a fully developed salmon-storage economy first appear on the Pacific Northwest Coast (Ames 2003:24). They also debate their relative importance in long-term cultural developments in the region (Matson 1992:422; Moss and Erlandson 1995:34). Resolution of these debates may eventually come from more extensive site survey and excavation, but progress toward their resolution can also come from new evidence derived from existing site collections. We present a new line of evidence based on ancient DNA analysis of salmon remains from the site of Namu, located in the traditional territory of the Heiltsuk Nation on the central coast of British Columbia (Figure 1). The results give new insight into the precise species composition of the fishery and lend weight to arguments that Namu was from as early as 5000 cal B.C. a permanent village settlement sustained by a salmon-storage economy.

Although storage and sedentism are no longer thought to be either sufficient or strictly necessary for the emergence of "complex" hunter-gatherers (Moss and Erlandson 1995:34), they are among a constellation of conditions widely linked to population growth, surplus production, and the development of social inequality (Arnold 1996; Rowley-Conwy 2001:44). Pacific Northwest Coast archaeologists generally recognize the mass harvest and storage of seasonally available resources, particularly salmon, as an essential basis for the ethnographic pattern of dense regional population, large permanent settlements, rich ceremonial traditions, highly developed material arts, and com-

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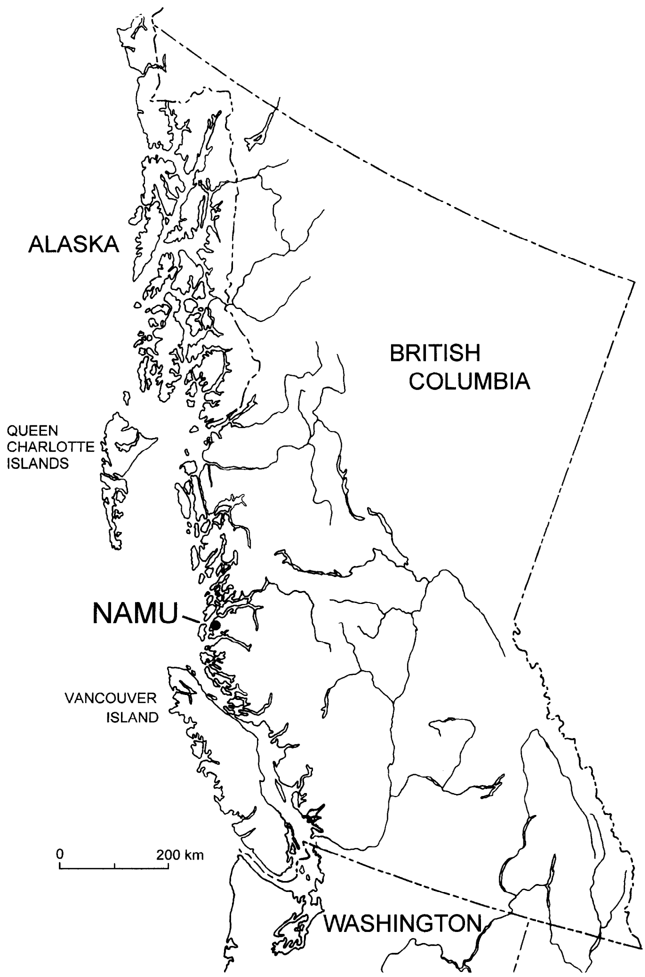

Figure 1. Location of Namu on the central coast of British Columbia.

plex social ranking (Matson 1992). Since sedentary settlement and the production and control of subsistence surplus are widely viewed as having enabled or directly caused the emergence of greater social and cultural complexity (Ames 1994; Maschner and Patton 1996:101; Matson 1992:422), material evidence of these developments has assumed a prominent place in archaeological research and debate.

Very early evidence of storage and sedentism could undermine posited relationships with increasing population density and greater social inequality, but indirect archaeological indicators always retain enough ambiguity to sustain established views in the face of potentially contradictory observations. Storage, for example, is acknowledged as having been based on relatively simple technology and therefore likely to have been present in some form from the earliest occupation of the region (Ames 1994:217; Ames and Maschner 1999:127). The mass harvest and storage of salmon is considered a much later development involving changes in the organization of production and more sedentary settlement. It is thought to be the basis for population increase and the emergence of increasing social differentiation (Croes and Hackenberger 1988), though population growth is also considered a likely reason for the development of a storage-based economy (Ames and Maschner 1999:252–253). The generally weak and equivocal evidence used to support arguments for and against storage is the major basis for contention. Large quantities of salmon remains, the relative representation of cranial elements versus vertebrae, mass capture technology, and storage structures have all been cited and debated as evidence for large-scale salmon storage.

One relatively simple indicator of storage is the presence of the remains of one particular resource in such abundance that their accumulation as the result of fresh consumption would seem unlikely. An abundance of salmon relative to other resources might suggest their consumption as dried stores since salmon are available for a limited period consisting of only weeks or months. Ames (1998:82) has suggested that such abundance could also be explained as the result of large-scale population aggregations coming together for short periods of time to consume fish fresh rather than as processed stores.

Salmon remains resulting from processing and storage have been differentiated from those consumed fresh on the basis of the relative proportions of cranial elements and vertebrae (Calvert 1970; Coupland 1998:43; Matson 1992). Controlled observations of processing and storage practices in more recent historic contexts support the proposition that village sites subsisting on stores of dried salmon can exhibit a preponderance of vertebrae while camps used for processing or where the consumption of fresh fish took place yield greater numbers of cranial elements (Hoffman et al. 2000). A wide range of other taphonomic and processing variables could also potentially produce assemblages varying in the relative representation of cranial elements (Ames 1994:217; Cannon 2001; Coupland 1998:51–52). There are also too few sites from controlled temporal contexts that exhibit clear patterns of element representation for this to be the deciding criterion for the development of large-scale storage on the Northwest Coast. Although widely cited, this variable alone is at best an ambiguous indicator of storage.

Additional support for intensive salmon fishing and storage comes from studies of weirs and fish traps built to facilitate mass harvest. Again, the reasoning is that such facilities would yield harvests in excess of what could be consumed as fresh fish, therefore implying their purpose was to enable the harvest of sufficient fish for winter storage. The relatively recent date of most fish weirs (Moss et al. 1990; Moss and Erlandson 1998) has led some to infer that intensive fishing for storage was also a relatively recent development (Ames 1994:217; Matson 1992:386, 2003:7). Early examples of fish weirs also indicate long-term use of this technology (Eldridge and Acheson 1992), but early populations probably made use of a variety of harvest techniques. Although common construction of weirs and fish traps may be a later development indicating intensification of fishing on local and regional scales, these constructions were not required for local populations to base their winter subsistence on stored salmon.

The absence of storage features in early archaeological contexts has also been cited as evidence against an early dependence on salmon storage (Ames and Maschner 1999:138). The ethnographic cultures of the Northwest Coast depended on boxes, baskets, and the corners and rafters of plank houses as storage facilities (Suttles 1968:63–64). Baskets and boxes are unlikely to be preserved in most early contexts, and they leave little other archaeological trace. The Northwest Coast cedar plank house has been described as a large storage facility (Ames 1996). The identification of large-scale storage has therefore focused on evidence for the advent of permanent residential structures (Ames 1994: 217–219). Unfortunately, early evidence for houses is very difficult to discern in the limited area expanse of most excavations into deep and complexly stratified shell midden deposits. Even when posited on the basis of floor and support post features uncovered through excavations of greater area extent (e.g., Ham et al. 1986), early evidence of permanent housing has been considered unconvincing (Ames and Maschner 1999:262; Matson 1992:382). The more unequivocal evidence for large, rectangular residential housing, of the form that would allow for large-scale storage, generally comes in the form of surface features consisting of structural outlines. The focus on surface features tends to support a later date for the development of permanent housing.

Arguments against an early storage-based subsistence economy presuppose an earlier, more mobile pattern of shifting residence to take advantage of seasonally available resources. The difficulty in applying this model to the Northwest Coast is that relatively few substantial resources are available in the winter months in this temperate region. It is possible to fish for some minor species, such as rockfish, year round. Shellfish are also available, though there is no early evidence to suggest they were sufficient basis for winter subsistence. Some game, such as deer and sea mammals, is also available, but a subsistence economy reliant on these types of typically singular and intermittently available resources would likely be precarious. The absence of large-scale, easily harvested, and reliable food resources throughout the winter could in itself argue for an emphasis on the mass harvest and storage of salmon, but the absence of early positive evidence for what is presumed to be such a pivotal development has been enough to undermine any argument based solely on seasonal resource availability.

The lack of substantial evidence from early archaeological contexts and the equivocal nature of all material indicators of storage from whatever context have left the timing of large-scale salmon storage open to question and debate. The consensus has been that intensive fishing and storage were relatively late developments. One researcher (Matson 1992:423) has gone so far as to say "we appear to be on the verge of being able to say with certainty that the Northwest Coast salmon-storage economy came into being during the 3500–3000 B.P. period."

The issue of when permanent sedentary or semisedentary winter village settlement emerged on the coast has been even more difficult to resolve. Part of the problem is a matter of definition, but even if permanent winter village settlement of the type described ethnographically, which also incorporates a substantial degree of seasonal mobility on the part of individuals and groups, is taken as the standard, unequivocal archaeological evidence for its development can be difficult to discern. Demonstration of permanent multiseasonal or winter village settlement has typically depended on the evidence of substantial residential structures or seasonally specific faunal indicators. The problem with discerning early evidence of substantial structures has already been described. The same issues noted for storage also apply to the question of village settlement. Given reliance on surface features to define substantial structures, the advent of village settlement on the coast tends to be placed relatively late (Ames 1994:218–219; Matson and Coupland 1995:187).

The problems with making seasonal determinations on the basis of faunal indicators have been widely discussed (Monks 1981:180–185). The seasonal availability of most faunal species cover such wide and often overlapping ranges that they provide little precise indication of when people inhabited any given site. Seasonally available fauna show minimally when people were present, but they cannot demonstrate continuous presence over any specific length of time. Growth increment analysis of shell has also proved unreliable (Maxwell 2003). The advent of permanent village settlement is therefore tied to the unequivocal evidence of large substantial residential structures, which are only clearly evident in the terminal occupations of village sites. These are generally recent at most locations.

Cannon (1991, 1998) has long argued on the basis of faunal remains that Namu was occupied year round by some portion of its resident population and was dependent on a storage-based economy focused on the mass harvest of salmon. He has also argued that that pattern remained fundamentally unchanged from the date of the earliest preserved faunal remains ca. 5000 cal B.C. The argument is based foremost on the large quantities of salmon among the fish remains other than herring. Salmon make up 89 percent of all identified fish other than herring in the earliest period for which faunal remains are available (Cannon 1991:18). Based on the analysis of auger samples, herring was even more abundant in this and all subsequent periods (Cannon 2000a). Although a variety of fish, shellfish, mammal, and bird species were harvested, it is clear that salmon and herring were the main foci of the subsistence economy throughout the last 7,000 years. Some archaeologists accept that the large quantity of salmon at the site is evidence of storage (Coupland 1998:44). Others, while not dismissing the possibility, have suggested alternative explanations, such as large seasonal fishing aggregations (Ames 1998:88). The somewhat weaker argument based on cranial element versus vertebra representation has not been addressed explicitly, but the Namu salmon consist overwhelmingly of vertebrae in all periods (Cannon 1991:18).

The argument for a permanent multiseasonal occupation of the Namu site is based on the consistent presence of seasonally specific resources, including neonatal harbor seal remains, indicative of presence at around the mid-June peak in the pupping season; salmon, which are available in summer/early autumn; and herring, which are available in late winter/early spring when they come near shore to spawn. Similar faunal evidence is cited by Ames and Maschner (1999:139) as indicative of year-round occupation of the Boardwalk site in Prince Rupert harbor by 2100 B.C., but they note on the same page: "There is also no direct evidence of storage at Namu, except for the large numbers of salmon. It seems perfectly feasible that mobile hunters and gatherers would gather at Namu for a fall fish run, perhaps even erecting structures, dispersing to other available food sources, and returning in the spring."

Multiseasonal fauna, specifically salmon and herring, have been cited at other locations on the coast as indicative of seasonal mobility typical of Binford's forager mode (Coupland 1998:41), but there are no obvious resources available between the times of the salmon and herring fisheries that would warrant movement away from the Namu site. The three clear seasonal indicators imply some residence at the site throughout much of the year. If winter subsistence was also supported by reliance on stores of dried or smoked salmon, then clearly Namu was a major winter village, typical of those described ethnographically, from the date of the earliest faunal remains ca. 5000 cal B.C.

It is nonetheless possible to argue reasonably, as Ames has done, that the early abundance of salmon could be the product of limited seasonal aggregation for a particular fishery. The site might then be abandoned until reoccupied by a similar aggregation for the herring fishery. A large number of people from a wide area congregating at one location for a limited time certainly could produce and immediately consume a large number of fish. Although it is not clear why Namu would be the focus for such a congregation, the reasons could be the same as those that might be offered to explain use of the site as a village location.

Based on the presence and abundance of morphologically identified fauna, there is not much likelihood of resolving the debate, especially not in the face of persistent views that sedentism, storage, population growth, and cultural complexity are mutually linked and relatively late developments. In the absence of unambiguous evidence of structural remains, it is unlikely that any amount of excavation would resolve this issue. Fortunately the development and refinement of new ancient DNA (aDNA) analytical techniques has proved capable of providing a new level of precision in the faunal data that goes some way toward bolstering the argument for early sedentism and storage. It also refines our knowledge and understanding of later disruption in the fishery, an event that Cannon (2002) has cited as a potentially critical juncture in the settlement history of the site and the surrounding region.

Ancient DNA Analysis of the Namu Salmon

The results of extensive aDNA analysis of salmon remains show a clear pattern and long-term consistency in the nature of the fishery. The identification of species from individual vertebrae followed techniques developed and refined by Yang et al. (2004). The analysis began at the McMaster University Palaeogenetics Institute with the initial experimental development of the protocols for consistent aDNA extraction and species identification, but was carried out largely at the Simon Fraser University Ancient DNA Laboratory. The project developed over several years between 2000 and 2004. Sampling proceeded in stages, initially to select a few vertebrae for testing, followed by expansion of the sample to encompass a range of time periods and vertebra sizes, and then more extensive sampling to produce comparable-size samples from the major time periods identified within the last 7,000 years of the site's occupation. Sampling, which is discussed in more detail below, involved a combination of random and size dependent selection from contexts chosen to cover evenly the broadest available temporal span. The results presented here are based on successful extraction and species identification of aDNA sequences from 116 individual vertebrae selected by Cannon from 28 excavation contexts across seven horizontally defined excavation units and two auger sampling locations.

Results

The results presented in Table 1 are summarized by major time periods defined on the basis of stratigraphic divisions, artifact content, and extensive radiocarbon dating (Carlson 1991, 1996). Overall, there is a clear emphasis on pink salmon, followed by sockeye and chum. Coho is also consistently present in smaller numbers, and one vertebra deliberately selected for analysis because of its unusually

Table 1. Number and Percentage of aDNA Identified Salmon Species by Time Period.

	Pink		Chum		Sockeye		Coho		Chinook		Totals	
Period	n	%	n	%	n	%	n	%	n	%	n	%
P6 (AD 1 - Contact)	11	42.3	5	19.2	7	26.9	2	7.7	1	3.8	26	100
P5 (2000 BC - AD 1)	5	16.1	11	35.5	15	48.4	0	0.0	0	0.0	31	100
P4 (3000 - 2000 BC)	9	45.0	6	30.0	4	20.0	1	5.0	0	0.0	20	100
P3 (4000 - 3000 BC)	13	76.5	2	11.8	2	11.8	0	0.0	0	0.0	17	100
P2 (5000 - 4000 BC)	11	50.0	5	22.7	4	18.2	2	9.1	0	0.0	22	100
Site Total	49	42.2	29	25.0	32	27.6	5	4.3	1	0.9	116	100

large size was identified as chinook. Therefore, all five major anadromous species of Pacific salmon are present at the site, though the emphasis is clearly on pink, which make up 42.2 percent of the identified salmon.

The morphology of salmon vertebrae does not allow their identification to species. An earlier attempt to infer the likely composition of the Namu salmon fishery based on radiographic analysis of incremental growth lines in vertebrae (Cannon 1988, 1998) had suggested an emphasis on chum, but had erroneously excluded sockeye from consideration based on the published observation that major runs of sockeye are restricted to large river systems such as the Fraser and Skeena. In fact, the Namu River has always supported runs of sockeye salmon, as do many of the other small rivers in the area. Failure to recognize the importance of the pink salmon fishery was due to the large number of vertebrae exhibiting what appeared to be two winter growth lines. Pink salmon almost invariably spawn in their second year. A comparative specimen of pink salmon and many of the archaeological specimens identified through aDNA as pink salmon show two growth increments. If these represented winter growth, as inferred in the radiographic analysis, they would indicate three-year-old fish. Studies have shown, however, that scales of pink salmon often exhibit a supplementary check line that can be confused with a winter annulus (Bilton and Ricker 1965). Since the aDNA results are unequivocal in their identification of pink salmon, we must conclude that a proportion of these fish exhibit two radiographically visible increments in their vertebrae. This observation makes the already ambiguous results of the radiographic analysis even less useful for the purpose of species identification.

Species identifications are supported by consistent results obtained from multiple DNA sequences. The majority (87.1 percent) of the 116 positively identified samples was identified consistently from at least two different mitochondrial fragments, from the cytochrome b gene and the D-loop region respectively (Yang et al. 2004). Fifteen vertebrae were successfully identified from only one DNA fragment, which could be attributed to poor DNA preservation, since in most cases these results were from a shorter fragment (Yang et al. 2004). The overall high DNA extraction success rate of 95.1 percent for all the samples examined (122 in total) confirms that the Pacific Northwest region of North America provides very favorable conditions for DNA preservation in ancient faunal remains (see also Speller et al. 2005).

Contamination between samples and between ancient and modern DNA was prevented through use of the strictest possible contamination prevention protocols (Yang et al. 2004). Following publication of the initial results of DNA extraction from archaeological samples of salmon bone (Yang et al. 2004), the efficiency of aDNA extraction was optimized to such a degree that an adequate amount of DNA could be obtained from just one half of a single vertebra. This enabled repetition of the analysis, and a further check on the accuracy of the results. We applied this test to approximately 10 percent of the positively identified samples, and identical DNA sequences were reproduced in all cases. Analysis also followed a blind test system in which the DNA analyst (Yang) was unaware of the provenance of the samples as they were submitted for analysis. This prevented any possibility of unconscious bias based on expectations of particular patterns in the results.

The remaining issue is whether the samples selected for analysis are representative of the fishery as represented by the overall assemblage. Although 116 samples is very large by the standards of most aDNA studies, it is still a very small number relative to the more than 200,000 salmon ver-

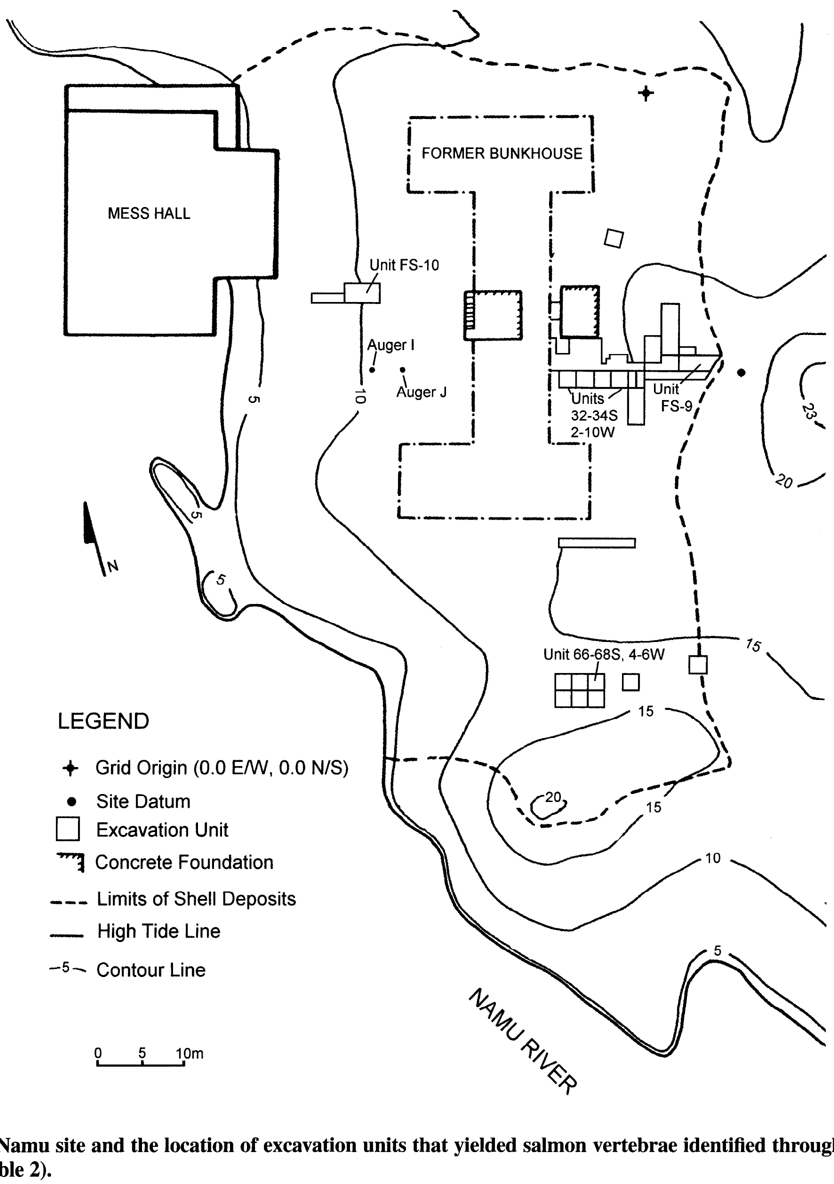

Figure 2. Namu site and the location of excavation units that yielded salmon vertebrae identified through aDNA analysis (see Table 2).

tebrae recovered in the last three seasons of excavation at the site. The possibility that vertebrae in some cases represent multiple elements from the same fish must also be addressed. For these reasons we provide extensive discussion of sampling procedures to support our contention that the results presented in Table 1 accurately represent the nature of the salmon fishery over the course of seven millennia.

Sampling

A map of the Namu site (Figure 2) shows the location of units excavated over the course of six seasons, first in 1968–1970 by the University of Colorado, under the direction of James J. Hester (Hester and Nelson 1978), and then in 1977–1978, and in 1994 by Simon Fraser University, under the direction of Roy L. Carlson (1979, 1991, 1996). The map also shows the location of auger samples collected by Cannon in 1994 (Cannon 2000a). Samples selected for aDNA analysis were obtained from one of the units excavated in the Rivermouth Trench in 1994, four units from the Central Main Trench excavated in 1977, a unit from each of the

Front and Rear Trenches excavated in 1970, and two of the auger sampling locations in the vicinity of the Front Trench. This range of excavation units allowed us to obtain comparable-size samples from securely dated contexts representing the full span of the last 7,000 years.

Table 2 lists the specific sampled contexts, along with associated radiocarbon dates, the number of recovered vertebrae from which the sample was drawn, the mode of sample selection, and the results of aDNA analysis. Given the large number of vertebrae recovered from most contexts and the wide range of contexts from which samples were drawn, we do not expect that the possibility of drawing multiple samples from the same individual fish would have had a marked biasing effect on our results. The mode of sample selection, involving a combination of deliberate selection for particular size or size range and random sampling does potentially influence our results and for that reason requires further discussion.

Our sampling strategy developed over the years as the project and its goals developed. Our initial concern was to determine whether aDNA sequences of sufficient length for species identification were preserved within archaeological samples of vertebrae. Accordingly, we selected a sample of the larger and most recent vertebrae then available at McMaster University. These were among fauna from the upper levels of the units excavated by Simon Fraser University in 1994. We presumed that the best chance for aDNA preservation was in more recent samples and further reasoned that extraction of sufficient aDNA was more likely with larger vertebrae. Based on our initial success we expanded our sampling to include older specimens and a wider range of sizes. At this stage we began to draw samples from a random split of the vertebrae recovered from each context. The vertebra assemblages were divided with a soil sample splitter to yield a number close or equal to the sample size we were looking to examine. We chose to look at a range of vertebra sizes within the split samples in order to maximize the potential range of species represented. Our goal was to determine the species range of the fishery. With our success in identifying a variety of species from deposits containing the earliest preserved faunal remains we set about to obtain more representative samples from the widest range of temporal contexts. The expense of aDNA analysis precluded our examination of samples of sufficient size to be statistically representative. Instead, we opted for randomly selected samples of small size from a greater range of spatial and temporal contexts.

In the end, our samples are potentially unrepresentative due to the small number of vertebrae selected from any given context and because in some cases we deliberately selected samples representing the widest range of vertebra sizes. The nonrandom selection of some samples may not be a significant biasing factor. The figures in Table 3 show that the overall results for the randomly and nonrandomly selected samples are similar. The decision to select for a range of vertebra sizes in some cases did result in an exaggerated representation of the largest and smallest vertebrae, but, as discussed below, this likely did not greatly skew the species representation.

We believe the consistency of species representation between individual contexts is the strongest indicator that our results are generally representative. Even samples consisting of as few as four vertebrae consistently show an emphasis on pink salmon. There are no grossly anomalous results for any context. Our observation of an anomalous lack of pink salmon in deposits dating to Period 5 (2000 cal B.C.–cal A.D. 1) was also consistent for multiple contexts dating to that period and to the early part of Period 6 (cal A.D.1–European Contact). Initially we thought this result might be due to our early emphasis on larger vertebrae from the first context we sampled (Unit 66-68S, 4-6W; 70-80 cm DBS), which dated to this time period. To compensate and to determine whether the low number of pink salmon was simply a sampling effect, we resampled from the same context with a deliberate emphasis on smaller vertebrae within the split sample. The results yielded a disproportionate number of sockeye, along with a few pink, but they verified that the low number of pink salmon was not a function of initially selecting larger vertebrae from this particular context.

The range of directly or indirectly associated radiocarbon dates shows that the identified samples cover a wide range of securely dated contexts. We think this lends further credence to our interpretation that the results are representative of the span of the last 7,000 years of site occupation. The consistency of our results across this range of dated

Table 2. Sample Selection Criteria and Results by Excavation Context.

Period	Excavation Unit; Depth (cm dbs)	Associated ^{14}C Dates	Unit Total	Sample Selection Criteria	Pink	Chum	Sockeye	Coho	Chinook	Failure
6	Auger I-2; 43-69	<980±100 (cal AD 830-1270)	1	all	0	0	1	0	0	0
	Auger I-4; 89-114	<980±100 (cal AD 830-1270)	1	all	1	0	0	0	0	0
	Auger I-10; 203-216	<980±100 (cal AD 830-1270)	2	all	2	0	0	0	0	0
	Auger J-6; 107-125	<980±100 (cal AD 830-1270)	1	all	0	0	1	0	0	0
	Auger J-19; 324-342		1	all	0	0	1	0	0	0
	FS 10.2	<480±80 (cal AD 1300-1640)	420	4 random	2	0	1	1	0	0
	FS 10.6	680±90 - 480±80 (cal AD 1180-1640)	739	random split to 8, 4 selected for size range	2	1	1	0	0	0
	FS 10.9	980±100 - 680±90 (cal AD 830-1430)	364	random split to 20, 4 selected for size range	2	1	1	0	0	0
	FS 10.12-15	1470±80 (cal AD 410-690)	178	4 random	1	2	0	1	0	0
	FS 9.1	1880±90 (cal BC 90 - AD 380)	1189	3 random, 1 very large added	1	1	1	0	1	0
5	66-68S,4-6W; 50-60	2170±40 (cal BC 370-100)[b]	73	3 random, 1 smallest added	1	1	2	0	0	0
	66-68S,4-6W; 70-80		593	4 selected for large size	0	3	1	0	0	0
	66-68S,4-6W; 70-80		593	4 selected for size range	0	2	2	0	0	0
	66-68S,4-6W; 70-80		593	4 selected for size range	0	2	2	0	0	0
	66-68S,4-6W; 70-80		593	random split to 34, three small selected	1	0	2	0	0	0
	66-68S,4-6W; 70-80		593	selection of 5 small	2	0	3	0	0	0
	66-68S,4-6W; 90-100		283	3 random	1	1	1	0	0	0
	66-68S,4-6W; 110-120	2990±40 (cal BC 1380-1100)[d]	394	4 selected for size range	0	2	2	0	0	0
4	66-68S,4-6W; 140-150		1635	random split to 6, 4 selected for size range	2	1	1	0	0	0
	66-68S,4-6W; 170-180		4445	4 selected for size range	2	1	0	1	0	0
	66-68S,4-6W; 200-210		2386	6 random	2	2	2	0	0	0
	66-68S,4-6W; 250-260	3690±40 (cal BC 2200-1950)[c]	775	6 random	3	2	1	0	0	0
3	66-68S,4-6W; 260-270		829	3 random, 1 large added	2	1	1	0	0	0
	32-34S,2-4W; 140-150	4775±130 - 4300±125 (cal BC 3940-2580)	369	random split to 6, 4 selected for size range	4	0	0	0	0	0
	32-34S,5-6W; 220-230	4700±125 - 4290±120 (cal BC 3750-2580)	22	random split to 5, 4 selected for size range	2	0	0	0	0	2
	32-34S,6-8W; 190-200	<4680±160 (cal BC 3770-2930)	119	3 random, 1 large and 1 medium added	3	1	1	0	0	0
	32-34S,8-10W; 260-270	ca. 4540±140 (cal BC 3630-2910)	46	random split to 5, all 3 caudal selected	2	0	0	0	0	1
2	66-68S,4-6W; 280-290	ca. 5170±90 (cal BC 4240-3770)	449	random split to 10, 4 selected for size range	2	2	0	0	0	0
	32-34S,2-4W; 180-190	5400±50 (cal BC 4145-4090)[a]	442	random split to 8, 5 selected for size range	1	0	1	0	0	3
	66-68S,4-6W; 320-330		371	4 selected for size range	2	0	1	1	0	0
	66-68S,4-6W; 330-340		270	4 random	2	1	1	0	0	0
	66-68S,4-6W; 340-350	5810±40 (cal BC 4740-4550)[e]	318	4 random	2	1	0	1	0	0
	66-68S,4-6W; 340-350	5810±40 (cal BC 4740-4550)[e]	318	4 random	2	1	1	0	0	0
				Totals =	49	29	32	5	1	

Notes: Radiocarbon dates are directly associated with the sampled context or are from higher and lower deposits in the same or adjacent excavation units. See Carlson (1991, 1996) for summary description and discussion of radiocarbon dates.
[a]see Cannon et al. (1999);
[b]Beta-200612, deer bone, $^{13}C/^{12}C$ -25.41.
[c]Beta-200610, deer bone, $^{13}C/^{12}C$ -25.11.
[d]Beta-203089, deer bone, $^{13}C/^{12}C$ -23.91.
[e]Beta-200611, deer bone, $^{13}C/^{12}C$ -24.91.
All dates calibrated with Calib 5.0.

Table 3. Comparison of Salmon Species Identifications Based on Randomly and Non-Randomly Selected Vertebrae.

	Pink		Chum		Sockeye		Coho		Chinook	
Period	ran	non	ran	non	ran	non	ran	non	ran	non
P6 (AD 1 - Contact)	7	4	3	2	5	2	2	0	0	1
P5 (2000 BC - AD 1)	2	3	2	9	2	13	0	0	0	0
P4 (3000 - 2000 BC)	5	4	4	2	3	1	0	1	0	0
P3 (4000 - 3000 BC)	7	6	0	2	1	1	0	0	0	0
P2 (5000 - 4000 BC)	6	5	3	2	2	2	1	1	0	0
Site total	27	22	12	17	13	19	3	2	0	1
Percentage	49.1	36.1	21.8	27.9	23.6	31.1	5.5	3.3	0.0	1.6

contexts suggests they are not the product of a small number of unrepresentative deposition events. Although we acknowledge that our sampling strategy is far from ideal, we feel we have followed every available means for ensuring the samples are unbiased without incurring the impractical expense of time and money needed to analyze truly representative samples of vertebrae from all available contexts.

We must also acknowledge that archaeologically recovered vertebrae may be biased from the outset as the result of differential processing and deposition of species. Unfortunately little can be done to control for such unknown factors. The presence of remains from all available species suggests that processing and deposition factors were probably not a significant source of bias. One possibility that might contribute to biased representation, especially the emphasis on pink salmon, is that recovered vertebrae represent discarded stores that had either spoiled or were in excess of winter needs and therefore thrown out when fresh food became available in the spring. This possibility cannot be assessed based on the available evidence, and might not be evident in any case, but it would provide further support for the contention that the emphasis on pink salmon is due to harvest and processing for storage rather than for immediate consumption.

Metric Analysis

One further check on the representativeness of the sample comes from the metric data, specifically the width of vertebrae, which was obtained for most samples prior to analysis. These results show a slight bias toward larger and smaller vertebrae, but support the pattern of species representation indicated by the identifications. They also point to another possible way to infer species from larger samples without the need for an impractical scale of aDNA analysis.

Following Cannon's earlier studies (1988, 1991), which showed wide variation in the sizes of vertebrae and some correlation to differences in inferred age classes and potential species represented, we recorded the transverse diameter of vertebrae before their destruction for analysis. The results for the aDNA identified samples are shown in Figure 3a. Figure 3b shows the results of similar measurements of statistically representative samples of vertebrae from all excavation contexts in the 3.5 m depth of deposits in unit 68-70S, 4-6W of the Rivermouth trench, which was excavated in 1978 (Cannon 1991). Comparison shows the aDNA samples are very close to the size range and profile of the much larger combined number from statistically representative samples, with the exception, as noted, of some exaggeration in the number of very large and very small vertebrae.

The exaggerated emphasis on large and small vertebrae probably does not greatly bias the species representation in our results. With the exception of the one chinook vertebra, which measured 18.0 mm in diameter, all the aDNA identified vertebrae measuring 10.5 mm in diameter or greater were identified as chum. All the vertebrae measuring 8.0 mm in diameter or less were either pink or sockeye. The full range of species other than chinook was represented between 8.0 and 10.5 mm. Among the representative sample of vertebra measurements, 854 or 45.5 percent were $\leq$8.0 mm and 280 or 14.9 percent were $\geq$10.5 mm. Among the measured aDNA analyzed samples, 51 or 47.7 percent were $\leq$ 8.0 mm and 17 or 15.9 percent were $\geq$ 10.5 mm. Our identifications may therefore show a very slight exaggeration in the number of chum, pink, and sockeye, but given the closeness of the size range of the aDNA sample to that of the representative sample, we think any bias is likely to be very slight and probably offset to a great degree by the

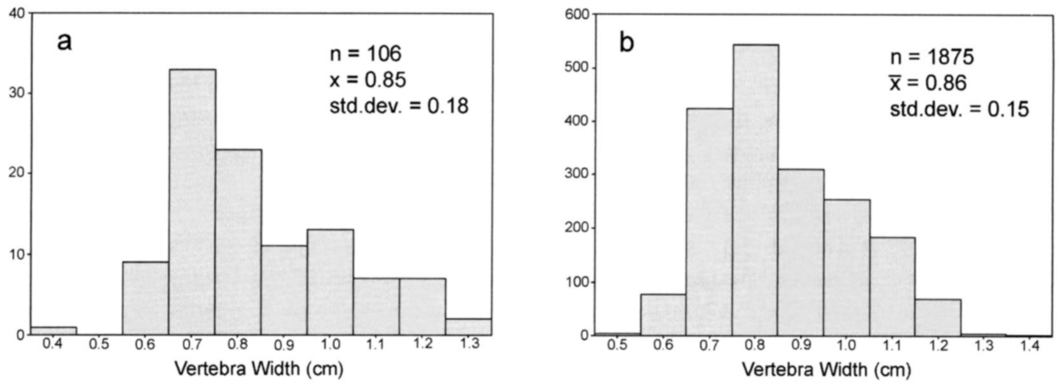

Figure 3. Transverse diameters of salmon vertebrae for: (a) aDNA identified samples, and (b) the combined statistically representative samples drawn from each vertical excavation context in Unit 68-70S, 4-6W.

fact that there is a bias toward both larger and smaller specimens.

Implications

If, as we contend, the aDNA results are an accurate representation of the range and relative proportions of species comprising the Namu salmon fishery, then they minimally indicate a multispecies fishery with an overwhelming emphasis on pink salmon, a strong but lesser emphasis on sockeye and chum, much less focus on coho, and just the presence of chinook. They also show that these patterns are consistent over time, with the exception of an anomalous decline in the representation of pink salmon, beginning sometime after 2000 cal B.C. and possibly ending by about cal A.D. 1000. We think the implications of these results are also more far-reaching with respect to resource selection criteria, the likelihood of sedentary settlement and storage throughout the past 7,000 years, and the cause of disruption in the fishery and local and regional settlement after ca. 2000 cal B.C.

Resource Selection

We were initially somewhat surprised by the strong emphasis on pink salmon. In part this was due to false expectations created by the problematic interpretation of radiographic analyses. We had also expected greater selection of species possessing what might reasonably be considered superior qualities. We expected an emphasis on chum because of their larger body size and low fat content, which makes them superior candidates for preservation, and on sockeye and coho because of their higher fat content, which makes them a richer source of food for fresh consumption. Pink salmon have very low fat content, which makes them well suited for preservation, but they are generally smaller than other species.

Romanoff (1985) provides an overview of Pacific Northwest ethnographic information that describes the selection of low-fat salmon for their superior preservation qualities. Fish with higher fat content were more likely to become rancid or moldy if preserved. If the aim of the Namu fishery was primarily to acquire fish for preservation, then the focus on leaner pink and chum salmon would make most sense. The greater emphasis on pink rather than chum, which is most often described ethnographically as the species of choice for preservation, and which might be expected to be the optimal choice on the basis of size, is less easy to explain. It is possible that the relative proportions of these species was more a function of their availability, or it could be that the smaller pink salmon required less processing for storage than the larger chum.

A fishery focused primarily on harvest for fresh consumption might have selected sockeye or coho over pink and chum, since relative fat content is such an important indicator of food preference among hunter-fisher-gatherers worldwide (Speth and Spielmann 1983). The presence of pink, chum, and sockeye in such large relative proportions suggests either that fresh consumption and processing for long-term storage were both important elements of the fishery or that the fishery was more opportunistic, with nutrition and preservation qualities playing little if any role in species selection.

If the deciding criterion for resource selection was not a combination of the richness and size of the individual species, but instead was their relative abundance, then the emphasis on pink salmon is much more easily explained. By current counts pink salmon are overwhelmingly more abundant than other species in the central coast region (Fisheries and Oceans Canada 2001). Chum is currently the second-most common species in the small streams and rivers of the central coast, followed by sockeye and coho in roughly equal numbers. Chinook do not generally spawn in the small streams in the region. Escapement records show considerable variability in the numbers of different species between streams and over time, but based on regional averages the apparent emphasis on pink salmon might be expected on the basis of their greater availability.

An opportunistic fishing strategy would require that people harvest whatever fish were available in numbers proportional to their availability. Based on ethnographic information from hunter-fisher-gatherers worldwide and from the Pacific Northwest Coast in particular, this possibility would seem unlikely. We can say very little about the fishing methods used in any particular period. There is a large stone-walled fish trap at the mouth of the Namu River (Carlson and Dalla Bona 1996:110), but the date of its construction is unknown. It is likely that a variety of methods were used to harvest salmon over the past 7,000 years. Most if not all would have provided ample opportunity to exercise species selection, as for example in the choice to keep or return individual fish caught within traps or in the timing of fishing on the river to coincide with the time that particular species ascended the river to spawn. The simplest explanation for the diversity of the salmon fishery is that it represents deliberate selection of a range of available species for their richness (sockeye) and preservation qualities (pink and chum). The further implication is that the variable focus on different species for different purposes extended over the longer term of the fishing season, as the availability of particular species waxed and waned.

Sedentism and Storage

The seasonal timing of the Namu salmon fishery is difficult to define with any precision since depending on the fishing methods used different species might be available for harvest over a long period of time. Most species spend time in the bays and estuaries adjacent to spawning streams before they actually ascend the stream to spawn. A fishery focused on the fish gathered in the estuary could have access to a range of species, either during a relatively short period in late summer or over much of the summer and early autumn. A focus on the harvest of fish as they ascended the river to spawn would be restricted to much narrower time frames. These times would be specific for each species and would extend from late summer well into the autumn.

Sockeye generally arrive earliest in the area of the central coast, schooling in the bays and estuaries of coastal streams beginning in June. They typically ascend rivers to spawn in tributary systems draining into freshwater lakes by late July or early August (Pomeroy 1980:207). Pink and chum are the next to arrive in the region. The peak arrival of pink is around late July and early August (Aro and Shepard 1967:282); chum arrive slightly later in August (Salo 1991:237). Both species can spend considerable time in bays and estuary environments prior to spawning (Hunter 1959:844). Most also spawn in the lower intertidal reaches of coastal streams. Pink typically spawn in August and September, while chum spawning takes place mainly in September (Aro and Shepard 1967:259, 282). Coho are the latest species to spawn on the central coast, with peak spawning taking place in October (Aro and Shepard 1967:289). A wide range of environmental variables can affect the specific timing of spawning runs (Heard 1991:136). Based on the time of arrival in bays and estuaries and the ascent of spawning streams, it is conceivable that all four species could be available in the vicinity of the Namu site within a relatively narrow time period in early August. Based on the times of peak availability and the enhanced opportunity to harvest species as they ascended or gathered to ascend the Namu River, a fishery focused on pink, chum, and sockeye is more likely to have extended from July through September.

If fishing was focused on the harvest of species from the estuary environment, it might well be possible that the fishery was the product of a short-term aggregation. If the purpose of such an aggregation was primarily for the harvest and consumption of fresh fish, then the indiscriminate harvest of large quantities of pink and chum salmon, along with the richer and therefore more desirable sockeye is more difficult to explain. A series of selective fisheries in the bay and estuary environment combined with selective harvest of species as they ascended the Namu River to spawn entails much longer residency, from July through to October. If the purpose in selecting pink and chum salmon in such large numbers was to process them for storage, then the implication is that a sizeable portion of the population continued to reside at the site through the winter, up to and including the time of the peak herring fishery in March. The presence of neo-natal harbor seal shows that some people were also at the site around mid June.

Based on the new level of precision in our knowledge of the Namu salmon fishery, there are two options to account for the available data. One is to propose a short-term species-indiscriminate fresh food fishery at the site sometime in mid-to-late summer, with the aggregate population then dispersing to other locations before returning in the late winter/early spring for the herring fishery. The other is to propose a selective fishery using different methods to harvest different species at different times for different purposes. This would have entailed harvest of richer, fatter species such as sockeye in the summer, largely for fresh consumption, coupled with later harvest of pink and chum salmon in even greater numbers for the purpose of processing and preservation to sustain a resident population through the winter. Strictly on the basis of seasonal availability and without information concerning the fishing methods used, either possibility is equally likely. Based on the seasonal and environmental circumstances involved and on our knowledge of hunter-fisher-gatherer decision making in general and that of the ethnographically described peoples of the Pacific Northwest Coast in particular, we think the latter proposition is far more likely.

The results of the aDNA analysis give us new insight into the nature of the Namu fishery that we think strengthens the argument in favor of early storage and sedentary settlement, but seasonal indicators alone can never establish continuous presence at a site with any certainty. Nor can the abundance of any one resource, even one as well suited to the purpose as pink salmon, indicate storage. Beyond its value in providing more precise evidence consistent with storage and sedentism, we think the greater weight of the aDNA evidence derives from the consistency of the species profile over the past 7,000 years. The salmon fishery is essentially the same in all time periods.

If the combined weight of evidence is insufficient to demonstrate a storage-based economy and permanent village settlement as early as 7,000 years ago, then it is also insufficient to demonstrate similar patterns at any time after that date. We think few Northwest Coast archaeologists would seriously argue that salmon storage and multiseason village settlement were absent anywhere on the coast as recently as 1,000 years ago. Given that the evidence looks the same for 7,000 years ago as it does for 6,000 years later, we see no basis for inferring anything other than this type of subsistence-settlement system as early as the earliest faunal evidence at Namu. The same pattern may extend even further back in time, but few sites of earlier date, including Namu, show any substantial evidence of subsistence or settlement.

Disruption in the Salmon Fishery

Analysis of faunal remains recovered in the 1977 and 1978 excavations showed a clear decline in the relative abundance of salmon in the periods following 2000 cal B.C. (Cannon 1991). Salmon remains from auger samples confirmed this pattern and suggested it might be even more pronounced (Cannon 2000a). More intensive use of a variety of alternative resources, some relatively marginal in nature, to compensate for the shortfall supports the interpretation of later periodic disruption in the salmon fishery (Cannon 1995, 2000b; Cannon et al. 1999; Zita 1997). The cause of the decline is still unknown, though Cannon (1991:39) had speculated that siltation of the productive spawning beds in the lower reaches of the Namu River might be responsible. Radiocarbon dating has shown that occupation in the vicinity of the Rivermouth Trench ended during this time, suggesting a reduction in the size of the settlement. Testing and dating of other sites in the area show nearby villages were established around the same time. Cannon (2002) has suggested that these local and regional developments are linked to disruptions in the Namu fishery, which might have encouraged some families to resettle at alternative village locations.

With the results of the aDNA analysis we can now attribute that disruption and any subsequent local and regional effects specifically to failures in the pink fishery. Our results point to a decline in pink salmon, which is evident in all of the sampled contexts dating to Period 5 and in those from Period 6 that predate cal A.D. 1000. Pink salmon is either absent or is less than or equal to the abundance of other species in all ten samples from six separate excavation contexts dating to between 1380 cal B.C. and cal A.D. 830 (Table 2). It makes up only 17.9 percent of the 39 identified salmon vertebrae from these contexts. In contrast, pink is the most abundant species in 17 of the 23 separate samples from 22 excavation contexts dating to before or after this period. It makes up 54.5 percent of the 77 identified vertebrae from these contexts. The fish remains from the Front Trench (FS 10) excavated by the University of Colorado in 1970 have not previously been reported, but our aDNA analysis shows apparent recovery in the pink salmon fishery after cal A.D. 1000, and a return to previous levels up until the time of European contact. Deposits dating to the past 1,000 years were not present in the areas excavated by Simon Fraser University in 1977 and 1978, but recently identified fish remains from unit FS 10 (Table 4) show that the intensity of the overall salmon fishery also apparently recovered after cal A.D. 1000.

Table 4. Abundance of Salmon Remains by Stratum in Front Trench Unit FS-10.

Stratum	Associated ^{14}C dates	Salmon Abundance NISP	% of fish
FS 10.1		945	70.8
FS 10.2		724	74.2
FS 10.3		NO DATA	
FS 10.4	480±80	696	92.8
FS 10.5		487	96.4
FS 10.6		742	96.4
FS 10.7		1664	97.7
FS 10.8	680±90	NO DATA	
FS 10.9		374	73.6
FS 10.10		262	85.6
FS 10.11	980±100, 1840±80	1652	56.5
FS 10.12	1470±80	181	86.6
FS 10.13		1460	81.5
FS 10.14		262	85.8
FS 10.15		84	87.5

At this stage we do not know the cause or causes of disruptions in the pink salmon fishery or the reasons for its later apparent recovery. A new approach, which is now feasible, will be to determine whether there was a dramatic change in the genetic profile of the pink salmon population before and after the period of disruption. A clear change will indicate a catastrophic pattern of population extinction and recolonization. In contrast, a strong indication of genetic continuity in the local population would suggest a lesser degree of depression on pink salmon productivity over this period of time.

The significance of tying disruption of the Namu fishery specifically to pink salmon is that it suggests an even greater potential impact on the lives of residents at the site, since this was likely to have been a storage staple that was critical for survival through the winter. If failure of this staple resource was, as is likely, also unpredictable, it might have been difficult if not impossible to compensate through increased emphasis on other species or on salmon obtained from other locations. The need to resort to more marginal foods, such as ratfish, at such times would have been that much greater (Cannon 1995). The further implication is that it is unlikely that periodic failure of the pink fishery was due to increasing siltation of the Namu River estuary over the long term. Since chum and pink salmon favor the same types of spawning ground, both species should have been equally affected by permanent environmental change. It is also less likely that the pink fishery would have recovered if this had been the cause of its decline or periodic failure. We cannot yet explain the disruption in the pink fishery, but whatever the cause, our aDNA identifications suggest we can at least narrow it to factors specifically related to this one species.

Discussion

The influence of preconceptions and prevailing frameworks on archaeological interpretation is well documented (Trigger 1989). We cannot say for certain that reluctance to accept evidence for early salmon storage and sedentism is due to a consensus among Northwest Coast archaeologists that these developments are fundamental thresholds in the long-term evolution of the region's cultures, but this would not be unprecedented. We can point to one example where a prevailing view affected the primary interpretation of faunal data and its subsequent use by other researchers.

In his original interpretation of the Namu faunal data, Cannon (1991:43) noted that "the scale of salmon fishing increased dramatically" between Period 2 (5000–4000 cal B.C.) and Period 3 (4000–3000 cal B.C.). This interpretation was based on observation of an increase in the proportion of salmon among identified fish remains other than herring, from 89 percent in Period 2 to 98 percent in Periods 3 and 4. By any measure, a fishery with an 89 percent focus is still one largely dependent on salmon fishing. There was no basis for Cannon's exaggeration other than the influence of an accepted model of long-term cultural development, proposed by Fladmark (1975), which argued that early dependence on salmon coincided with increased productivity due to postglacial environmental stabilization at around 4000 cal B.C. Although this model as developed for major inland river systems was less applicable to small coastal streams and lake systems (Cannon 1996), its one-time widespread acceptance as a model for the entire Northwest Coast affected the interpretation of empirical observations that should have emphasized much earlier dependence on salmon. Cannon's exaggeration and its basis have subsequently been reiterated by other researchers (Ames and Maschner 1999:137; Coupland 1998:43; Matson and Coupland 1995:140).

Northwest Coast archaeologists are increasingly aware of greater variation in the history of culture change in the region, with recognition that storage, sedentary settlement, and social differentiation may not be as closely linked as once thought and may have developed at different times in different places on the coast (Ames and Maschner 1999; Matson 2003; Matson and Coupland 1995). The likelihood that these were not aspects of linear evolution, but were rather historical developments that may have come and gone repeatedly through time is increasingly embraced (Ames 2003; Moss and Erlandson 1995; Prentiss and Chatters 2003a, 2003b). Despite this more sophisticated view of the region's archaeological history, the consensus remains that variability in the timing of these developments is largely confined to the past 3,500 years. Even those researchers willing to accept the possibility of a fully developed salmon-storage economy and sedentary settlement at Namu as early as 5000 cal B.C. see it more as an exceptional case in the overall history of the region (e.g., Ames 2003:24; Prentiss and Chatters 2003b:38).

Given a consensus of opinion, it seems fair to demand a higher standard of evidence for anything that stands apart from prevailing points of view. As in any area of research this should be an incentive to improve the number and quality of lines of evidence in support of contrary opinion. We think we have done this. The aDNA evidence is one more piece in a long line of ancillary evidence that supports Cannon's original interpretations regarding the early pattern and subsequent history of subsistence and settlement at Namu. We think the evidence is also sufficient to support decoupling the advent of permanent multiseasonal settlements and storage-based economies from population growth and greater social differentiation, as others have also suggested (e.g., Moss and Erlandson 1995:34). There is no evidence for large-scale population growth at Namu or anywhere on the Northwest Coast in the millennia immediately following 5000 cal B.C., when salmon storage and sedentism are first evident. The earliest indication of significant population expansion in the Namu vicinity is at around 1000–500 cal B.C. (Cannon 2002). The evidence for social differentiation on the coast is more equivocal, and may be much later, depending on the definition used.

Even if our view of the Namu salmon fishery and its implications is widely accepted, it is currently impossible to say how widespread this pattern might have been. All current views of long-term cultural developments on the coast, whether based on traditional cultural evolutionary frameworks or more recent Darwinian perspectives, must rely on few data from a very few sites dispersed over a broad area. New consensus concerning long-term patterns and developmental trends may emerge over time, but these will need to be based on more thorough analysis and on more extensive multisite investigations. Namu is exceptional for the length of its occupational record and for the detail of the evidence it has yielded, but it is too soon to say if it is exceptional for its early mode of permanent settlement and storage-based salmon fishing economy.

Conclusions

We have demonstrated a more extensive application of aDNA analysis of faunal remains than has so far been generally attempted in archaeology. We think this research is also unusual among emerging aDNA applications in its focus on the resolution of a particular existing problem in archaeological knowledge and interpretation. Our results provide a new level of precision in our ability to characterize an early salmon fishery on the Northwest Coast. They show consistent emphasis in the Namu fishery on pink salmon, as well as strong emphasis on sockeye and chum together with at least some harvest of coho and chinook.

We think this new information provides further support of the interpretation that the site was the focus of permanent multiseason settlement and a storage economy by at least 5000 cal B.C. A fully developed settlement-subsistence pattern of this kind at this early date should alert researchers to the need to rethink explanatory frameworks that strongly link population growth and social complexity with sedentism and storage-based economies. We have shown that aDNA insight into the composition of salmon fisheries and their variability over time can also help us to understand better the implications of resource fluctuations for populations dependent on storage for winter subsistence.

We see great potential for gaining further understanding of the diversity and temporal variability in salmon fisheries throughout the coast and over time. Insight into the key role of salmon in the archaeological histories of the Pacific Northwest Coast can be derived from much wider application of aDNA analysis. Much could be done with the vertebrate fauna collections already available in the storerooms of museums, universities, and archaeological consulting firms. Although ancient DNA analysis is and will remain an expensive undertaking, on a large-scale, strategic sampling designed to provide data relevant to specific problems, possibly coupled with inferences from vertebra size, can yield more precise knowledge and better understanding of the history and implications of salmon fishing on the Northwest Coast.

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References Cited

Ames, Kenneth M.
1994 The Northwest Coast: Complex Hunter-Gatherers, Ecology, and Social Evolution. *Annual Review of Anthropology* 23:209–229.
1996 Life in the Big House: Household Labor and Dwelling Size on the Northwest Coast. In *People Who Lived in Big Houses: Archaeological Perspectives on Large Domestic Structures*, edited by Gary Coupland and E. B. Banning, pp. 131–150. Monographs in World Archaeology No. 27. Prehistory Press, Madison, Wisconsin.
1998 Economic Prehistory of the Northern British Columbia Coast. *Arctic Anthropology* 35:68–87.
2003 The Northwest Coast. *Evolutionary Anthropology* 12:19–33.

Ames, Kenneth M., and Herbert D.G. Maschner
1999 *Peoples of the Northwest Coast: Their Archaeology and Prehistory*. Thames and Hudson, London.

Arnold, Jeanne E.
1996 The Archaeology of Complex Hunter-Gatherers. *Journal of Archaeological Method and Theory* 3:77–126.

Aro, K. V., and M. P. Shepard
1967 Pacific Salmon in Canada, Salmon of the North Pacific Ocean Part IV. *International North Pacific Fisheries Commission Bulletin* 23:225–327.

Bilton, H. T., and W. E. Ricker
1965 Supplementary Checks on the Scales of Pink Salmon (*Oncorhynchus gorbuscha*) and Chum Salmon (*O. keta*). *Journal of the Fisheries Research Board of Canada* 22:1477–1489.

Calvert, Gay
1970 The St. Mungo Cannery Site: A Preliminary Report. *BC Studies* 6–7:54–76.

Cannon, Aubrey
1988 Radiographic Age Determination of Pacific Salmon: Species and Seasonal Inferences. *Journal of Field Archaeology* 15:103–108.
1991 *The Economic Prehistory of Namu: Patterns in Vertebrate Fauna*. Department of Archaeology, Simon Fraser University, Publication 19. Burnaby, British Columbia.
1995 The Ratfish and Marine Resource Deficiencies on the Northwest Coast. *Canadian Journal of Archaeology* 19:49–60.
1996 Scales of Variability in Northwest Salmon Fishing. In *Prehistoric Hunter-Gatherer Fishing Strategies*, edited by Mark G. Plew, pp. 25–40. Boise State University Monograph Series. Boise, Idaho.
1998 Contingency and Agency in the Growth of Northwest Coast Maritime Economies. *Arctic Anthropology* 35:57–67.
2000a Assessing Variability in Northwest Coast Salmon and Herring Fisheries: Bucket-Auger Sampling of Shell Midden Sites on the Central Coast of British Columbia. *Journal of Archaeological Science* 27:725–737.
2000b Faunal Remains as Economic Indicators on the Pacific Northwest Coast. In *Animal Bones, Human Societies*, edited by Peter Rowley-Conwy, pp. 49–57. Oxbow, Oxford.
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. Craig Gerlach and Maribeth S. Murray, pp. 178–187. BAR International Series S944. British Archaeological Reports, Oxford.
2002 Sacred Power and Seasonal Settlement on the Central Northwest Coast. In *Beyond Foraging and Collecting:*

Evolutionary Change in Hunter-Gatherer Settlement Systems, edited by Ben Fitzhugh and Junko Habu, pp. 311–338. Kluwer Academic-Plenum, New York.

Cannon, Aubrey, Henry P. Schwarcz, and Martin Knyf
1999 Marine-based Subsistence Trends and the Stable Isotope Analysis of Dog Bones from Namu, British Columbia. *Journal of Archaeological Science* 26:399–407.

Carlson, Roy L.
1979 The Early Period on the Central Coast of British Columbia. *Canadian Journal of Archaeology* 3:211–228.
1991 Appendix B: Namu Periodization and C-14 Chronology. In *The Economic Prehistory of Namu: Patterns in Vertebrate Fauna*, by Aubrey Cannon, pp. 85–95. Department of Archaeology, Simon Fraser University, Publication 19. Burnaby, British Columbia.
1996 Early Namu. In *Early Human Occupation in British Columbia*, edited by Roy L. Carlson and Luke Dalla Bona, pp. 83–102. University of British Columbia Press, Vancouver.

Carlson, Roy L., and Luke Dalla Bona (editors)
1996 *Early Human Occupation in British Columbia*. University of British Columbia Press, Vancouver.

Coupland, Gary
1998 Maritime Adaptation and Evolution of the Developed Northwest Coast Pattern on the Central Northwest Coast. *Arctic Anthropology* 35:36–56.

Croes, Dale R., and Steven Hackenberger
1988 Hoko River Archaeological Complex: Modeling Prehistoric Northwest Coast Economic Evolution. In *Prehistoric Economies of the Pacific Northwest Coast*, edited by Barry L. Isaac, pp. 19–85. Research in Economic Anthropology, Supplement 3. JAI Press, Greenwich, Connecticut.

Eldridge, Morley, and Steven Acheson
1992 The Antiquity of Fish Weirs on the Southern Coast: A Response to Moss, Erlandson and Stuckenrath. *Canadian Journal of Archaeology* 16:112–116.

Fisheries and Oceans Canada
2001 Statistical Areas—North Coast. Electronic document, http://www.pac.dfo-mpo.gc.ca/northcoast/Areas/Area8/, accessed November 29, 2005.

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

Ham, Leonard C., Arlene J. Yip, Leila V. Kullar, and Debbie L. Cannon
1986 A Charles Culture Fishing Village: The 1982/83 Archaeological Excavations at the St. Mungo Site (DgRr-2), North Delta, British Columbia. Unpublished Report on File, Heritage Conservation Branch, Government of British Columbia, Victoria.

Heard, William R.
1991 Life History of Pink Salmon (*Oncorhynchus gorbuscha*). In *Pacific Salmon Life Histories*, edited by C. Groot and L. Margolis, pp. 121–230. University of British Columbia Press, Vancouver.

Hester, James J., and Sarah M. Nelson (editors)
1978 *Studies in Bella Bella Prehistory*. Simon Fraser University, Department of Archaeology, Publication 5. Burnaby, British Columbia.

Hoffman, Brian W., Jessica M. Z. Czederpiltz, and Megan A. Partlow
2000 Heads or Tails: The Zooarchaeology of Aleut Salmon Storage on Unimak Island, Alaska. *Journal of Archaeological Science* 27:699–708.

Hunter, J. G.
1959 Survival and Production of Pink and Chum Salmon in a Coastal Stream. *Journal of the Fisheries Research Board of Canada* 16:835–886.

Maschner, Herbert D. G., and John Q. Patton
1996 Kin Selection and the Origins of Hereditary Social Inequality: A Case Study from the Northern Northwest Coast. In *Darwinian Archaeologies*, edited by Herbert D.G. Maschner, pp. 89–107. Plenum Press, New York.

Matson, R. G.
1992 The Evolution of Northwest Coast Subsistence. In *Long-term Subsistence Change in Prehistoric North America*, Research in Economic Anthropology, Supplement 6, edited by Dale R. Croes, Rebecca A. Hawkins, and Barry L. Isaac, pp. 367–428. JAI Press, Greenwich, Connecticut.
2003 Introduction: The Northwest Coast in Perspective. In *Emerging from the Mist: Studies in Northwest Coast Culture History*, edited by R. G. Matson, Gary Coupland, and Quentin Mackie, pp. 1–11. University of British Columbia Press, Vancouver.

Matson, R. G., and Gary Coupland
1995 *The Prehistory of the Northwest Coast*. Academic Press, San Diego.

Maxwell, David
2003 Growth Coloration Revisited: Assessing Shell Fishing Seasonality in Coastal British Columbia. In *Archaeology of Coastal British Columbia: Essays in Honour of Professor Philip Hobler*, edited by Roy L. Carlson, pp. 175–188. Archaeology Press, Simon Fraser University. Burnaby, British Columbia.

Monks, Gregory G.
1981 Seasonality Studies. In *Advances in Archaeological Method and Theory*, Vol. 4, edited by Michael B. Schiffer, pp. 177–240. Academic Press, New York.

Moss, Madonna L., and Jon M. Erlandson
1995 Reflections on North American Pacific Coast Prehistory. *Journal of World Prehistory* 9:1–45.
1998 A Comparative Chronology of Northwest Coast Fishing Features. In *Hidden Dimensions: The Cultural Significance of Wetland Archaeology*, edited by Kathryn Bernick, pp. 180–198. University of British Columbia Press, Vancouver.

Moss, Madonna L., Jon M. Erlandson, and Robert Stuckenrath
1990 Wood Stake Weirs and Salmon Fishing on the Northwest Coast: Evidence from Southeast Alaska. *Canadian Journal of Archaeology* 14:143–158.

Pomeroy, John Anthony
1980 *Bella Bella Settlement and Subsistence*. Unpublished Ph.D. Dissertation, Department of Archaeology, Simon Fraser University, Burnaby, British Columbia.

Prentiss, William C., and James C. Chatters
2003a The Evolution of Collector Systems on the Pacific Coast of Northwest North America. In *Hunter-Gatherers of the North Pacific Rim*, edited by Junko Habu, James M. Savelle, Shuzo Koyama, and Hitomi Hongo, pp. 49–80. Senri Ethnological Studies No. 63. National Museum of Ethnology, Osaka.
2003b Cultural Diversification and Decimation in the Prehistoric Record. *Current Anthropology* 44:33–58.

Romanoff, Steven
1985 Fraser Lillooet Salmon Fishing. *Northwest Anthropological Research Notes* 19:119–160.

Rowley-Conwy, Peter
2001 Time, Change and the Archaeology of Hunter-Gatherers: How Original is the 'Original Affluent Society'? In *Hunter-Gatherers: An Interdisciplinary Perspective*, edited by Catherine Painter-Brick, Robert H. Layton, and

Peter Rowley-Conwy, pp. 39–72. Cambridge University Press, Cambridge.

Salo, E. O.
1991 Life History of Chum Salmon (*Oncorhynchus keta*). In *Pacific Salmon Life Histories*, edited by C. Groot and L. Margolis, pp. 233–309. University of British Columbia Press, Vancouver.

Speller, Camilla F., Dongya Y. Yang, and Brian Hayden
2005 Ancient DNA Investigation of Prehistoric Salmon Resource Utilization at Keatley Creek, British Columbia, Canada. *Journal of Archaeological Science* 32:1378–1389.

Speth, John D., and Katherine A. Spielmann
1983 Energy Source, Protein Metabolism, and Hunter-Gatherer Subsistence Strategies. *Journal of Anthropological Archaeology* 2:1–31.

Suttles, Wayne
1968 Coping with Abundance: Subsistence on the Northwest Coast. In *Man the Hunter*, edited by Richard B. Lee and Irven DeVore, pp. 56–68. Aldine, Chicago.

Trigger, Bruce G.
1989 *A History of Archaeological Thought*. Cambridge University Press, Cambridge.

Yang, Dongya, Aubrey Cannon, and Shelley R. Saunders
2004 DNA Species Identification of Archaeological Salmon Bone from the Pacific Northwest Coast of North America. *Journal of Archaeological Science* 31:619–631.

Zita, Paul
1997 Hard Times on the Northwest Coast: Deer Phalanx Marrow Extraction at Namu, British Columbia. In *Drawing Our Own Conclusions, Proceedings of the 1997 McMaster Anthropology Society Students Research Forum*, edited by Alexis Dolphin and Dara Strauss, pp. 62–71. McMaster Anthropology Society, Hamilton.

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