An experimental approach to understanding burnt fish bone assemblages within archaeological hearth contexts

Martina Steffen & Quentin Mackie

2005

Canadian Zooarchaeology / Zooarchéologie canadienne

UVic Libraries ePublishing Services

Original citation:

Steffen, M., & Mackie, Q. (2005). An experimental approach to understanding burnt fish bone assemblages within archaeological hearth contexts. *Canadian Zooarchaeology | Zooarchéologie canadienne*, *23*, 11–38.

An Experimental Approach to Understanding Burnt Fish Bone Assemblages within Archaeological Hearth Contexts

Martina Steffen[1, 2*] and Quentin Mackie[1]

[1]Department of Anthropology, University of Victoria, PO Box 3050 STN CSC, Victoria, BC V8W 3P5
[2]Royal BC Museum, 675 Belleville Street, Victoria, BC V8W 9W2
* corresponding author: msteffen@royalbcmuseum.ca

Abstract

The Richardson Island site, an early Holocene site located in Haida Gwaii, has produced an extensive lithic assemblage. The faunal assemblage from this highly stratified, raised beach site is derived from the contents of several hearth features and consists predominately of burnt fish bone. Compared to a roughly contemporaneous faunal assemblage from the nearby site of Kilgii Gwaay, the Richardson Island site has produced a paucity of large individuals for several common fish taxa – in particular, *Sebastes* sp. This paper describes an experimental approach to understanding the nature of the Richardson Island fish assemblage. Experimental burning of fish bones in a controlled laboratory setting and in simulated hearths was conducted to determine how the size, survivorship, and identifiability of fish elements would be affected by exposure to high temperatures and fire. The controlled burning of rockfish elements resulted in an average reduction in size of nine percent as well as the eventual disintegration of all otoliths. The experimental hearths illustrate the taphonomic complexity involved in the formation of burnt fish bone assemblages and in the quantification and interpretation of fish remains from hearth contexts.

Résumé

Le site de Richardson Island, un site du début de l'Holocene localisé à Haida Gwaii, contient un assemblage lithique de grande taille. La faune de ce site côtier stratifié dérive de nombreux foyers et consiste surtout d'os de poisson brulé. En comparaison avec la faune du site contemporain de Kilgii Gwaay, Richardson Island a produit peu d'individus de grande taille parmis les taxons communs, tel *Sebastes* sp. Cet article décrit une approche expérimentale qui nous permet de comprendre la nature de l'ichthyofaune de Richardson Island. Une étude expérimentale de combustion d'os de poisson dans le laboratoire et dans des foyers reconstitués nous a permis de déterminer comment le feu et les hautes températures affectent la préservation différentielle de l'os. La combustion controlé d'éléments a donné une réduction moyenne de taille de 9% des os conservés et la désintégration des otolithes. Les foyers expérimentaux illustrent la complexité taphonomique des ichtyofaunes et les subtilités de l'interprétation des os de poisson provenant de foyers.

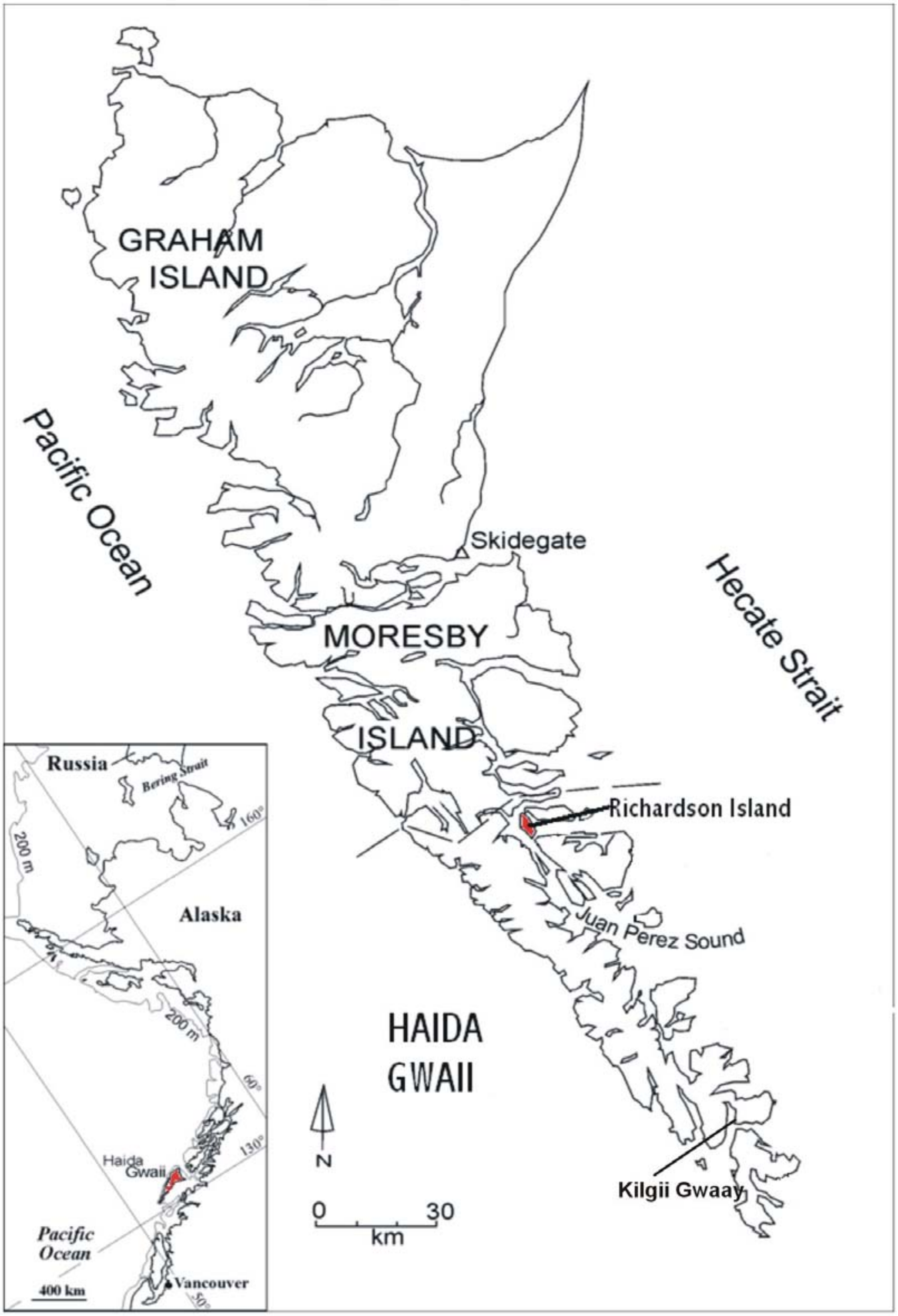

Figure 1: Map of Haida Gwaii. Modified from original by Daryl Fedje.

This paper describes an experimental approach to the interpretation of archaeological fish assemblages excavated from the Richardson Island site, Haida Gwaii,[1] British Columbia. This early Holocene archaeological site has a well-defined, artifact-rich, and high-resolution stratigraphic sequence and has produced one of very few faunal assemblages from coastal British Columbia dating to earlier than 9,000 years ago (^{14}C YBP).[2] The Richardson Island faunal assemblage consists entirely of burnt fish remains concentrated within hearth features. In the sample analyzed thus far, the fish taxa appear to be represented predominately by relatively small individuals. The research presented here investigates the possible taphonomic reasons for the lack of large fish in the Richardson Island hearth assemblages.

Archaeological and Geological Context

Richardson Island is located in southeastern Haida Gwaii, near the northern boundary of the Gwaii Haanas National Park Reserve/Haida Heritage Site (Figure 1). The archaeological site[3] is situated on the west side of Richardson Island and includes both inter-tidal and raised beach components. Archaeological investigations at the site have focused on the highly stratified raised beach deposits that are positioned approximately between 15 and 20 m above current sea level. Test excavations by Parks Canada in 1995 and 1997 established that the site had been occupied between 9,300 and 8,500 years before present[4] (Fedje and Christensen 1999; Fedje et al. 2005c); additional excavations were conducted by the University of Victoria in 2001 and 2002. The site consists of over 50 distinguishable layers which can be grouped into 20 separate, well-sealed depositional units of analysis. These layers have been dated by sixteen AMS radiocarbon age estimates (Fedje 2003:33), all but one of which fall in sequence consistent with stratigraphic ordering. In addition to numerous hearth complexes, the site contains features such as ash lenses and post-moulds. The lithic assemblage from the site consists of approximately 3,600 tools and tens of thousands of pieces of debitage. Several small, calcined bone tool fragments were recovered from the hearths. The lower Richardson component (pre-8,750 BP) is assigned to the Kinggi Complex, characterized by large core and flake tools and bifacial technology. The upper Richardson component (8,750 to 8,500 BP) is assigned to the Early Moresby Tradition, characterized by the addition of microblade technology to the Kinggi Complex toolkit (Fedje and Christensen 1999; Fedje and Mackie 2005). The hearth assemblages discussed in this paper are from the Kinggi Complex component of the site.

From approximately 12,000 to 8,900 BP, the sea rose by about 165 m at Richardson Island, from 150 m lower to 15 m higher than modern levels (Fedje 1993; Josenhans

---

[1] By request of the Haida First Nation, we refer to the Queen Charlotte Islands as Haida Gwaii.

[2] All dates are in uncalibrated radiocarbon years before present (BP).

[3] Parks Canada archaeological site designation 1127T, found within Borden block FeTw, but not assigned a Borden number.

[4] More precisely, the youngest radiocarbon date derived from cultural layers at the Richardson site is 8490 ± 70 ^{14}C age BP; this is a 9,440-9,530 calibrated age range. The oldest date from cultural layers is 9290 ± 50 ^{14}C age BP; this is a 10,640-10,260 calibrated age range.

et al. 1995, 1997; Fedje et al. 2005a). Consequently, the timing of human occupation at the Richardson Island site coincided with the final centuries of sea level rise and the first several centuries of sea level stability. Sea levels remained quite stable at this high stand until approximately 5,000 years ago, before slowly receding to their present position. Rising sea levels contributed to rapid site formation, resulting in very deep and highly stratified deposits. The matrix at this site is composed largely of well-sorted beach gravels, presumably aggregated by long-shore drift from the prevailing south-easterly winds that push through Darwin Sound.

Subsequent storm toss and supra-tidal berm development created an ever-rising flat platform of well-drained and lightly vegetated terrain along the otherwise steep slope of Richardson Island, attracting repeated human settlement. The complex stratigraphic profile of numerous sealed layers is the result of sea-level transgression, supra-tidal berm building, and occasional down-slope silt mudflows mixing with upslope gravel storm tosses, especially in the low, wet swale immediately inland of the berm. Humans revisiting the site would have occasionally found a “refreshed” gravel surface capping earlier deposits. All this has resulted in an unusually high-resolution stratigraphic profile spanning almost 4.5 vertical meters of deposit, with each depositional unit representing at most a few decades.

Despite these rapid depositional episodes, there is evidence that site formation processes have not dramatically disturbed the integrity of spatial patterning at the Richardson Island site. This evidence includes many clearly defined, intact hearth and post-mould features, a paucity of water-worn artifacts, the association of artifacts with occupation surfaces and features, some lithics in close proximity that refit with one another, the consistent ordering of the radiocarbon age estimates, and the presence of numerous A and B soil horizon couplets.

The Richardson Island Faunal Assemblage

The Richardson Island faunal assemblage consists entirely of calcined bone, mainly from the contents of sixteen hearths. The hearth features span a relatively short period of less than 200 radiocarbon years, from approximately 9,290 BP to 9,120 BP, with each hearth representing one or several burning events. Hearths were excavated following their composite morphology, which typically included a central area rich with calcined bone surrounded by a charcoal halo and fire-altered sediments. The different hearth components were classified as follows: “a” for the calcined bone-rich central areas, “b” for peripheral charcoal-rich areas, and “c” for fire-altered sediments (Figure 2). All identifiable bone elements and fragments were removed from the hearth matrices with the aid of magnification, with some fragments smaller than 1 mm in size. This study focuses on three hearth samples from unit EU-13 (Q12-F1a, S22-F1a, and K26-F1a), the analysis of which has been completed. Full analysis of all hearth fauna from the site is currently in progress (Steffen 2006).

Table 1: Fish Remains Recovered from Three Richardson Island Hearths

Richardson K26-F1A	**Skeletal Element**	**NISP**	**MNI**
greenling (*Hexagrammos* sp.)	vertebra (caudal)	2	1
Irish lord (*Hemilepidotus* sp.)	scute	1	1
lingcod (*Ophiodon elongatus*)	vertebra	1	1
lingcod/arrowtooth flounder/hake/cabezon	tooth, tooth row	7	-
sand lance* (*Ammodytes hexapterus*)	vertebra	3	1
prickleback (Stichaeidae)	vertebra	2	1
rockfish (*Sebastes* sp.)	(see Appendix A)	80	5
Richardson S22-F1A			
dogfish (*Squalus acanthias*)	tooth	10	1
flatfish* (Pleuronectiformes)	scute	2	1
Pacific herring (*Clupea pallasi*)	vertebra	1	1
Irish lord (*Hemilepidotus* sp.)	gill raker, pterygiophore	8	1
great-type sculpin (*Myoxocephalus* sp.)	vertebra (abdominal)	1	1
lingcod/arrowtooth flounder/hake/cabezon	tooth, tooth row	22	-
rockfish (*Sebastes* sp.)	(see Appendix A)	150	2
Richardson Q12-F1A			
dogfish (*Squalus acanthias*)	tooth, vertebra	16	1
halibut* (*Hippoglossus stenolepis*)	vertebra	1	1
lingcod/arrowtooth flounder/hake/cabezon	tooth, tooth row	48	-
Pacific herring (*Clupea pallasi*)	prootic	1	1
salmon (*Oncorhynchus* sp.)	gill raker, parapophyses, vertebra	41	1
starry flounder* (*Platichthys stellatus*)	scutes	5	1
rockfish (*Sebastes* sp.)	(see Appendix A)	163	2

*tentative identification

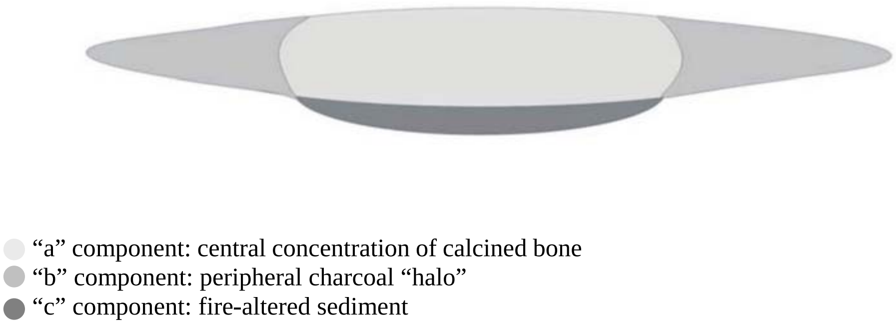

Figure 2: Cross-sectional model of hearth component structure

A list of fish species and elements recovered from the three hearths is presented in Table 1. At least 13 taxa are represented in the assemblages. In each hearth, rockfish (*Sebastes* sp.) is most abundant, both in terms of number of identified specimens (NISP) and minimum number of individuals (MNI). All fish bones were assigned to a size class when possible. This was done by visual comparison with comparative specimens at the University of Victoria. Rockfish elements were divided into categories from very small (total fish length of <15 cm), small (15-30 cm), medium (30-50 cm), large (50-70 cm), to very large (>70 cm). Upon initial observation, the rockfish specimens from the Richardson Island hearths appeared to be noticeably smaller than those recovered from the early Holocene site of Kilgii Gwaay, 90 km to the southeast. Subsequent examination confirmed this assessment.

At Kilgii Gwaay (Parks Canada site designation 1325T), which dates to 9,450 BP (Fedje et al. 2001, 2005b), the faunal assemblage is dominated by fish remains, which represent 72% of the total assemblage NISP (Fedje et al. 2005b). As at Richardson Island, rockfish remains dominate the Kilgii Gwaay fauna, comprising 83% of the fish NISP. When assigned to size classes, the fish bones from Kilgii Gwaay exhibit a different pattern than Richardson Island, with larger individuals represented (Table 2). The two sites represent very different depositional contexts. Kilgii Gwaay is an inter-tidal, single component wet site with excellent organic preservation,[5] while Richardson is a highly stratified raised-beach site with fauna preserved within hearth feature contexts. Despite their different taphonomic histories, the two sites may represent human exploitation of a similar ecological niche during the early Holocene. Both sites are located within protected areas of coastline with immediate access to near-shore fishes, although Kilgii Gwaay is closer to the exposed west coast where there may have been greater opportunity for deep-water fishing for large rockfishes. This difference in access may have resulted in a greater number of larger rockfishes being present at Kilgii Gwaay. Deep-water fishing would nonetheless have been possible from the Richardson Island site as it is situated at the northern end of Darwin Sound with good access to Hecate Strait.

Table 2: Size Comparison of *Sebastes* Elements

	Richardson Island	**Kilgii Gwaay**
n	224	601
very small	1.3%	0%
small	73.7%	20.5%
medium	25.0%	67.0%
large	0%	11.5%
very large	0%	1.5%

Before the size difference in rockfish between the two sites may be attributed to ecology or human behavior, it is necessary

---

[5] There are also differences in faunal recovery methods between these two sites. At Richardson, hearth samples were sieved through mosquito netting to maximize recovery of small elements, while 1/8 screen was used for faunal recovery at Kilgii Gwaay. This may account for the relative lack of small and very small individual specimens identified at Kilgii Gwaay, but it does not account for the absence of large individuals at Richardson.

to examine how taphonomic processes – in particular, the burning of the fish bones in the Richardson Island assemblage – may have affected the size, preservation, and subsequent quantification of the fish bone specimens. Two experiments were designed to address this issue. In the first, a laboratory-based controlled burning of fish bones was conducted to determine how the size of fish elements is affected by exposure to high temperatures. In the second, a series of experimental hearths was created to simulate those found at the Richardson Island excavation. The hearths were used to burn fish of various species, abandoned, and then subsequently excavated. An analysis of the experimental hearth contents was conducted to determine the influence of this depositional environment on the survival, recovery, and quantification of fish bones. In this paper, we focus on fish remains because these dominate the Richardson Island assemblage and because most of the literature on burnt bone addresses mammal bone. (For studies of the burning of mammal bone, see Andrews 1995; Binford 1981; Bonnichsen 1989; Coard and Dennell 1995; Lyman 1994; Noe-Nygaard 1983; Outram et al. 2005; Rabinovich et al. 1996; Stiner et al. 1995; for fish bone studies see Butler 1993, 1996; Lubinski 1996; Nicholson 1991, 1993, 1996; Richter 1986; Stewart 1991; Van Neer et al. 1992).

Experimental Program 1: Fish bone size reduction from exposure to high temperatures

As noted above, many of the rockfish in the Richardson Island hearths are small in size. This laboratory-based examination of the effects of high temperatures on fish bone was designed to investigate one aspect of the size of burnt bone. Has burning reduced the size of the fish bone in the Richardson Island assemblage, and if so, by how much? Does burning cause fish bone shrinkage to a degree that may significantly affect our size estimates of archaeological samples? In studies of mammal bone, Shipman et al. (1984) found a mean percent shrinkage of about 15%, while Gilchrist and Mytum (1986) documented a range of shrinkage of 5% to 30% for bovine and sheep bones. Size reduction of such magnitude would lead to inaccurate assessment of live body size, possibly biasing our understanding of fish procurement and utilization. This study looks at *Sebastes* fish bone size reduction due to burning.

Methodology

This experiment was conducted in the archaeology labs at the University of Victoria. Four rockfish (*Sebastes* sp.) were purchased, weighed, measured, and gutted. To facilitate flesh removal, the fish were poached slightly by placing them into a pan of shallow water above a hot plate emitting only enough heat to loosen the bone from surrounding flesh. A variety of different bone elements were selected for measurement. Some were chosen based on their frequency in the Richardson Island assemblage and others for their inclusion in the size regression formulae developed by Orchard (2003). The bones included in this experiment are the atlas, vomer, dentary, pre-maxilla, epihyal, maxillary, second vertebra, and basioccipital. Both left and right sides of paired bones were removed and measured. Measurements of the first vertebrae (atlas), vomer, dentary, pre-maxilla, and epihyal elements followed Orchard (2003). These and measurements taken of the maxillary, second vertebra,[6] basioccipital, and otolith elements are listed in Table 3.

After measurement to the nearest 0.01 mm, the *Sebastes* bones were placed on a flat ceramic tile in a Fisher Scientific Isotemp Muffle furnace, Model 182A kiln. The bones were burned in two identical kiln episodes with two rockfish individuals each. In both episodes, kiln temperature was brought to 900°C (1650°F) over the duration of 35 minutes. This temperature was chosen as it was the maximum temperature recorded during the field-based burning experiments, which will be described later. It also approximates maximum temperatures recorded in previous experimental research (see Shipman et al. 1984 for a review). Subsequent to reaching maximum temperature, the kiln was left to cool overnight. The cooling rate was measured the first half hour after the kiln was turned off, during which the temperature fell approximately 290°C (550°F). Identical measurements of each element were taken before and after kiln burning.

Results

Size Reduction After Burning

All elements showed some degree of size change after burning. For those that shrank, the average size reduction was 9.0%. There was some variability in percent shrinkage between elements, with parasphenoids displaying the least amount of shrinkage at 7.6% and vertebrae displaying the most at 10.9%. There was also considerable variability in the size reduction within each element type (Table 4).

Table 3: Measurements Taken Before and After Burning

Vomer
1. Maximum width of toothed surface
2. Maximum anterior-posterior diameter of toothed surface

Dentary
1. Maximum anterior-posterior diameter of the body (superior margin)
2. Maximum height of the symphysis
3. Maximum anterior-posterior diameter from the symphysis to the external posterior incision

Premaxilla
1. Maximum antero-posterior diameter of the body
2. Maximum height of the ascending process
3. Maximum height of the articular process

Epihyal
1. Maximum length of the ventral margin
2. Height of the posterior process
3. Maximum height perpendicular to the ventral margin

First vertebra (atlas) and second vertebra
1. Maximum height of the centrum
2. Maximum width of the centrum
3. Maximum anterior-posterior diameter of the centrum

Maxillary
1. Maximum length
2. Maximum width of the posterior margin
3. Maximum depth of the articular end

Basioccipital
1. Maximum height of the centrum
2. Maximum width of the centrum

Otolith
1. Maximum length
2. Maximum width

---

[6] The anterior measurements of the second vertebra were taken as a proxy for the posterior measurement of one first vertebra (atlas) that was lost during processing. All other vertebral measurements are posterior.

Table 4: Percent Shrinkage and Standard Deviation (SD) After Burning

Skeletal Element	Average % Shrinkage	SD
vomer	8.2	2.1
dentary	8.1	2.0
premaxilla	9.1	1.7
epihyal	8.8	4.1
first vertebra (atlas)	10.2	2.8
second vertebra	10.9	2.6
basioccipital	8.4	3.2
maxilla	9.4	2.6
parasphenoid	7.6	2.3
otolith	- *4.5*	1.8
Average	**9.0**	**2.8**

The six otoliths in the sample exhibited an average of 4.5% size *increase*. Each otolith was measured the day after burning, and each specimen exhibited a number of small fracture lines. This process of fragmentation appeared to continue unaided, and within a week of the burning episode, all otoliths had disintegrated into ash (Plate 4). This is an interesting observation because, as noted below, no otolith fragments have been recovered from the Richardson Island hearths thus far.

Variability and Measurement

In addition to investigating the overall shrinkage of fish bones due to burning, this study was also interested in examining the variability in shrinkage between elements (Table 4). Some measurements were more skewed after burning than others. For example, even though the premaxillae have the lowest SD, it was evident that the curve of the premaxilla anterior-posterior length had changed during burning. This would introduce a slight skew into not only the measurement of its length but also into the maximum height of the extending processes, with the original curvature height being slightly modified through warping. The maxillary and parasphenoids have thin and fragile posterior edges, which curled slightly during burning. This change in shape could have increased apparent shrinkage. Given that only two or three measurements were taken for each of a small sample of element types, the actual range of variation in shrinkage between elements may not be clearly defined here, but it is important to note the existence of such variation if burned elements are used to reconstruct the live size of individual fish.

Estimates of Richardson Island Fish Size

Size regression formulae have been developed to estimate the size of different species of animals, including fish, based on measurements of various elements (e.g., Crockford 1997; Orchard 2003; Casteel 1974). We used Orchard's (2003) regression formulae to examine how an approximate 9% reduction in the size of elements due to burning would affect the estimates of the length and weight of whole fish at the Richardson Island site.

Calculations based on a vomer and epihyal from hearth Q12-F1a and on five left epihyals from hearth K26-F1a determined a range of live fish lengths from 247 mm to 365 mm and live fish weight from 187 g to 870 g (Table 5). If the percent size reduction due to burning is incorporated into these calculations, the estimated live fish lengths would increase by approximately 4-8% and the estimated live weights by approximately 20-31%. The adjusted weight estimates indicate that the fish were small (mostly from 400-600g), but qualitatively speaking, large enough to be worth eating.

This experiment was designed to determine if burning causes *Sebastes* fish bone to shrink enough to bias our interpretations of archaeological fish remains. The degree of shrinkage documented is less than that observed in the studies of mammal bones noted above but may significantly affect size (primarily weight) estimates of fish individuals. It does not appear to explain the size difference in *Sebastes* from the Richardson Island and Kilgii Gwaay sites.

Table 5: Comparison of Size Estimates Based on Measurements of Burnt and Unburnt Bone

	Vomer	**Epihyal**					
	1	1	2	3	4	5	6
A. Measurement of burnt specimen (mm)	8.5	1.2	2.7	1.8	2.1	1.9	2.2
B. Projected measurement (mm) if not burnt	9.3	1.3	2.9	2.0	2.3	2.1	2.4
Live length (mm, based on A)	286	239	346	283	305	292	309
Live length (mm, based on B)	307	247	365	296	320	306	324
% Difference	**7.3**	**3.3**	**5.5**	**4.6**	**4.9**	**4.8**	**4.9**
Live weight (g, based on A)	366	156	725	342	462	388	483
Live weight (g, based on B)	468	186	867	409	552	464	578
% Difference	**27.9**	**19.2**	**19.6**	**19.6**	**19.5**	**19.6**	**19.7**

To obtain "projected" measurements (B), values for vomer and epihyal were increased by 8.2% and 8.8%, respectively (see Table 4).
Length = alpha + (beta*bone_measurement)
Weight = alpha * (bone_measurment^beta)

Experimental Program 2: Short-term use hearth replications

A field-based replication of short-term single-use and multiple-use hearths was conducted to examine additional effects of high temperatures on fish bones and their quantification. Two short-term use hearth features were created to better understand the formation processes affecting the Richardson Island faunal assemblage. While archaeological hearth features are exposed to taphonomic factors not replicable in this type of experiment (e.g., millennia of compression under four metres of gravel overburden), this approach can help us address a number of issues concerning the interpretation of archaeological fish bone assemblages. Our objectives were to determine 1) which skeletal elements of the fish species observed within the Richardson Island assemblage are most identifiable after burning within hearths (see also Nicholson 1995) and 2) how burning and deposition in hearth contexts affect the subsequent quantification of fish remains (e.g., the calculation of number of identified specimens [NISP] and minimum number of individuals [MNI]).

Methodology

"Short-term use hearth" is defined here as the repeated use of a single hearth for fewer than 10 burning episodes. The fish placed in these hearths were caught at various locations in southern Juan Perez Sound, Haida Gwaii, near the field campsite on southeast Wanderer Island where the experiments were conducted. This camp is approximately 50 km south of the Richardson Island site.

Two fires, each approximately 50 cm in diameter, were assembled with wood placed directly on beach gravel. No pit was dug and no hearth lining used. A variety of wood from the surrounding beach was used, including alder, red cedar, and yellow cedar. Fire temperature was measured at regular intervals with a thermocouple pyrometer, the probe tip of which was placed in the centre of the fire and at points along its periphery.

The first fire was a single-use hearth that was lit only once and within which was placed a single, filleted rockfish (Table 6). This hearth was created as a general reference for what one might expect from a single burning event in terms of charcoal, ash, and other fire alterations, as well as quantity and condition of calcined bone; clearly, there may be much variation between such single-use events.

The second hearth was lit eight times. Fauna were introduced during all but the last of these burnings. Fish specimens included eight rockfish (*Sebastes* sp.), two lingcod (*Ophiodon elongatus),* one rock sole (*Lepidopsetta bilineata),* one dogfish (*Squalus acanthias),* and one kelp greenling (*Hexagrammos decagrammus)* (Table 6). These individuals were filleted but not gutted before being placed skeletally whole into the fire. Because of the large size of halibut (*Hippoglossus stenolepis*), only the ultimate seven caudal vertebrae and the tail assemblage from one individual was included in this experiment. Each burning episode lasted from between 45 to 135 minutes, during which time the fire was fed before being allowed to extinguish naturally overnight.

Table 6: Fish Used in Hearth Experiments

SINGLE USE HEARTH	**Length**	**Weight**
copper rockfish *(Sebastes caurinus)*	23.0 cm	140 g
MULTIPLE USE HEARTH		
rockfish (*Sebastes* sp.)	29.4 cm	365 g
rockfish (*Sebastes* sp.)	34.1 cm	725 g
rockfish (*Sebastes* sp.)	42.0 cm	1050 g
rockfish (*Sebastes* sp.)	49.0 cm	1800 g
rockfish (*Sebastes* sp.)	32.5 cm	500 g
rockfish (*Sebastes* sp.)	26.6 cm	225 g
rockfish (*Sebastes* sp.)	30.5 cm	320 g
rockfish (*Sebastes* sp.)	34.5 cm	635 g
lingcod *(Ophiodon elongatus)*	67.0 cm	2,315 g
lingcod* *(Ophiodon elongatus)*	62.0 cm	no data
rock sole *(Lepidopsetta bilineata)*	28.5 cm	225 g
canary rockfish *(Sebastes pinniger)*	31.0 cm	450 g
greenling *(Hexagrammos decagrammus)*	38.0 cm	590 g
dogfish *(Squalus acanthias)*	76.0 cm	2,360 g
Pacific halibut** *(Hippoglossus stenolepis)*	98.0 cm	~12,220 g

* Stomach contents included two small fish which were also placed in hearth.

** Only 7 caudal vertebrae and tail were placed into fire. Weight is estimated from length.

Temperature may be highly variable in small campfires, with localized temperature fluctuating considerably at any given moment. Most hearths had a maximum temperature around 760°C (1400°F), with the highest temperature of 900°C (1650°F) recorded during one episode that took place on a particularly blustery evening. In general, fire temperature increased quickly after lighting. For example, in Episode 2 the first temperature reading was 260°C (500°F), taken less than five minutes after the fire was started. Four minutes later, it had risen to 730°C (1350°F). The hearths were excavated twenty days after the first burning episode.

The methods used to excavate the experimental hearths were identical to those used in the archaeological excavation of the hearth features at the Richardson Island site, following the component morphology of each hearth (Figure 2). This morphology developed quite quickly. After just two burnings of the multiple-use hearth, the charcoal rich "b" component had developed around the "a" component which was centrally concentrated with less charcoal. This pattern is comparable to that observed in the Richardson Island archaeological hearths and suggests that they are not necessarily the result of frequent re-use. Subsequent burning episodes did seem to increase the visual definition of the hearth structure. Interestingly, portions of fish from burning episodes sometimes remained charred, with blackened fleshy components still visible at the periphery of the hearth, while other portions of the same fish placed in the middle of the fire became completely calcined. Also notable was the lack of evidence or observation of any disturbance of the experimental hearths by scavengers such as eagles, ravens, raccoon, or bear, all of which were present on the Wanderer Island shoreline at this time.

Results

Skeletal Element Representation

Burning renders bones more susceptible to fragmentation, resulting in a corresponding reduction in identifiability (Stiner et al. 1995). It has been noted that, for mammals, small dense bones of smaller animals are more likely than other bones to survive in identifiable condition in highly fragmented assemblages (Klein and Cruz-Uribe 1984). Our findings suggest that this observation also applies to fish bones, but on a much smaller size scale than for mammals.

In order to better understand if smaller bones survive more often in identifiable condition in burnt fish bone assemblages, we examined which skeletal elements from burnt assemblages are commonly damaged beyond recognition during burning (see also Nicholson 1995). This is a primary methodological consideration relevant to the Richardson Island archaeological hearth assemblages, keeping in mind that both human behavior (e.g., species choice and butchery practices) and taphonomic processes (e.g., differential durability, soil chemistry, coarseness of matrix, and compression from overburden) have influenced the assemblage composition. This study obviously cannot replicate all of the relevant, complex site-specific and time-dependent taphonomic processes. It attempts primarily to assess pre-burial hearth formation processes to gain insight into how fish bone elements are affected in archaeological hearth contexts. Because the "b" component of the experimental hearths remains to be analyzed, only the "a" components of the experimental and archaeological hearths are used in this comparison.

Sebastes: Appendix A lists the number of *Sebastes* bone elements identified after the two hearth experiments and three Richardson Island hearth assemblages. Elements from all regions of the skeleton are present in both the experimental hearths – in which whole fish were deposited – and in archaeological hearths. There is no complete absence of any skeletal region in the archaeological examples, suggesting that all portions of at least some fish were deposited in this context. In general, skull elements, the suspensorium, and gill rakers are fairly well-represented in all five hearths. When assessing the presence of specific bones, elements that appear in all five hearth contexts include the nasal, dentary, gill rakers, vertebra, and pterygiophores. In many cases, only part of the bone survived, but diagnostic portions were present for identification. The diagnostic attributes of bone elements sometimes survived in unusual patterns. For example, in hearth K26-F1a a total of seven epihyal bones, five left and two right, were recovered, resulting in a rockfish MNI of five within a hearth containing relatively few identifiable rockfish elements overall (n=80).

Rockfish exhibit considerable discrepancy in the relative representation of elements between the experimental and the archaeological contexts. Specifically, there are 166 rockfish vertebrae in the multiple-use and 16 in the single-use hearth, compared to the three archaeological hearth contexts, which produced only 4, 5, and 2 rockfish vertebral elements in total. There has been considerable interest in the variable frequencies of fish cranial and vertebral elements in the study of food processing and storage on the Northwest Coast (e.g., Calvert 1973; Huelsbeck 1983; Moss 1989). The paucity of identifiable vertebral elements in the Richardson Island hearths may be a result of cultural factors, such as differential processing of fish carcasses (Chatters 1984; Butler and Chatters 1994). Butchery practices that are dependent upon the size of fish are known on the Northwest Coast and elsewhere (Zohar et al. 2001). A particularly salient example of this has been observed for large Pacific halibut, which are often butchered on the beach (Stewart 1977). The edible fleshy parts of the halibut are then hauled up to living areas, while the guts and the remainder of the carcass, likely including most bones, are left on the beach. Smaller fish were more likely brought into camps whole for processing and cooking (e.g., Binford 1981). Accordingly, it is likely that the many smaller rockfish within the Richardson hearths were brought into camp whole, and the relative lack of rockfish vertebrae may be indicative of a type of fish processing or consumption that was practiced within the vicinity of hearths. The presence of gill structures (gill rakers) and many bony head elements indicates that the initial processing of small fish taxa, including rockfish, may have taken place here. Conversely, the lack of vertebrae suggests that these elements, possibly along with the fish fillets, may have been used and deposited elsewhere.

Differential preservation of skeletal elements can also contribute to disproportionate representation of fish vertebrae. Butler and Chatters (1994) found that the density of salmon vertebrae far exceeded that of most of their cranial elements and are thus more likely to survive over time, potentially skewing their relative abundance in archaeological contexts. In addition, experimental modeling of the effects of cooking and soil pH on various fish bones demonstrates that the vertebrae of some fish are better able than cranial elements to withstand post-depositional degradation after cooking (Lubinski 1996). It may be that *Sebastes* vertebrae are also relatively dense, although density values have not been derived for this taxon. Other intrinsic factors, such as bone shape and size, may have influenced element survival in the archaeological deposits (Lyman 1994). Overall, the paucity of rockfish vertebrae in the Richardson Island hearths may not be entirely attributable to differential preservation. Any fragmentation of these vertebrae renders them extremely difficult to identify to species, and it is possible that rockfish vertebrae were present but too fragmentary to be counted.

Other Fish Taxa: Other than *Sebastes,* the fish deliberately placed in the multiple-use experimental hearth include dogfish, lingcod, greenling, rock sole, and the partial halibut skeleton. Fish elements identified from the multiple-use experimental context are compared to those identified in the three Richardson hearths in Appendix B. There are few identifiable elements of taxa other than *Sebastes* within the three archaeological hearths, making it difficult to compare patterns in element representation. However, the distribution of elements of several species invites comment despite their small numbers. Dogfish occurred in two of the archaeological hearths, represented by both teeth and vertebrae. Because dogfish are predominately cartilaginous, their dorsal spines are the only other element that one might expect to find (see Rick et al. 2002). The absence of these dorsal spines appears to be as a result of the peripheral location of the dogfish within the experimental hearth. The dogfish was burned near the fire periphery during the last burning episodes. Charred portions of the fish remained apparent around the outside of the hearth feature during excavation and constituted much of the “b” component of the experimental hearth, which was not included in this study. This does not explain the absence of dogfish spines within archaeological hearths, but placement of ancient fish remains within different locations in the hearth may also have biased the appearance of specific skeletal elements within archaeological hearths in general. Herring were represented by vertebral and prootic bones in two archaeological hearths and the multiple-use experimental hearth, suggesting that these elements were most likely to survive. There was only one herring element in each of the two archaeological hearths, presumably because their small bones do not survive well once burnt (but see Nicholson 1995). Given the paucity of herring elements, this taxon may have been introduced as the stomach contents of other fish, as was the case in the experimental context. Vertebral elements occurred for several taxa including greenling, sculpin, halibut, and salmon. A number of teeth and tooth row fragments were identified as lingcod, arrow tooth flounder, hake, or cabezon, as they display a diagnostic “arrow”-tip tooth and similar tooth row patterning. Halibut also have a similar tooth row structure. It is difficult to distinguish between these species simply on the basis of teeth or very small fragments of the tooth row alone. In contrast, scutes, which are modified scales or skin spines, can be relatively diagnostic. Irish lord, flatfish, and starry flounder were all identified by their scutes. This is interesting for the archaeological samples because it suggests that the skin of these fish was deposited into the hearths, likely as result of the clean-up of fish processing debris.

Element Representation Summary: In the current study, the survival of fish bone after burning appears to have been influenced by shape, size, and, perhaps, bone density. Flat and less "sculptural" diagnostic elements tend to survive burning and subsequent fragmentation less frequently than diagnostic bones with a more spherical or simple, robust shape. Bone size is also a factor in survivability, with smaller, more diagnostic bones such as gill rakers and pterigiophores fragmenting less than larger flat bones. They are thus more likely to remain identifiable despite – and perhaps because of – their small size. In fact, very small fish bones and fragments were identifiable. In addition, smaller fish are more likely to be brought into camps whole than large fish, contributing more skeletal elements per individual.

In archaeological fish bone assemblages that have not been burned, the higher density bones, including vertebrae and robust head bones such as the angular and maxillary, may be expected to survive after burial more readily than less dense bones, such as the ceratohyal (Butler and Chatters 1994). This is likely to be true of burnt fish bone assemblages as well, although enough of the specific diagnostic regions of bones must also be present for elements to be identified to a specific taxon. The relative lack of rockfish vertebrae in the three Richardson hearth samples may be due to the high level of fragmentation, as very small fragments of these vertebrae are not identifiable to taxon. It has been noted that burning causes some loss in the mechanical strength of bone (Knight 1985 in Lyman 1994; Stiner et al. 1995). In the absence of density data for these fish species, size and shape may present a reliable but coarse indicator of the potential of fish bone survival within some contexts.

What is of particular interest is the fact that no otolith fragments have yet been recovered from the Richardson Island hearths. Only a few, very fragile otolith remnants were identified in the experimental hearths. It appears that, despite being extremely dense (Butler and Chatters 1994), otoliths do not survive well in burnt contexts (or in other archaeological contexts [Wigen and Stucki 1988]).

Fragmentation, Identification, and the Size of Skeletal Elements

In their analysis of how fragmentation affects the identification of mammal bones, Lyman and O'Brien (1987) concluded that there is a minimum identifiable size of bone fragment which varies between taxa and skeletal elements. Beyond a certain variable size threshold, the proportion of identifiable mammal bone fragments will decrease dramatically (Watson 1972; Hesse and Wapnish 1985). Elements that occur in an assemblage may not be identified and quantified due to high levels of fragmentation. Here we are interested in examining the concept of a minimum identifiable size for various fish bones.

It is apparent that there are few identified elements in each of the three Richardson hearths compared to the experimental contexts (Appendices A and B), which is likely evidence of significant taphonomic attrition. The heavy overburden at this site, consisting of over four meters of gravel-rich sediments, may alone have been sufficient to cause loss of identifiable specimens through high levels of fragmentation. The level of fragmentation and the paucity of element types identified at Richardson Island suggest that the number of identifiable elements has decreased since deposition. Virtually all the identified elements from the archaeological hearths are entirely calcined and hence would be expected to have turned to powder due to soil compaction and, in some contexts, trampling and other disturbances (Stiner et al. 1995). The calcined fragments recovered from the Richardson Island hearths may have survived in the gaps between individual gravels.

The relative difference in fragment size between the experimental and the archaeological hearths offers a coarse comparison of degree of fragmentation (see also Grayson 1984; Klein and Cruz-Uribe 1984). Three sub-samples of two hundred fragments of unidentifiable bone were randomly selected from both experimental and archaeological contexts and then weighed. The average experimental hearth sub-sample weighed 2.9 g (0.015 g/specimen), while the same number of elements from Richardson Island hearth K26-F1a weighed 1.3 g (0.007 g/specimen) and those from hearth Q12-F1a weighed 0.9 g (0.005 g/specimen), showing the average unidentified fragment in the experimental context to be much larger. A similar pattern holds true for identified elements. During the identification process the amount of each bone element present was assessed and recorded on the following scale of completeness: 1 (0-20%), 2 (20-40%), 3 (40-60%), 4 (60-80%), and 5 (80-100% whole) (Figure 3).

Statistical analysis shows that identified skeletal elements were significantly more complete in the experimental hearths than in the archaeological hearths (Mann-Whitney *U*=201105, *p*=0.0001). The significantly higher level of fragmentation in the archaeological samples has likely resulted in an overall reduction of the number of identifiable skeletal elements.

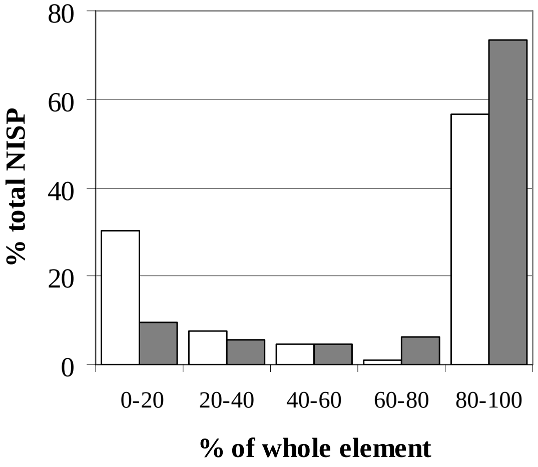

Figure 3: Comparison of fragmentation between elements recovered from experimental hearths (gray columns) and archaeological hearths (white columns).

Quantification of Hearth Assemblages

There has been a longstanding debate about the relative merits of number of identifiable specimens (NISP) and the minimum number individuals (MNI) as measures for quantification of taxonomic abundance in faunal assemblages (e.g., Casteel 1977; Grayson 1973, 1984; Lyman 1979; Marshall and Pilgram 1993; White 1953). Highly fragmented bone assemblages introduce additional interpretive challenges (for reviews, see Grayson 1984; Klein and Cruz-Uribe 1984; Ringrose 1993). Considering the problems that arise from the use of either NISP or MNI, it is generally agreed that neither figure should be used in isolation.

This portion of the analysis examines how accurately the numbers of individual specimens put into the fire are detected or quantified after burning. MNI was derived through visual assessment of skeletal elements, incorporating size comparisons and the siding of paired elements. NISP is the number of whole or fragmentary specimens identified, not including fragments that were unidentifiable beyond the classification "fish".

Table 7: Fish Introduced Into and Recovered from Multiple-Use Experimental Hearth

Taxon	Number placed in fire	MNI after burning	MNI derived from:	NISP after burning
rockfish	8	8	first vertebra (atlas)	923
dogfish	1	1	vertebra, teeth	109
halibut	1	1	caudal vertebra	10
herring	0	*1	vertebra, prootic	41
flatfish	0	*1	vertebra	33
rock sole	1	1	posttemporal	8
lingcod	2	2	basioccipital, quadrate	295
starry flounder	0	*1	basioccipital	1
greenling	1	*2	basioccipital, 2nd vertebra	66
crab	0	*1	claw fragment	1
TOTAL	**14**	**19**		**1490**

* possible stomach contents of other fish

Table 7 shows the number of fish individuals introduced into the multiple-use experimental hearth as well as the MNI and NISP of all species identified during analysis. This analysis produced a number of interesting results. Of note are the elements from which MNI was derived for each taxon. These elements were considered to be the most reliable measures of MNI because they were often the least fragmentary. Other elements, such as the dentary and premaxilla, which are commonly used in calculating MNI in unburnt assemblages, were in some cases very fragmentary, making accurate visual matching of fragments difficult. It has been suggested by some researchers that only a limited range of specific elements need to be identified within fish bone assemblages for the calculation of measures such as MNI (Leach 1997). In contrast, this study indicates that, when calculating MNI within highly fragmented fish bone assemblages, a wide range of elements should be examined.

Some of the individuals identified in the experimental assemblage had not been documented as part of the original experiment. A herring and a small flatfish were observed to be part of the stomach contents of the lingcod carcass. Because taxonomic determination is often very difficult when using Pleuronectiformes vertebrae, the flatfish vertebrae that were recovered were not identified to species (Table 7). While both rock sole and starry flounder were identified in the calcined assemblage, the presence of starry flounder is based on a single basioccipital element which is morphologically quite similar to rock sole. Elements of one greenling and one crab were also introduced unintentionally, either through stomach contents of another fish or through environmental contamination. This second greenling was much smaller than the one that was intentionally placed in the fire, and it was most likely introduced as the stomach contents of another fish. Butchery practices that involve the gutting of small fish at fires may result in the deposition of non-food refuse into hearth features.

In quantifying *Sebastes* remains recovered from the multiple-use hearth, it was noted that many bones were fragmented, resulting in high NISP counts for specific elements (Appendix A). Elements with long diagnostic components, such as the parasphenoid, the tooth row regions of the premaxilla, and the dentary, are most affected because a large proportion of these bones are distinctive, resulting in the identification of more fragments. At the same time, other elements have become unidentifiable through fragmentation and thus are not counted toward NISP. The NISP for *Sebastes* in the multiple-use hearth is 923, which may seem fairly high for the number of individuals (8) placed into the fire. One might assume that the relatively high NISP is a result of elements being fragmented and counted multiple times, but in this case, the major cause of the high NISP was the identification of gill rakers, which contribute 479 of the 923 identified specimens. The identification of gill rakers within the hearths is a result of our methodology, a process that incorporated the assessment of very small diagnostic elements. *Sebastes* have a large number of gill rakers that seem to be more durable than those of other species (Susan Crockford, pers. comm.), and the abundance of these elements may increase the relative abundance of *Sebastes* NISP when compared to other taxa.

Each individual fish that was intentionally introduced into the multiple-use hearth was represented in the recovered assemblage. Therefore, while fragmentation of elements in the experimental hearth may have resulted in increased NISP for some taxa, it had no effect on the quantification of the MNI of taxa that were intentionally placed into the fire. The implications of this for the Richardson Island hearth assemblages are unclear, partly because the sample size of each hearth is so small. The use of MNI with small sample sizes may result in the exaggeration of the dietary significance of less important species (Payne 1972). While we cannot know the number of individuals originally deposited in the archaeological hearths, our experiments do suggest that MNI values may not be greatly affected by burning.

Species Representation

Species representation may offer insight into economic activity when dealing with highly fragmentary assemblages that are from short-term contexts and contain few identifiable elements, as is the case at Richardson Island.[7] Consideration should be given to the fact that not all species present will have direct economic importance and may simply represent discard of offal or other unintentional occurrence. The experimental hearth study presented here affirms the possibility that some species or individuals recovered from the archaeological hearth contexts may constitute refuse (such as fish stomach contents) and thus do not represent human dietary items. Thus, it is not only important to identify species but also to understand their relationships within the specific ecological niche being exploited by people. In addition, for large faunal assemblages, it may be possible to investigate whether site occupants had fished out the larger individuals from the near-shore environment so that only small individuals remained.

---

[7] For example, one way of presenting presence and absence data within a number of different contexts is through the development of a ubiquity index of taxa (see Dean 2005, McKechnie 2005).

The Richardson Island assemblage included small individuals representing several near-shore fish species. This shows that its prehistoric occupants were exploiting the near-shore environment, catching rockfish one day and greenling the next, then processing and cooking the fish and discarding the refuse from their catch in their campfires.

Conclusions

The effects of human activity may be difficult to distinguish from those of natural taphonomic processes within archaeological contexts. This presents complications for the interpretation of faunal assemblages, challenges that are compounded by the added taphonomic complexity typical of hearth contexts. Few studies have focused on fragmentary burnt fish bone within hearth features (but see Hanson 1998), primarily because highly fragmented bones are not easily identifiable to skeletal element or taxon. The importance of the Richardson Island site – given its early Holocene age, its unusually high-resolution stratigraphy, and its rich lithic assemblage – and its lack of any other faunal evidence led us to focus on the study of the calcined fish assemblages.

Preliminary investigation of the Richardson Island fauna has found that rockfish (*Sebastes*) are by far the most abundantly represented fish and that the rockfish individuals from this site are small compared to those from nearby Kilgii Gwaay. This study investigated potential reasons for the lack of large fish within the Richardson hearth assemblages. Controlled burning and hearth replication experiments were conducted not to replicate the entire, complex taphonomic history of the Richardson assemblages, but to provide insight into the specific characteristics of the archaeological hearth features.

Our controlled burning experiment demonstrated that burning causes a size reduction of these fish bones that may result in significant underestimates of live fish weight. An average bone shrinkage of about 9% was observed for the rockfish elements in this study. Researchers studying calcined fish bone may wish to conduct similar burning experiments to determine the degree of size reduction for other taxa of interest. Our experiment also showed that otoliths turn to ash after being exposed to high temperatures (900ºC), providing a viable explanation for the lack of otoliths in the Richardson hearths.

The hearth replication experiments demonstrated the complex taphonomy of burnt fish bone assemblages. For example, fragmentation affects NISP in two ways: when specific skeletal elements (for example the parasphenoid) are broken, pieces of the same bone can be counted more than once, resulting in an increased NISP for those elements. More commonly, fish skeletal elements were broken beyond recognition, reducing NISP. This study also observed that high levels of fragmentation may result in an inverse relationship between the body size of an animal and the identifiability of its remains. Large mammal and bird bones fragmented into small pieces may be less identifiable than fish bones broken into similarly sized fragments. At the Richardson Island site, not only were there very few identified mammal and bird specimens, but there were also very small burnt fish bone fragments that were identifiable.

In examining how MNI counts may be affected by burning in hearths, we found that all of the individual fish that were placed into the experimental hearth were accounted for in the recovered assemblage. Of particular note was the fact that several additional fish had been introduced into the assemblage, likely as stomach contents of other fish. Small fish in archaeological assemblages may thus represent discard that did not contribute directly to human subsistence. This does not appear to be entirely the case at Richardson Island. Preliminary analysis of *Sebastes* skeletal elements from two hearth contexts suggests that the individuals recovered were large enough to represent a food resource. It is unlikely that all these fish were brought to the hearth to be discarded in the fire or that they only represented stomach contents of larger fish. In addition, the large proportion of *Sebastes* of all sizes in a variety of contexts at the Kilgii Gwaay site supports the conclusion that this taxon was caught to be eaten.

The Richardson Island hearth assemblages derive from a very localized and specific hearth context. As a result, they represent the material remnants of activities conducted at or near the hearth. If complete butchery and discard of bones preceded arrival at the hearth, those remains would not have been introduced into these features. This is especially relevant given that larger animals, such as bear, albatross, halibut or seal, which represented a major portion of the Kilgii Gwaay faunal assemblage, are more likely to be butchered prior to transport to residential sites (Binford 1981).

While taphonomic factors may complicate interpretations concerning the species that contributed to the diet of the prehistoric inhabitants of Richardson Island, the hearth assemblages still provide behavioural information about the activities of the site occupants. The experimental hearths suggest that their archaeological counterparts represent a series of short-term events – specific activities, such as logistical forays into the environment. The hearth contents thus illustrate the niches that were exploited by humans across short time spans in the distant past. Despite the difficulties in working with such highly fragmented faunal assemblages, they provide a rich source of information that may prove critical in our understanding of the subsistence practices of peoples in the past.

Acknowledgements

We thank Becky Wigen for sharing her unparalleled knowledge of Northwest Coast fish bone identification. Susan Crockford was also very generous with her knowledge. We also thank Iain McKechnie, Trevor Orchard, and Daryl Fedje. Alexander Mackie photographed the experimental hearth process. The Richardson Island Archaeological Project took place in 1995, 1997, 2001 and 2002, and we thank the field crews from those years. Volunteers in the University of Victoria archaeology lab performed much of the painstaking work of preliminary sorting of the hearth contents, especially the Wednesday evening "Richardson Rock Wash" group. Students in the course Anthropology 449 also sorted some hearth material.

We acknowledge the financial and logistical support of Gwaii Haanas National Park Reserve/Haida Heritage Site, particularly the warden service and support staff. Major financial support for the 2001 and 2002 field seasons was provided by Social Sciences and Humanities Research Council of Canada Grant #410-2001-0898 to Q. Mackie. The Royal British Columbia Museum, through their Employee Development Program, has generously helped fund and facilitate Martina Steffen's graduate studies, of which this research is a part. We thank Kathy Stewart, Yin Lam and two anonymous reviewers of this article for their insights and suggestions.

References Cited

Andrews, P.
1995 Experiments in taphonomy. *Journal of Archaeological Science* 22:147-153.

Binford, L. R.
1978 *Nunamiut Ethnoarchaeology*. Academic Press, New York.

1981 *Bones: Ancient Men and Modern Myths*. Academic Press, New York.

Bonnichsen, R. and H. M. Sorg
1989 *Bone Modification*. Center for the Study of the First Americans, Orono, ME.

Bunn, H. T. and E. M. Kroll
1986 Systematic butchery by Plio-Pleistocene hominids at Olduvai Gorge, Tanzania. *Current Anthropology* 27:431-452.

Butler, V. L.
1993 Natural versus cultural salmonid remains: origin of the Dalles Roadcut bones, Columbia River, Oregon, USA. *Journal of Archaeological Science* 20:1-24.

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.

Calvert, S. G.
1973 *Cultural and non-cultural variation in the artifact and faunal samples from the St. Mungo Cannery Site, B.C. (DgRr-2).* M.A. thesis. University of Victoria.

Casteel, R. W.
1977 Characterization of faunal assemblages and the minimum number of individuals determined from paired elements: continuing problems in archaeology. *Journal of Archaeological Science* 4:125-134.

Chatters, J. C.
1989 Resource intensification and sedentism on the Southern Plateau. *Archaeology in Washington* 1:3-19.

Coard, R. and R. W. Dennell
1995 Taphonomy of some articulated skeletal remains: transport potential in an artifactual environment. *Journal of Archaeological Science* 22:441-448.

Crockford, S. J.
1997 Archaeological evidence of large Northern Bluefin Tuna, *Thunnus thynnus*, in the coastal waters of British Columbia and northern Washington. *Fishery Bulletin* 95:11-24.

Dean, R. M.
2005 Site-use intensity, cultural modification of the environment, and the development of agricultural communities in southern Arizona. *American Antiquity* 70:403-431.

Fedje, D. W.
1993 *Sea levels and prehistory in Gwaii Haanas*. M.A. thesis. University of Calgary.

2003 Ancient landscapes and archaeology in Haida Gwaii and Hecate Strait. In *Archaeology of Coastal British Columbia: Essays in Honour of Professor Philip M. Hobler*, edited by R. Carlson, pp. 29-38. SFU Press, Vancouver.

Fedje, D. W. and T. Christensen
1999 Modelling paleoshorelines and locating early Holocene coastal sites in Haida Gwaii. *American Antiquity* 64:635-652.

Fedje, D. W., H. Josenhans, J. J. Clague, J. V. Barrie, D. J. Archer and J. Southon
2005a Hecate Strait paleoshorelines. In *Haida Gwaii: Human History and Environment from the Time of Loon to the Time of the Iron People*, edited by D. W. Fedje and R. Mathewes, pp.21-37. UBC Press, Vancouver.

Fedje, D. W., A. P. Mackie, R. J. Wigen, Q. Mackie and C. R. Lake
2005b Kilgii Gwaay: An early maritime site in the south of Haida Gwaii. In *Haida Gwaii: Human History and Environment from the Time of Loon to the Time of the Iron People*, edited by D. W. Fedje and R. Mathewes, pp. 187-203. UBC Press, Vancouver.

Fedje, D. W. and Q. Mackie
2005 Overview of cultural history. In *Archaeology of Coastal British Columbia: Essays in Honour of Professor Philip M. Hobler,* edited by R. Carlson, pp. 154-162. SFU Press, Vancouver.

Fedje, D. W., M. P. R. Magne and T. Christensen
2005c Test excavations at raised beach sites in southern Haida Gwaii. In *Haida Gwaii: Human History and Environment from the Time of Loon to the Time of the Iron People*, edited by D. W. Fedje and R. Mathewes, pp. 204-241. UBC Press, Vancouver.

Fedje, D. W., R. J. Wigen, Q. Mackie, C. R. Lake and I. D. Sumpter
2001 Preliminary results from investigations at Kilgii Gwaay: an early Holocene archaeological site on Ellen Island, Haida Gwaii, British Columbia. *Canadian Journal of Archaeology* 25:98-120.

Gilchrist, R. M. and H. C. Mytum
1986 Experimental archaeology and burnt animal bone from archaeological sites. *Journal of Mammalogy* 30:163-169.

Grayson, D. K.
1973 On the methodology of faunal analysis. *American Antiquity* 38:432-439.

1984 *Quantitative Zooarchaeology: Topics in the Analysis of Archaeological Faunas*. Academic Press, New York.

Hanson, D. K.
1998 *Representation of cremated fauna from hearths at Gulkana (49-GUL-077), Alaska*. Unpublished report. Office of History and Archaeology, Department of Natural Resources, Anchorage.

Hesse, B. and P. Wapnish
1985 *Animal Bone Archaeology: From Objectives to Analysis*. Taraxacum Press, Washington, D.C.

Huelsbeck, D. R.
1983 *Mammals and Fish in the Subsistence Economy of Ozette.* Ph.D. dissertation. Washington State University.

Josenhans, H. W., D. W. Fedje, K. W. Conway and J. V. Barrie
1995 Post glacial sea levels on the Western Continental Shelf: evidence for rapid change, extensive subaerial exposure, and early human habitation. *Marine Geology* 125:73-94.

Josenhans, H. W., D. W. Fedje, R. Pienitz and J. R. Southon
1997 Early humans and rapidly changing Holocene seal levels in the Queen Charlotte Islands -- Hecate Strait, British Columbia, Canada. *Science* 277:71-74.

Klein, R. G. and K. Cruz-Uribe
1984 *The Analysis of Animal Bones from Archaeological Sites*. University of Chicago Press, Chicago.

Leach, F.
1997 *A Guide to the Identification of Fish Remains from New Zealand Archaeological Sites*. University of Otago, Dunedin.

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.
1979 Available meat from faunal remains: a consideration of techniques. *American Antiquity* 44:536-546.

1994 *Vertebrate Taphonomy*. Cambridge University Press, Cambridge.

Lyman, R. L. and M. J. O'Brien
1987 Plow-zone zooarchaeology: fragmentation and identifiability. *Journal of Field Archaeology* 14:493-500.

Mackie, Q., M. Steffen, N. Smith, D. W. Fedje and D. McLaren
n.d. Preliminary results from the Richardson Island archaeological site, a highly stratified early Holocene occupation in southern Haida Gwaii.

Marshall, F. and T. Pilgram
1993 NISP vs. MNI in quantification of body-part representation. *American Antiquity* 58:261-269.

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.

Moss, M. L.
1989 *Archaeology and Cultural Ecology of the Prehistoric Angoon Tlingit.* Ph.D. dissertation. University of California at Santa Barbara.

Nicholson, R. A.
1993 A morphological investigation of burnt animal bone and an evaluation of its utility in archaeology. *Journal of Archaeological Science* 20:411-428.

1995 Out of the frying pan into the fire: what value are burnt fish bones to archaeology? *Archaeofauna* 4:47-64.

1996 Bone degradation, burial medium and species representation: debunking the myths, an experiment-based approach. *Journal of Archaeological Science* 23:513-533.

Noe-Nygaard, N.
1983 The importance of aquatic resources to Mesolithic man at inland sites in Denmark. In *Animals and Archaeology: 2. Shell Middens, Fishes and Birds*, edited by C. Grigson and J.

Clutton-Brock, pp.125-142. BAR International Series 183.

Orchard, T.
2003 *An Application of the Linear Regression Technique for Determining Length and Weight of Six Fish Taxa: the Role of Selected Fish Species in Aleut Paleodiet*. BAR International Series 1172.

Outram, A. K., C. J. Knusel, S. Knight and A. F. Harding
2005 Understanding complex fragmented assemblages of human and animal remains: a fully integrated approach. *Journal of Archaeological Science* 32:1699-1710.

Payne, S.
1972 On the interpretation of bone samples from archaeological sites. In *Papers in Economic Prehistory*, edited by E. S. Higgs, pp.65-82. Cambridge University Press, Cambridge.

Rabinovich, R., O. Bar-Yosef and E. Tchernov
1996 How many ways to skin a gazelle: butchery patterns from an Upper Paleolithic site, Hayonim Cave, Israel. *Archaeozoologia* 8:11-52.

Reitz, E. J. and E. S. Wing
1999 *Zooarchaeology*. Cambridge University Press, Cambridge.

Richter, J.
1986 Experimental study of heat induced morphological change in fish bone collagen. *Journal of Archaeological Science* 12:477-481.

Rick, T. C., J. M. Erlandson, M. Glassow and M. L. Moss
2002 Evaluating the economic significance of sharks, skates, and rays (elasmobranchs) in prehistoric economies. *Journal of Archaeological Science* 19:111-122.

Ringrose, T. J.
1993 Bone counts and statistics: a critique. *Journal of Archaeological Science* 20:121-157.

Shipman, P., G. Foster and M. Schoeninger
1984 Burnt bones and teeth: an experimental study of color morphology, crystal structure and shrinkage. *Journal of Archaeological Science* 11:307-325.

Steffen, M.
2006 *Early Holocene Hearth Features and Burnt Faunal Assemblages at the Richardson Island Archaeological Site, Haida Gwaii, British Columbia*. M. A. thesis. University of Victoria.

Stewart, H.
1977 *Indian Fishing: Early Methods on the Northwest Coast*. J. J. Douglas, Vancouver.

Stewart, K. M.
1991 Modern fishbone assemblages at Lake Turkana, Kenya: a methodology to aid in recognition of hominid fish utilization. *Journal of Archaeological Science* 18:579-603.

Stiner, M. C., S. L. Kuhn, S. Weiner and O. Bar-Yosef
1995 Differential burning, recrystallization, and fragmentation of archaeological bone. *Journal of Archaeological Science* 22:223-237.

Stiner, M. C. and N. D. Munro
2002 Approaches to prehistoric diet breadth, demography, and prey ranking systems in time and space. *Journal of Archaeological Method and Theory* 9:181-194.

Van Neer, W. and A. M. Morales
1992 Fish middens: anthropogenic accumulations of fish remains and their bearing on archaeoicthyological analysis. *Journal of Archaeological Science* 19:683-695.

Watson, J. P. N.
1972 Fragmentation analysis of animal bone samples from archaeological sites. *Archaeometry* 14:221-228.

Wheeler, A. and A. K. G. Jones
1989 *Fishes*. Cambridge University Press, Cambridge.

White, T. E.
1953 Method of calculating the dietary percentage of various food animals utilized by aboriginal peoples: I. *American Antiquity* 17:337-338.

Wigen, R. J.
2002 *Excavations at 1325T (Kilgii Gwaay)*. Unpublished report. Parks Canada Archaeology Services.

2003 *Identification of fauna from Richardson Island, 2003*. Unpublished report. University of Victoria.

2005 Vertebrate fauna. In *The Hoko River Archaeological Site Complex*, edited by D. R. Croes. Washington State University Press, Pullman.

Wigen, R. J. and B. R. Stucki
1988 Taphonomy and stratigraphy in the interpretation of economic patterns at Hoko River Rockshelter. In *Prehistoric Economies of the Pacific Northwest Coast*, edited by B. L. Isaac, pp. 87-146. JAI Press, London.

Zohar, I., T. Dayan, E. Galili and E. Spanier
2001 Fish processing during the early Holocene: a taphonomic case study from coastal Israel. *Journal of Archaeological Science* 28:1041-1053.

Skeletal element by anatomical region	**Number per rockfish**	**Multiple-use hearth**	**Single-use hearth**	**K26 F1a (ca. 9290 BP)**	**S22 F1a (ca. 9240 BP)**	**Q12 F1a (ca. 9120 BP)**
Total NISP		**923**	**136**	**80**	**150**	**166**
Total MNI		**8**	**1**	**5**	**2**	**2**
Skull Element						
parasphenoid	1	18	4	2	2	1
vomer	1	11		1	3	1
frontal	2	1				
prefrontal	2	1				
alisphenoid (pterosphenoid)	2					
sphenotic	2	1		3		1
prootic	2				1	
pterotic	2	1	1			
opisthotic (intercalar)	2					
exoccipital	2	13		1		1
epiotic (epioccipital)	2	6	1		2	3
supraoccipital	1			1		
basioccipital	1	6			1	2
parietal	2	6	1		1	2
ethmoid	1	3	1			
supratemporal	2					
suborbital/infraorbital	6					
otolith	2	7				
TOTAL	**35**	**73**	**8**	**8**	**10**	**11**
Appendicular Skeleton (Pectoral Girdle)						
supracleithrum	2	10	1	1		1
posttemporal	2	11	1	1	1	2
cleithrum	2	3	1		1	1
hypercoracoid (scapula)	2			2	1	
hypocoracoid (coracoid)	2					
postcleithrum	2	3		1	1	
pelvis (basipterygium)	2	3				1
interhaemal spine	1	2				1
mesocoracoid	2					
radials	6	13	1		1	1
TOTAL	**23**	**45**	**4**	**5**	**5**	**7**
Vertebrae						
atlas vertebra	1	8	1	1		
atlas vertebra process	1	8	1		1	2
vertebra	26	149	14	4	1	5
TOTAL	**28**	**166**	**16**	**5**	**2**	**7**
Tail Assemblage						
ultimate vertebra	1			1		1
hypural/epural	4	4	1	1	3	1
TOTAL	**5**	**4**	**1**	**2**	**3**	**2**

Skeletal element by anatomical region	Number per rockfish	Multiple-use hearth	Single-use hearth	K26 F1a (ca. 9290 BP)	S22 F1a (ca. 9240 BP)	Q12 F1a (ca. 9120 BP)
Suspentorium (Lateral "Face" Elements)						
premaxilla	2	18	7	5	3	2
maxilla	2	6		3	2	7
supramaxilla	2					
palatine	2	1		1		1
dentary	2	17	4	4	3	1
articular (angular)	2	3		1		
retroarticular	2	9				
mesopterygoid (endopterygoid)	2					
metapterygoid	2					
pterygoid (ectopterygoid)	2	7			1	
quadrate	2	12	2	1	1	2
symplectic	2	1				
hyomandibular	2	7				
preoperculum	2	6				
operculum	2	8	1			
suboperculum	2	1				
interoperculum	2					
nasal	2	7	1	4	2	2
TOTAL	**36**	**103**	**15**	**19**	**12**	**15**
Hyoid Arch						
glossohyal (lingual plate)	1					
basihyal	1					1
basibranchial	4					1
basisphenoid	1			1		
hypohyal	2	13				
ceratohyal	2	4				
epihyal	2	10		7		2
interhyal	2	4				
TOTAL	**15**	**31**		**8**		**4**
Branchial Arch						
urohyal	1			1	1	2
branchials	30	4	1			
TOTAL	**31**	**4**	**1**	**1**	**1**	**2**
gill rakers	>200	479	84	29	105	99
pterygiophores	25?	18	7	3	12	19

Appendix A: *Sebastes* (rockfish) NISP by element in experimental and archaeological hearths

Taxon	**Multiple-Use Experimental Hearth**	**Richardson Hearths Q12-F1a, S22-F1a, K26-F1a**
dogfish (*Squalus acanthias*)	spines, teeth, vertebra	teeth, vertebra
flatfish (Pleuronectiformes)	otolith, supracleithrum, vertebra	scutes
greenling (*Hexagrammos* sp.)	articular, basioccipital, dentary, epihyal, frontal, hyomandibular, maxilla, operculum, palatine, post-temporal, premaxilla, quadrate, supracleithrum, vertebra (caudal), vertebra (abdominal), vomer	vertebra (caudal)
halibut* (*Hippoglossus stenolepis*)	vertebra (caudal)	vertebra
herring (*Clupea pallasi*)	prootic, vertebra	prootic\sphenotic, vertebra
lingcod	articular, basioccipital, epibranchial, gill raker, hyperal, maxilla, parasphenoid, premaxilla, quadrate, radials, teeth**, first vertebra, vertebra (caudal), vertebra (abdominal)	teeth**
rock sole (*Lepidopsetta bilineata*)	first hypohyal, post-temporal, premaxilla, scutes	**not present**
starry flounder* (*Platichthys stellatus*)	basioccipital	scutes
sand lance* (*Ammodytes hexapterus*)	**not present**	vertebra
prickleback (Stichaeidae)	**not present**	vertebra
Irish lord (*Hemilepidotus* sp.)	**not present**	gill rakers, pterygiophores, scutes
great-type sculpin (*Myoxocephalus* sp.)	**not present**	vertebrae (abdominal)
salmon (*Oncorhynchus* sp.)	**not present**	gill rakers, parapophyses, vertebra

*tentative identification
**lingcod/arrowtooth flounder/hake/cabezon

Appendix B: Fish elements represented in experimental and archaeological hearths