2019

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Using bone fragmentation records to investigate coastal human ecodynamics: A case study from Číxʷicən (Washington State, USA)

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ARTICLE INFO

ABSTRACT

Coastal shell middens are known for their generally excellent preservation and abundant identifiable faunal remains, including delicate fish and bird bones that are often rare or poorly preserved at non-shell midden sites. Thus, when we began our human ecodynamics research project focused on the fauna from Číxʷicən (45CA523, pronounced *ch-WHEET-son*), a large ancestral village of the Lower Elwha Klallam Tribe, located on the shore of the Strait of Juan de Fuca, Port Angeles, Washington (USA), we anticipated generally high levels of bone identifiability. We quickly realized that the mammal bones were more fragmented and less identifiable than we had expected, though this was not the case with the bird and fish bone or invertebrate remains. To better understand why this fragmentation occurred at Číxʷicən, we evaluate numerous hypotheses, including both post-depositional and behavioral explanations. We conclude that multiple factors intersected (to varying degrees) to produce the extreme bone fragmentation and low identifiability of mammal bones at the site, including bone fuel use, marrow extraction, grease rendering, tool production, and post-depositional breakdown. Using a human ecodynamics framework, we further consider how both social factors and external environmental forces may mediate human choices, such as the economic decision to use bone for fuel or render bone grease. We place our findings from Číxʷicən in a regional context and discuss the potential of the approach for other coastal archaeological sites worldwide.

1. Introduction

Taphonomy is the study of the myriad behavioral, physical, and chemical factors that collectively influence deposition, survival, and recovery of bones and other animal parts from archaeological sites. Since the 1970s, archaeologists have recognized the importance of taphonomic analysis in isolating the factors that affect faunal remains across their 'life history' before drawing meaningful interpretations about past human activities (e.g., Behrensmeyer and Hill, 1980; Blumenschine, 1988; Brain, 1981; Ferraro et al., 2013; Gifford, 1981; Lyman, 1994; Orton, 2012). Taphonomic scholarship has two main goals: "to strip away the taphonomic overprint" (Lawrence, 1979:903; cited in Gifford, 1981) to obtain an accurate understanding of the original biological community or the systemic context (e.g., *sensu* Schiffer, 1987); and to understand the so-called overprint itself—with the idea that the overprint holds behavioral meaning in its own right (Gifford, 1981; Lyman, 1994).

The different ways scholars have approached bone fragmentation illustrates this important distinction. In some cases researchers have evaluated the extent to which differences in bone fragmentation may affect taxonomic or element identifiability (Grayson, 1991; Lyman and O'Brien, 1987; Nagaoka, 2005). In these cases, fragmentation is viewed as a *bias* structuring the assemblage, since it can misdirect our view of the target variable of interest—taxonomic or element representation. On the other hand, bone fragmentation itself has become a major focus of scholarship, as it can provide insights into carcass processing and broader questions of resource use. Scholars have studied bone fragmentation for its potential link to extraction of marrow, extraction of grease, and use as fuel (e.g., Binford, 1978; Church and Lyman, 2003; Ellis et al., 2011; Morin, 2010; Noe-Nygaard, 1977; Outram, 2003). Building on this theme, some researchers have sought to identify factors that promote bone processing, for example nutritional stress (Ellis et al.,

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2011; Outram, 2003). Nagaoka's (2005) study of moas, large flightless birds, at a southern New Zealand site illustrates both of these approaches. She evaluated changing bone fragmentation through time to see if it affected body part representation, and then drew on human behavioral ecology to account for changing patterns in processing moa bones for grease. She found that processing intensity increased through time, which she explains in the larger context of declining foraging efficiency.

The developing field of *human ecodynamics* offers a useful interdisciplinary framework for the study of the drivers behind patterning in bone fragmentation. Such research incorporates concepts from historical ecology, resilience theory, human behavioral ecology, and systems thinking—with the goal of building a long-term history of human-environmental interactions (Fitzhugh et al., this issue). Human ecodynamics scholarship takes the view that people are integral parts of the environment, not external actors. Human agency and historical contingency are incorporated into explanations of socio-ecological change. Faunal remains have figured prominently in human ecodynamics research, as a proxy for evaluating changes in the overall subsistence economy. Given that faunal remains are also a critical source of raw material across many human societies, for tools, fuel and grease, house construction and landform construction, we suggest that changing dynamics of environmental and social conditions would influence the ways human groups selected and processed animal carcasses through time.

The Čí̓xʷicən research project provides an important case study for applying human ecodynamics research to bone fragmentation. Čí̓xʷicən,[1] located in northwest Washington State on the shore of the Strait of Juan de Fuca (Fig. 1), is a traditional village of the Lower Elwha Klallam Tribe, and is linked more broadly to Coast Salish groups of the Salish Sea. The site was excavated as part of a large-scale mitigation in 2004, with materials excavated from an area of over 500 m², representing multiple houses and extramural middens (Butler et al., this issue a). Geoarchaeological study shows that both abrupt and gradual environmental processes (earthquakes, climate change, shoreline development) occurred over the ~2700 year period of site occupation (Campbell et al., this issue; Hutchinson et al., this issue).

Our research project, focusing on a large sample of the fauna representing the last ~2150 years of occupation, identified over one million specimens from at least 39 orders, 68 families and 81 genera of shellfish, fish, birds, and mammals (Butler et al., this issue b). A significant and unexpected finding was that the mammal bones are extremely fragmented, both in comparison to other vertebrate remains at the site, and to other sites in the region. Out of 16,520 specimens recovered in 1/4″ and larger mesh screens identified as mammal from all contexts, only 9% could be identified at least to order, while approximately 50% of both fish and bird were identified. The high degree of mammal fragmentation is distinctive in a regional context (Table 1, and see Section 2).

We initially viewed this high degree of fragmentation as a detraction, as it limited our ability to obtain specific taxonomic identifications, important to the larger project goal of studying the ways animals (and, in turn, people) were affected by a range of socio-ecological changes. On further reflection, we realized that taxon-specific patterns and temporal trends in fragmentation itself could provide insights on changing carcass use under differing socio-ecological conditions. The high level of precision in field sampling and deposit description, good chronological control (with 102 radiocarbon dates), and faunal samples obtained from multiple houses and extramural activity areas would allow us to begin to disentangle the many factors that challenge taphonomic analyses in general. In addition, we could use the human ecodynamics framework, which we were already using to examine changing animal use, to consider the range of factors behind fragmentation.

Thus our project on Čí̓xʷicən bone fragmentation emerged. This paper summarizes that effort. First we place the Čí̓xʷicən faunal record in a larger regional context to illustrate the distinctiveness of mammal fragmentation at the site. Then we outline the main behavioral factors that could account for the breakage, including bone tool manufacture, grease production, and use of bone as fuel, as well as post-depositional factors such as diagenesis, trampling, and carnivore gnawing. Next, we evaluate the relative importance of these factors at Čí̓xʷicən using comparisons from the bird and fish remains. Finally, we examine the higher-level economic and cultural factors that might condition carcass processing (group size, social interaction, circumscription). We consider how environmental forces mediate cultural decision-making about grease production or use of bone for fuel, and whether it is possible to link bone fragmentation to ritual practices.

2. Čí̓xʷicən mammal fragmentation in regional context

As noted above, we were initially surprised by the high degree of fragmentation in the Čí̓xʷicən mammal bone assemblage, which did not fit our expectations based on prior experiences with coastal archaeological sites in the North Pacific. We first need to place the Čí̓xʷicən mammal data in a larger regional context to see if our impressions were correct. Is the Čí̓xʷicən mammal assemblage more fragmented than assemblages from other sites in the region? For that comparison, we compiled data from selected published and unpublished literature (Table 1). To be included in our review, site reports needed to meet three main criteria: 1, materials must have been recovered with a minimum mesh size of 1/4″; 2, if smaller size fractions were recovered, they must have been analyzed and reported separately from the larger size fractions; and 3, the number of bones identified only as 'mammal' must also have been reported. Many sites, including Ozette (45CA24; Huelsbeck, 1994) and McNichols Creek (Coupland, 2006), discussed below, did not meet these criteria and were excluded from the regional comparison.

Our comparative sample of 13 sites includes nine on the outer coast of Washington and Vancouver Island to Alaska and four from the Salish Sea in Washington State (Fig. 1, Table 1). Our sample derives from a large geographic area reflecting the broad similarity in dietary use of animals by coastal foragers along this entire region of the North Pacific. We assess the *identifiability* of each assemblage (as a proxy for fragmentation) using a simple comparison of two standard zooarchaeological measures: *Number of Identified Specimens* (NISP) and *Number of Specimens* (NSP) (Grayson, 1991—see Section 4.1). NISP includes specimens identified at least to order, while NSP is the total number of mammal specimens in the assemblage (including both identifiable and unidentifiable fragments). The ratio of NSP to NISP provides an indication of identifiability, with values increasing as identifiability decreases. The NSP:NISP values from our list of comparative sites range from 1.4 (Amaknak Bridge) to 11.0 (Čí̓xʷicən). The English Camp site (45SJ24) has a comparable value to Čí̓xʷicən (10.6), but all of the others are ≤7.0. The average for all fourteen sites in the sample is 4.4, which corresponds to an identification rate (NISP/NSP*100) of 23%, which is considerably higher than the 9% identification rate for Čí̓xʷicən. We conclude that the mammal bones from Čí̓xʷicən are, indeed, more fragmented than is the norm for shell midden and rockshelter sites from the North Pacific coast.

While some of the differences between specific NSP:NISP values may be due to issues of site preservation (e.g. variation in abundance of shell and thus pH) or differing analysis methods, they also likely reflect disparities in how people processed different kinds of animals. For example, McMillan and McKechnie (2015) have noted that sites on the outer coast tend to be dominated by marine mammals, while terrestrial mammals are more frequent in sites in the Salish Sea. The

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[1] An alternative spelling for the site name, Tse-whit-zen, has been used in some previous reports and publications. The Klallam language spelling, Čí̓xʷicən (Montler, 2012) is preferred by the Lower Elwha Klallam Tribe.
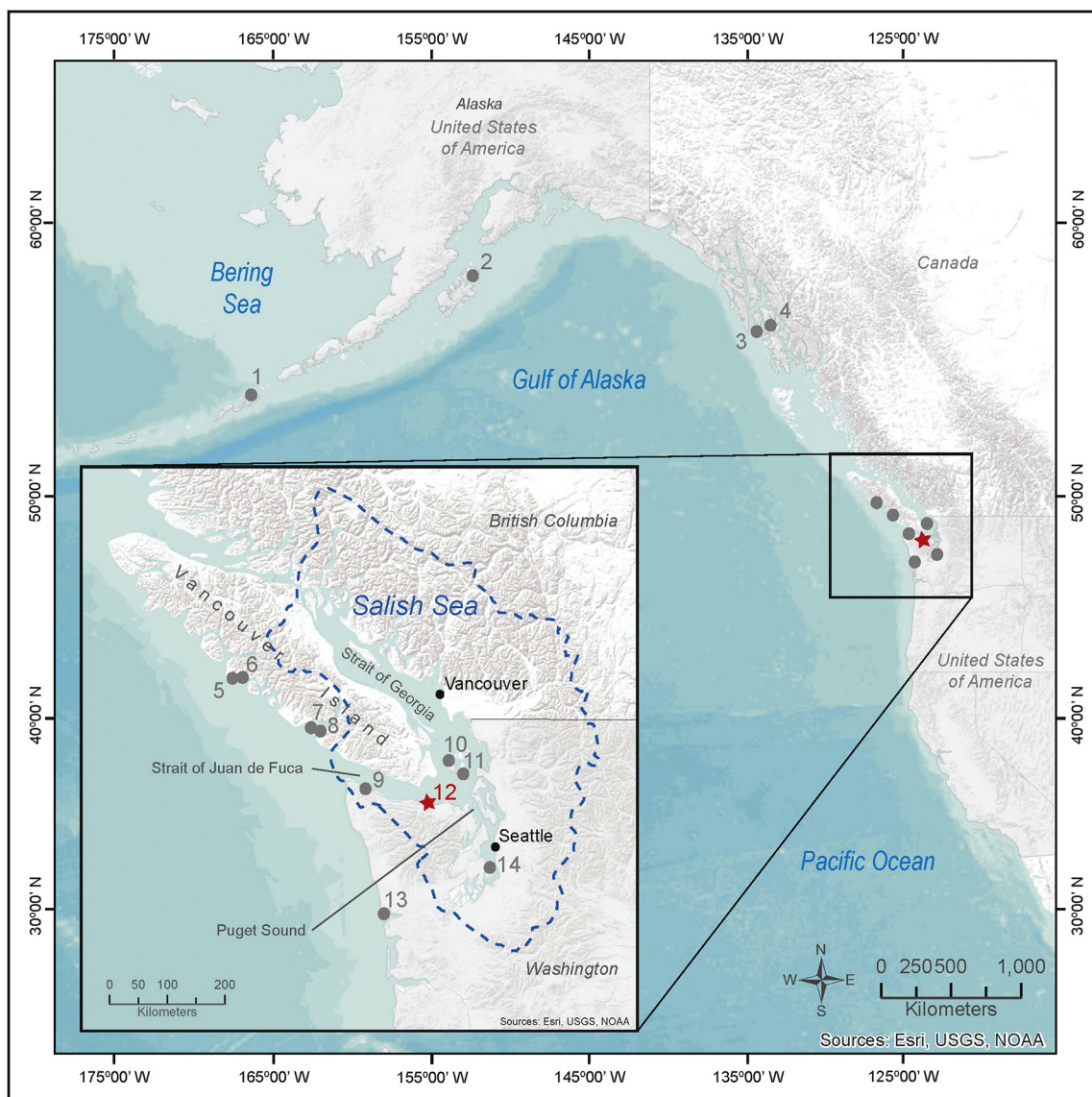
Fig. 1. Map of North Pacific showing the location of Číxʷicən village (12) and comparative sites: (1) Amaknak Bridge, (2) Igvak, (3) Cape Addington Rockshelter, (4) Coffman Cove, (5) Hesquiat Village, (6) Yaksis Cave, (7) Ts'shaa, (8) HuuẔii, (9) Hoko River Rockshelter, (10) English Camp, (11) Watmough Bay, (13) Minard, and (14) Burton Acres. Dashed line shows outline of Salish Sea watershed. See Table 2 for more information on each site (figure drafted by Kendal McDonald.)

two sites with the greatest identifiability, Amaknak Bridge (49UNL50) and Hesquiat Village (DiSo1) are located on the outer coast and have assemblages dominated by pinnipeds (seals and sea lions; Calvert, 1980; Crockford et al., 2004). In contrast, the two sites with lowest identifiability, Číxʷicən and English Camp, are located on interior waters and have greater relative proportions of artiodactyls (deer and elk; Butler et al., this issue b; Pegg, 1999). Thus, the differences in identifiability may be due, in part, to differences in how sea mammals and terrestrial mammals are processed, a point we return to below (Section 5.4).

3. Overview of factors controlling bone breakage

Extensive scholarship on bone fragmentation in archaeology, as well as in paleontology and forensics, includes ethnographic, experimental, and zooarchaeological analyses (see Church and Lyman, 2003; Outram, 2001; Morin and Soulier, 2017 and Munro and Bar-Oz, 2005 for summaries of archaeological bone fragmentation research). Many of these studies focus either on domesticated animals or large terrestrial mammals. Here we focus on the most relevant literature related to complex

coastal foragers, such as the people living at Číxʷicən, who hunted and processed both terrestrial and marine mammals, as well as birds, fish and shellfish. We investigated a number of systemic and post-depositional explanations for bone fragmentation (Table 2, Fig. 2). We give a brief overview of these factors here, and provide more detail on the most relevant ones below (Section 5).

Fig. 2 compares the hypothetical 'life histories' of bones from birds, fish, and three types of mammals: pinnipeds, cetaceans (whales, porpoises), and artiodactyls. All of these taxonomic groups have the potential to be fragmented during processing or cooking; for example, bird bones may be broken during roasting (as evidenced by burning along the broken shaft; e.g., Bovy, 2005:120; Howard, 1929:379). Selected bird and mammal bones may be chosen for bone tool production. Bird wing bones are commonly curated for both awls and ornaments (e.g., Bovy, 2012; Crockford et al., 1997). Tougher materials like antler and whalebone are favored for wedges and harpoons, and hard brittle materials (e.g., splintered artiodactyl long bones) are used for pointed tools, such as awls and points (Margaris, 2009, 2014). Large cetacean bones may be used as building material for construction of features (e.g., water-diversion or bank stabilization features; Huelsbeck, 1994)

Table 1

Comparison of mammal bone identifiability for sample of North Pacific archaeological sites (Number of Specimens [NSP]: Number of Identifiable Specimens [NISP]). Includes ≥1/4″ mesh samples only. The Čí̓xʷicən village site is indicated in bold.

Map #	Site name (number; location)	NSP	NISP[a]	NSP:NISP	Comments	Reference
1	Amaknak Bridge (49UNL50; Amaknak Island, Alaska)	18,347	13,160	1.4		Crockford et al., 2004
2	Igvak (49AFG016; Afognak Island, Alaska)	1980	697	2.8	Reportedly screened down to 1/8″, but size of faunal remains consistent with 1/4″ screening	Etnier et al., 2016
3	Cape Addington Rockshelter (49CRG188; Prince of Wales Island, Alaska)	1851	908	2.0		Moss, 2004
4	Coffman Cove (49PET067; Prince of Wales Island, Alaska)	2193	315	7.0		Moss, 2016
5	Hesquiat Village (DiSo1; Vancouver Island, British Columbia)	3990	2188	1.8	All temporal assemblages	Calvert, 1980
6	Yaksis Cave (DiSo16; Vancouver Island, British Columbia)	286	133	2.2		Calvert, 1980
7	Ts'ishaa (DfSi16; Vancouver Island, British Columbia)	2995	1474	2.0		Frederick and Crockford, 2005
8	Huu7ii (DfSh7; Vancouver Island, British Columbia)	12,955	2828	4.6	2004 and 2006 sample; excludes column samples	Frederick, 2012
9	Hoko River Rockshelter (45CA21; Olympic Peninsula, Washington)	16,802	5129	3.3	"Antler detritus" counted as identifiable	Wigen, 2005
10	English Camp (45SJ24; San Juan Island, Washington)	4359	413	10.6	Op-A excavation	Pegg, 1999
11	Watmough Bay (45SJ280; Lopez Island, Washington)	1078	264	4.1	Data from 2004 excavation; conservative estimate (unidentified mammal may include some bird)	Bovy, n.d.
12	**Čí̓xʷicən (45CA523; Port Angeles, Washington)**	**15,416**	**1399**	**11.0**	Areas A4 & A5 (all bag types); value varies depending on bag type (Table 5): range = 2.9–20.0	Etnier, 2018
13	Minard (45GH15; Grays Harbor, Washington)	20,397	4882	4.2	Conservative estimate (unidentified mammal may include some bird?)	Fancher, 2001
14	Burton Acres (45KI437; Vashon Island, Washington)	1194	288	4.1	Conservative estimate (unidentified mammal may include some bird)	Bovy, 2002

[a] NISP only includes things identified at least to Order (e.g., does not include 'unidentified sea mammal' or 'unidentifiable terrestrial mammals').

or house architecture (e.g., McCartney and Savelle, 1993). Artiodactyl bones are likely to be broken to extract nutritious marrow (Binford, 1978; Munro and Bar-Oz, 2005), while bones from all types of mammals may be fragmented for grease and oil extraction or soup making (Munro and Bar-Oz, 2005).

Further processes may cause fragmentation after bones are discarded, both during the occupation of the site (systemic context) or after site abandonment (post-depositional processes). Discarded mammal bones may be mixed with wood for use as a fuel (Heizer, 1963), resulting in increased fragmentation (Théry-Parisot, 2002; see Section 5.2). All types of animal bone (mammals, birds, fish) may be burned intentionally for trash disposal and hence further fragmented or completely destroyed (Yravedra and Uzquiano, 2013). Wild carnivores or domesticated dogs may gnaw on and fragment discarded animal bones (Marean, 1991). All types of animal bone are also potentially subjected to mechanical pressure, such as compaction or trampling. Burned, and to a lesser extent boiled, bones are particularly vulnerable to destruction by trampling after discard (Roberts et al., 2002; Stiner et al., 1995). Finally, post-depositional weathering (Behrensmeyer, 1978) and chemical breakdown (Linse, 1992) may occur, depending on the length of exposure on the surface, percolation of ground water, and the acidity of the soils.

Overall, we expect that mammal bones would be more fragmented than those from fish or bird, given their value for a greater range of purposes, including tool production, marrow extraction, grease or oil production and use as a fuel additive (Fig. 2). And among mammals, artiodactyl bones are more likely to be fragmented in the systemic context than are pinniped and cetacean bones (Fig. 2). Artiodactyl long bones and antler are preferred raw materials for many types of tools. Artiodactyl long bones also offer valuable marrow, which is absent from sea mammals. Additionally, Outram (1999) has argued that seal bones are unlikely to be used for grease extraction, whereas artiodactyl bones are known to provide grease (Binford, 1978; Church and Lyman, 2003; see discussion in Section 5.4). In addition to all these cultural factors,

the inherent differences in the size of individuals from different animal classes, and the size of the resulting skeletal elements, may affect identifiability. In a summary of bird analyses from 24 Oregon coast sites, Bovy et al. (in press) list NSP and NISP values; the overall NSP:NISP value for all of these analyzed collections is 2.1, suggesting that relatively high identifiability is typical for bird assemblages from coastal shell middens.

4. Overview of Čí̓xʷicən faunal analysis

4.1. Methods & materials

The Čí̓xʷicən midden samples presented a large, complex analysis involving four different taxonomic specialists (KMB, birds; MAE, mammals; VLB, fish; SKC, invertebrates). Our study is focused on samples derived from seven block excavations in Areas A and B (Fig. 3) representing a range of different ages, contexts, and activity areas (Reetz et al., 2006; see Butler et al., this issue b, and Campbell et al., this issue, for details). Field sampling was designed to allow integration of all classes of faunal data (Reetz et al., 2006), and simple calculation of matrix volume (following Stein, 1992). Matrix was excavated from each uniquely defined deposit in each 1 × 1 m unit into 10 L buckets, which were water-screened through graded mesh 1″ (25.6 mm), 1/2″ (12.8 mm), and 1/4″ (6.4 mm). At least one bucket per stratum (per 1 × 1 m unit), labeled 'C' (*Complete*), was also put through nested screens down to 1/8″ (3.2 mm) mesh, which was also the only bucket from which shell was retained (Kaehler and Lewarch, 2006). After excavation, faunal remains were sorted into four main animal groups (fish, bird, mammal, shellfish) by lab personnel, and all materials were curated by the Burke Museum of Natural History and Culture. Formal artifacts recognized during the initial sorting were catalogued and curated separately from the midden samples (see Section 5.5).

There are four sample types from Čí̓xʷiən (Table 3). All analysts examined both 'C' buckets, which included material from the 1/8″ and

Table 2
Overview of factors affecting mammal bone fragmentation and expectations at Čḷx̌ʷicən.

Possible factors for mammal bone fragmentation	Archaeological expectations	Selected references	Expectation supported?
Post-depositional factors (may have occurred while site was still occupied or after abandonment)			
Chemical breakdown	Acidic soils negatively affect faunal preservation for all animal classes.	Linse, 1992	No
Surface exposure (weathering)	Solar and wind processes may cause bone fragmentation.	Behrensmeyer, 1978	No
Carnivore gnawing	Carnivore gnawing causes fragmentation (especially on epiphyses of long bones).	Marean, 1991	No
Mechanical pressure (e.g., compaction, trampling)	Bones more broken on floors or activity areas across all animal classes.	Lyman, 1994; Stahl and Zeidler, 1990	Yes
Post-depositional effects of burning or boiling in systemic context	Burned or boiled bones fragment more frequently than non-burned or boiled bones when trampled within top 4 cm of surface.	Roberts et al., 2002; Stiner et al., 1995	Yes
Behavioral/systemic context (the following explanations relate to intentional decisions made by site occupants)			
Trash disposal (burning)	Burning rates high for all food refuse (mammal, bird, fish).	Yravedra and Uzquiano, 2013	No
Fuel use	Mammal bones should be more frequently burned if used as fuel, and exhibit different patterns of burning than bird and fish.	Théry-Parisot, 2002	Yes
	Mammal bones should be found in contexts near hearths or burning activity areas.	Costamagno et al., 2002	No
	Dead/dry wood should be present, since bone fuel use increases efficiency of deadwood fires.	Théry-Parisot, 2002	Yes
Bone marrow extraction	Impact fractures are expected on artiodactyl elements that are high in marrow.	Munro and Bar-Oz, 2005	No - obscured by later processing?
	Artiodactyl bones are more likely to be fragmented compared to canid bones (less marrow), and also bird and pinniped bones (no marrow).	Lyman, 1991; Munro and Bar-Oz, 2005	Yes
Boiling bones: bone grease rendering and soup/stew making	Bone fragments should be relatively small. Fragments up to 5 cm (=2 in) are suitable for grease rendering, though smaller fragments require less water and fuel for processing.	Church and Lyman, 2003; Janzen et al., 2014; Morin and Soulier, 2017	Yes
	Association with thermal features.	Morin and Soulier, 2017	No
	Anvils (for processing bone fragments) should be recovered.	Morin and Soulier, 2017	2 recorded
Bone tool production	Bone and antler tools should be abundant, especially in comparison to lithic tools.		Yes
	Bone debris from tool production and tools for bone working should be present.		Yes

larger mesh screen, and 'CX' buckets, which were screened down to 1/4″ minimum mesh size, as well as relatively large remains recorded *in situ* ('E' samples). Additional mammal and bird bones from 'S' buckets were analyzed by Etnier and Bovy, respectively, in order to bolster the overall sample size for those taxonomic classes (Table 3). These four types of samples combined represent the total 'population' or 'universe' of bone fragments recovered from the site, while the C/CX bags are a sample of this larger population. The totals shown in Table 4 reflect only the C/CX samples assigned to a specific temporal analytical unit or chronozone (hereafter, CZ, detailed in Campbell et al., this issue). Seven CZs were defined for the research project area. The oldest, CZ 1, ranges in age from 2150 to 1750 cal BP while the youngest, CZ 7, spans the time period 300–150 cal BP.

In general, each specialist identified individual fragments to the most specific taxon possible, although the protocols of each specialist varied slightly (Bovy, 2018; Butler et al., 2018; Etnier, 2018). An important aspect of our analysis was to document 'unidentified' fragments, to the extent possible given the size and nature of the specimen(s) in question. A bone was considered 'identifiable' if it was identified to at least taxonomic order. As is typical of many zooarchaeological analyses, the decision was made not to identify some skeletal elements; for example, no attempt was made to identify bird vertebrae, ribs, or phalanges (toes) beyond the class level. In this way, we relied on two main counting units (as discussed above): NISP, for specimens identified at least to order, and NSP, which joins NISP with specimens which could not be identified below main animal type (bird, mammal, fish, invertebrate). Etnier and Bovy assigned the majority of unidentifiable specimens from the 1/8″ screens to a 'non-fish vertebrate' category, due to the difficulty in distinguishing bird from mammal in the fragments not identifiable to element. One exception was bone chips and shavings (see Section 5.5), which were consistently recognizable as being from mammal bones based on their texture and bone structure. Most of the non-fish vertebrate specimens

represent fragments of larger specimens from larger-bodied animals (e.g. alcids, anatids, artiodactyls, pinnipeds), as opposed to whole elements from small-bodied animals, as was the case with much of the 1/8″ fish sample. The ~ 17,000 'non-fish vertebrate' remains (Table 4) are not included in this paper's analyses.

Analysts recorded standard zooarchaeological data for each specimen, such as element, portion, and taphonomic signatures. The taphonomic signatures recorded include presence and degree of burning, evidence of carnivore or rodent gnawing, intentional (or accidental) surface modification (i.e., percussion flake scars, chop marks, cut marks, etc.), gastric pitting, and distinctive breakage patterns. During the course of our analyses, we recognized that we were having difficulty clearly distinguishing various types and degrees of thermal alteration using only visual characteristics. We therefore restricted the term 'burning' only to fragments that were clearly burned, charred, or calcined—i.e. were dark brown to black to blue-ish white. We excluded bones that were uniformly gray, with a characteristic sound quality reminiscent of porcelain, which may have been subjected to indirect heating (Bennett, 1999). We also excluded dark brown specimens that may have been stained brown by the surrounding sediment. Thus, we believe that our coding of burning is conservative, as are our estimates of rates of burning across bones from different taxa. That said, in a reanalysis of random samples of fish remains, Nims and Butler (2017) found up to 10% error in burning assessments, indicating that at least for fish, subtle differences in burning rates may not be meaningful. Since taphonomy was not the initial goal of our study, we did not conduct specific studies relating to the physico-chemical effects of boiling (e.g., Roberts et al., 2002), or burning (Thompson et al., 2013), or more general analyses such as measurements, assessments of fracture freshness, crushing or tear marks, weathering stages, and presence of micro-inclusions (e.g., Heinrich, 2014; Morin and Soulier, 2017; Outram, 1999).

We used several different measures of fragmentation and identifiability to evaluate a series of related hypotheses concerning the
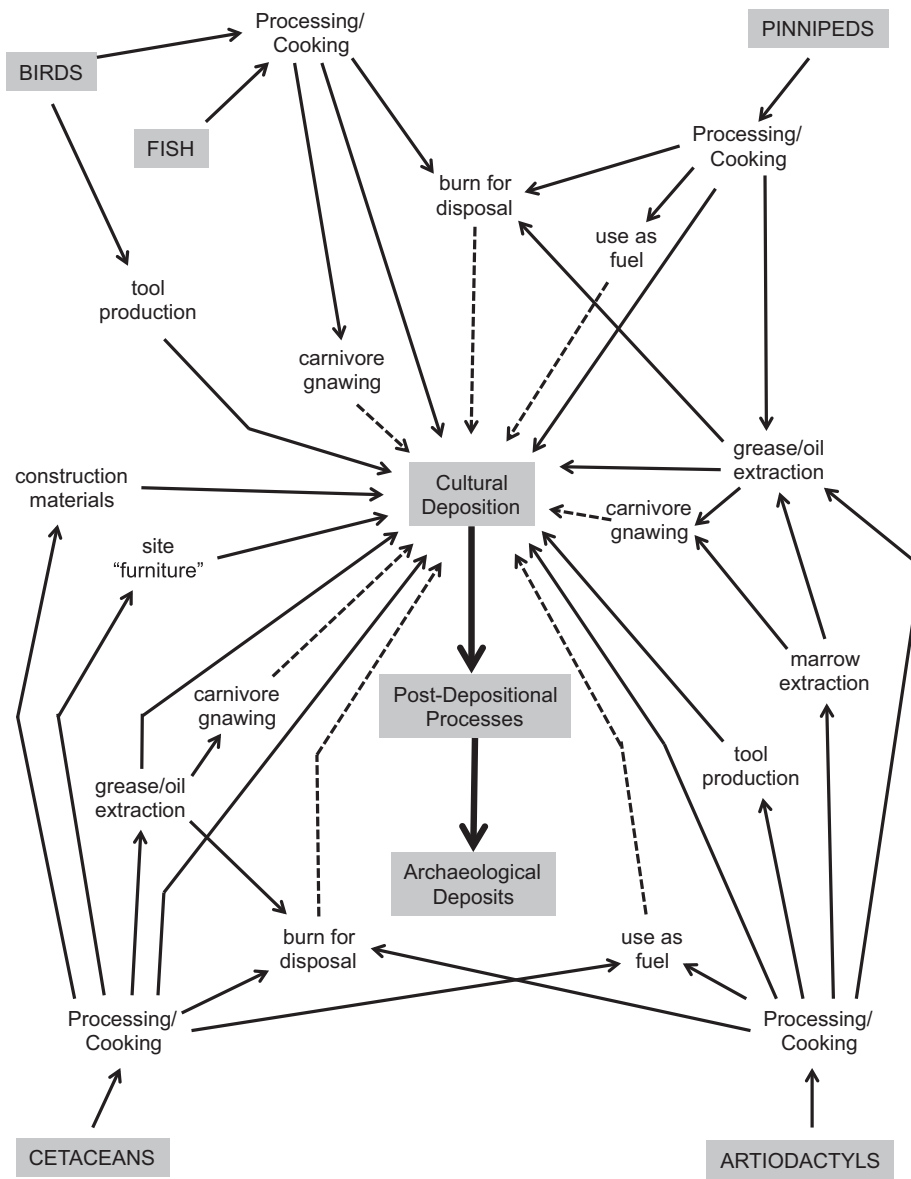
Fig. 2. Flow chart of 'life history' of bones from different taxonomic groups. Dashed lines indicate activities that may result in complete destruction of some or all of the bones subjected to that treatment.

taphonomic life histories of the various taxa included in our study. At a most basic level, the identifiability of vertebrate skeletal remains—whether to a specific taxon or even to skeletal element—provides an index of the fragmentation of that assemblage. Following Grayson (1991) and Nagaoka (2005), we examine the ratio of NSP to NISP. This can be thought of as 'the number of bones examined to yield one identified specimen,' and will range in value from one to infinity. Low NSP:NISP ratios indicate high identifiability, whereas high NSP:NISP ratios indicate low identifiability. Note that values of zero are impossible due to the structure of the ratio. In Tables 4 and 5 we include the inverse measure, NISP / NSP $*$ 100, which we label *identification rate*. We also calculated the proportion of whole vs. broken skeletal elements (% Whole), known as the *extent of fragmentation* (Lyman, 1994, 2008; Munro and Bar-Oz, 2005; Nagaoka, 2005; Nagaoka et al., 2008; Wolverton, 2002), for elements from the appendicular skeleton (minus the scapula and the pelvis). The *intensity of fragmentation* is commonly evaluated through ratios of NISP to minimum number of elements (MNE) or sizes of broken bones (Lyman, 1994). NISP to MNE ratios were not calculated for Čʼíxʷicən due to the very low sample sizes for individual skeletal elements of mammals. Instead, we calculate the

number of identified and unidentified fragments recovered in each of the different mesh sizes (1″, 1/2″, 1/4″) as a proxy for fragment size.

4.2. Overview of bone fragmentation at Čʼíxʷicən

The initial examination of identifiability clearly shows that the mammal bones from Čʼíxʷicən are less identifiable than the bird and the fish bones (Table 4). For birds and fish from the ≥1/4″ size fraction, one specimen was identified for every two specimens examined, indicating high levels of identifiability. Mammals, on the other hand, had much lower identifiability, requiring examination of 18 specimens to obtain a single identified specimen. This corresponds to identification rates of approximately 50% for birds and fish, but only 5% for mammals. Fish identifiability is the same in both the ≥1/4″ and ≥1/8″ size fractions, but the NSP:NISP ratios for mammals and birds are harder to interpret for the smaller screen size because Bovy and Etnier assigned most specimens not identifiable to element to the 'non-fish vertebrate' category (Table 4). For this reason, we focus on those materials that are ≥1/4″ for all of our subsequent analyses.

Table 5 shows the differences in mammal identifiability by sample type; here we focus only on material from Areas A4 and A5, which allows
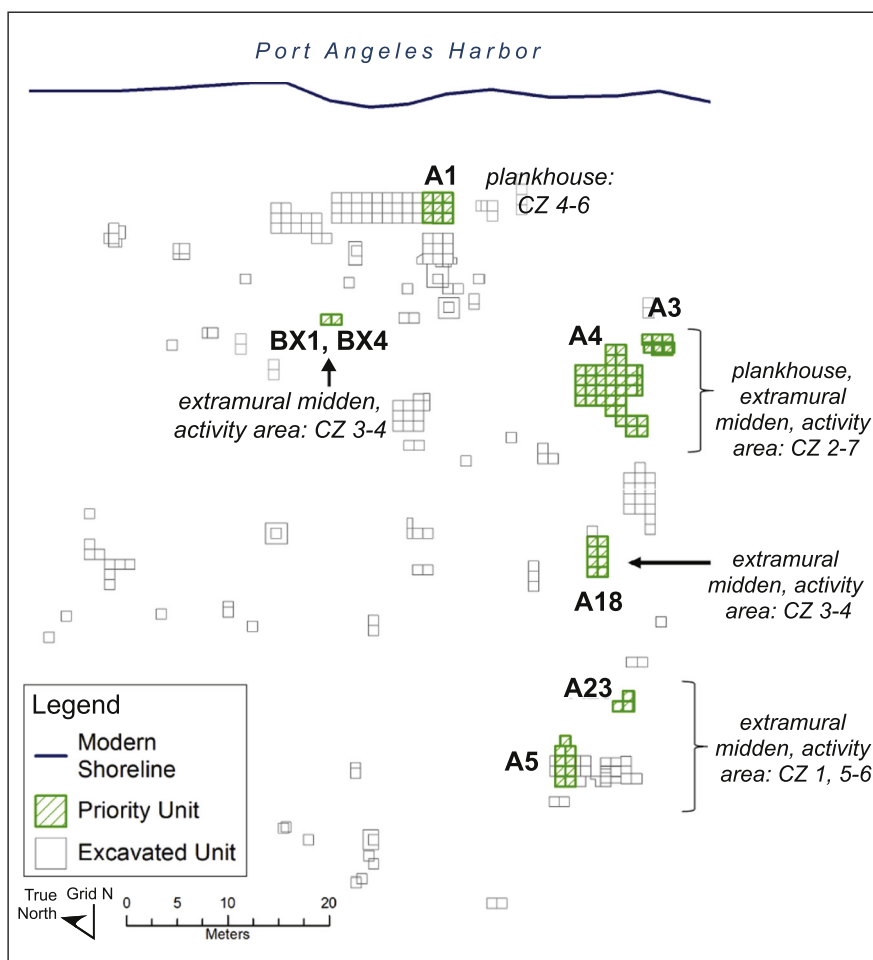
Fig. 3. Map of the Čḯxʷicən village site, showing areas targeted for geo-zooarchaeological analysis, with chronozone (CZ) assignments and cultural activity indicated (figure drafted by Kristina Dick).

Table 3
Summary of field sampling methods and types at Čḯxʷicən, including bucket samples included in current project.[a]

Sample code	Description	Fauna collected	# of buckets analyzed
C	10 L bucket, to 1/8″ mesh	All	457
CX	10 L bucket, to 1/4″ mesh	All	363
S[b]	10 L bucket, to 1/4″ mesh	Mammal, bird, fish	Mammal: 1863; Bird: 401
E	Recorded *in situ*	All, typically larger specimens	

[a] Samples from excavation areas A1, A3, A4, A18, A23, A5, BX1/BX4.
[b] Additional S samples from A4 & A5 were analyzed for mammals because of the relatively small numbers of specimens identified to taxon in the C/CX buckets; bird remains from A4 (Units 17–20 only), A5 and A23 S buckets were also studied.

us to maximize the number of mammal bones included in the analysis, as all of the samples (C/CX, S, E) were examined from these two areas. Note that the specimens collected *in situ* ('E' bags) are much more identifiable than those recovered in the screens (35% identifiable vs. 5–8%). This makes sense given that these were typically larger fragments, which field crewmembers observed and recorded during excavation. Nonetheless, the *in situ* mammal remains are still much less identifiable than those of birds recovered from the same contexts; 89% (304/343) of the bird bones from 'E' bags from A4 and A5 were identifiable to taxon.

5. Explaining fragmentation at Čḯxʷicən: hypotheses and results

5.1. Post-depositional factors

Potential 'post-depositional' factors affecting mammal fragmentation include those that occurred after abandonment as well as while the site was still actively occupied; some factors, such as carnivore gnawing and mechanical pressure, might occur at both times (Fig. 2, Table 2). In addition, the impact of post-depositional processes may have been exacerbated by intentional human behaviors (burning or boiling bones) prior to deposition.

If chemical processes or weathering were the primary cause of mammal bone fragmentation at Čḯxʷicən, we would expect the bird and fish bones to be similarly affected, which is not the case. Qualitative assessments indicate good overall preservation at the site, which is typical of shell middens. Delicate bird and fish bones are present, such as bird skull fragments and tracheal rings, and neural spines on herring (*Clupea pallasii*) vertebrae. Soil pH measurements (n = 36) obtained following the 2004 field project range from 7.0–7.7, with an average of 7.5, and are relatively uniform throughout horizontal and vertical space, indicating soils were neutral or moderately alkaline, rather than acidic. As for weathering from surface exposure, only seven mammal bones exhibited any attributes indicative of exposure such as cracking.

Carnivore gnawing is known to increase mammal bone fragmentation, especially of the epiphyses of long bones (Blumenschine, 1988; Brain, 1981; Lyman, 1994; Marean, 1991; Weigelt, 1927). Coast Salish peoples had domesticated dogs (Crockford, 1997); and dog is the

Table 4
Overview of bone identifiability at Čḭx̌ʷicən.[a]

	≥1/4″ (C/CX buckets)				≥1/8″ (C buckets)			
	NSP	NISP	NSP:NISP	ID rate[b]	NSP	NISP	NSP:NISP	ID rate[b]
Fish	13,545	6766	2.0	50.0	85,559	43,373	2.0	50.7
Bird	3261	1588	2.1	48.7	4203	1508	> 2.8[c]	35.9
Mammal	4627	252	18.4	5.4	3417	231	> 14.8[c]	6.8
Vertebrate (non-fish)	170				16,930			

[a] Includes all samples assigned to Chronozone for areas A1, A4, A5, A18, A23, and BX1/BX4; analyzed volume for this comparison = 433 10 L C buckets and 355 10 L CX buckets. See text for details on calculation of NSP and NISP.

[b] Identification rate = NISP / NSP * 100.

[c] The ≥1/8″ NSP:NISP values for birds and mammals are low because most fragments not identified to element were coded as 'non-fish vertebrate'. See discussion in text.

Table 5
Mammal identifiability by sample type for 1/4″ and larger.[a]

Sample type	# of buckets analyzed	NSP	NISP	NSP:NISP	ID rate (NISP / NSP * 100)
C/CX	645	3933	197	20.0	5.0
S	1863	10,512	866	12.1	8.2
E (*in situ*)	n/a	971	336	2.9	34.6
Total	2508	15,416	1399	11.0	9.1

[a] Includes Areas A4 & A5 only (100% of the mammal bones was examined from those two areas). Bones from E bags were not recovered in the screens, but tended to be fairly large (> 1/4″).

second most abundant mammalian taxon at Čḭx̌ʷicən after cervids (Butler et al., this issue b). Evidence for carnivore gnawing and digestive erosion is limited at Čḭx̌ʷicən (gnawing: birds, n = 11; mammals, n = 82; gastric pitting: fish, n = 10; birds, n = 24; mammals, n = 21), indicating carnivore action contributed little to fragmentation. Of course it is possible that some bones were completely consumed by dogs, a hypothesis impossible to test.

All else being equal, mechanical pressure, such as trampling or sediment compaction would also be expected to affect bone from all animal types more or less uniformly, and would be more likely to occur on house floors. If we compare the identifiability for occupation surfaces (floors, pre-house activity areas) versus secondary refuse contexts (extramural deposits, fill) from House A4, we find that mammals are less identifiable on occupation surfaces, consistent with the effects of trampling in activity areas (Fig. 4). This pattern does not hold for bird and fish, which have uniformly high identifiability in both contexts (Fig. 5). Note that while there is some variation within the occupational surface and secondary refuse categories, these overall trends are consistent.

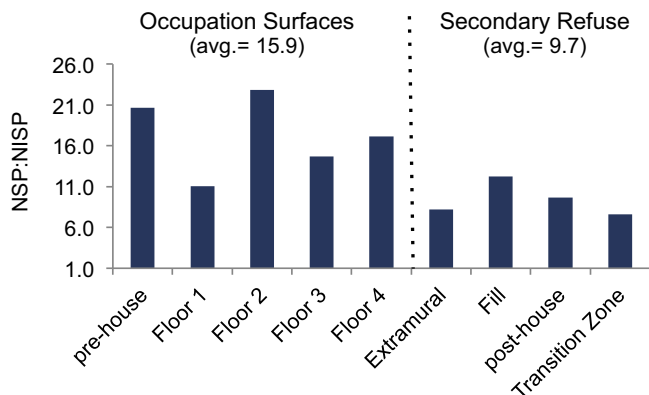Why might mammal bones be more fragmented on occupational

Fig. 4. Mammal bone identifiability (NSP:NISP) in Area A4 by depositional context. All sample types included; ≥1/4″ mesh screen.
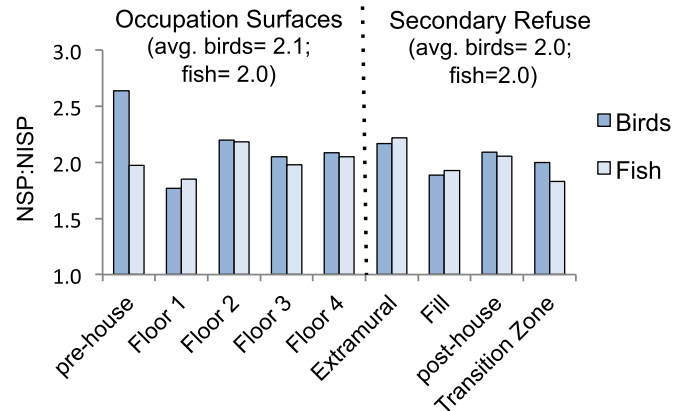

Fig. 5. Bird and fish bone identifiability (NSP:NISP) in Area A4 by depositional context. Samples included: C/CX only; ≥1/4″ mesh screen.

surfaces than bird or fish? Both burning and boiling are known to contribute to fragmentation. In experimental studies, Stiner et al. (1995) found that burned bones were more likely to be fragmented due to trampling than unburned bones; furthermore, bones that were subjected to higher burning intensity were more highly fragmented and less identifiable to element. Similar to burning, boiling as part of food processing may contribute to fragmentation after deposition, because of loss of mechanical strength. In boiling experiments, Roberts et al. (2002) found decreased collagen content, and increased crystallization and porosity in bovine rib bones boiled over prolonged periods of time (> 9 h), which would likely reduce mechanical strength and accelerate diagenesis.

In sum, post-depositional factors such as chemical breakdown, surface weathering, and carnivore gnawing had negligible impacts on fragmentation at Čḭx̌ʷicən. However, mechanical pressure does appear to have been a factor contributing to mammal bone fragmentation. Below we explore patterns of burning (Section 5.2) and boiling (Section 5.4) at Čḭx̌ʷicən to further assess whether these systemic processes may have affected the bone condition at the site.

5.2. Intentional burning of fresh bone: trash disposal and fuel use

In several scenarios, fresh bone may have been intentionally burned, which could result in increased fragmentation, either as a direct result of the burning or through post-depositional trampling. In the context of permanent long-term residential areas, these scenarios include general trash disposal and use as fuel or a fuel additive.

High degrees of burning in vertebrate assemblages may reflect intentional burning for trash disposal, which might be done to make living conditions more hygienic and/or deter scavengers (Yravedra and Uzquiano, 2013). Although use of bone for fuel is rarely discussed for North American contexts (but see Grayson, 1991; Morgan et al., 2012),

the use of bone fuel has been posited for many Upper Paleolithic sites (e.g., Beresford-Jones et al., 2010; Costamagno et al., 2002; Heizer, 1963; Théry-Parisot et al., 2002) and Middle Paleolithic sites of Europe (e.g., Goldberg et al., 2012). Heizer (1963:188) also describes historic accounts of people in northern latitudes using a combination of cetacean oil and bone for fuel in place of wood. Experimental work has shown that a wood and bone fuel mix has advantageous properties compared to wood fires alone, including longer combustion times (Théry-Parisot, 2002). Théry-Parisot (2002) conducted experiments to determine the optimal fuel mix in terms of heat transfer and duration, and found mixed bone-wood fires burn on average 33% longer than fires fueled by wood alone. She found that bone fuel was particularly effective at improving the longevity of fires using 'deadwood' (wood already detached from the tree and in a state of decomposition). Vaneeckhout et al. (2013) discovered that a combination of bone and wood burns with lower temperature, but produces more light, which may be especially useful in winter months in northern latitudes.

Archaeologists have assumed that mammal bones, especially the grease-rich spongy epiphyses of long bones (e.g., Costamagno et al., 2002; Morin, 2010; Théry-Parisot et al., 2002; Yravedra and Uzquiano, 2013), are more likely to be chosen as fuel than birds or fish. For example, in their analysis of a Neandertal hearth at El Esquilleu cave, Spain, Yravedra and Uzquiano (2013) found high proportions of charred ibex (*Capra pyrenaica*) shafts (relative to epiphyses) and argued occupants were burning for trash disposal rather than intentional fuel use. Vaneeckhout et al. (2013) compared qualities of bones from moose (*Alces alces*), brown bear (*Ursus arctos*), and phocid seals in terms of fire temperature and duration; they found that fires using seal bones had lower temperatures and bones were less fragmented (compared to the moose and bear). They reasoned that seal bones were not as useful for fuel because seals store fat under their skin, rather than in the bones, unlike moose and bear bones, which contain fatty marrow. However, if pinniped or seal bones were combined with oil from the animals (as in the historic example noted by Heizer above), they may have been effective for fuel.

Distinguishing accidental burning (during cooking or after discard), from intentional refuse burning or use of bone as fuel, is a challenging task (Heizer, 1963:188). We suggest that if occupants of Čḯxʷicən were burning bones for trash disposal, or if this burning happened post-depositionally, all animal types would show a similar frequency of burning; whereas if bones were burned for fuel use, the mammal bones would be more frequently burned. Our expectation for trash disposal is not met: mammal bone consistently shows a higher frequency of burning than bird or fish bone (Fig. 6). Mammal bones are burned 51.4% of the time (on average) for occupation surfaces and 30.2% of the time in secondary refuse contexts, compared to 32.8% and 23.3% respectively for bird, and 7.2% and 4.9% for fish. The fact that burning rates for mammals are much higher on occupation surfaces may account for the lower identifiability of mammal bones in these contexts (Fig. 4; see Section 5.1), supporting the hypothesis that post-depositional mechanical pressure of burned bones contributed to the mammal fragmentation. However, the relationships are more complex than this. While frequency of burning appears to contribute to low identifiability on the A4 house floors, this is not the case in all contexts at Čḯxʷicən. Fig. 7 plots mammal identifiability vs. burning rates for thirteen different spatial contexts and CZ pairings; there is no overall relationship between burning and identifiability ($R^2 = 0.02992$; $p = 0.57201$).

If trash disposal is not the cause for the high rates[2] of mammal burning (and subsequent fragmentation), how does the bone fuel hypothesis measure up? To test this hypothesis further, we consider

Fig. 6. Percent burned bone in Area A4 by depositional context. Samples included: all sample types for mammal; C/CX only for birds and fish; ≥ 1/4″ mesh screen.
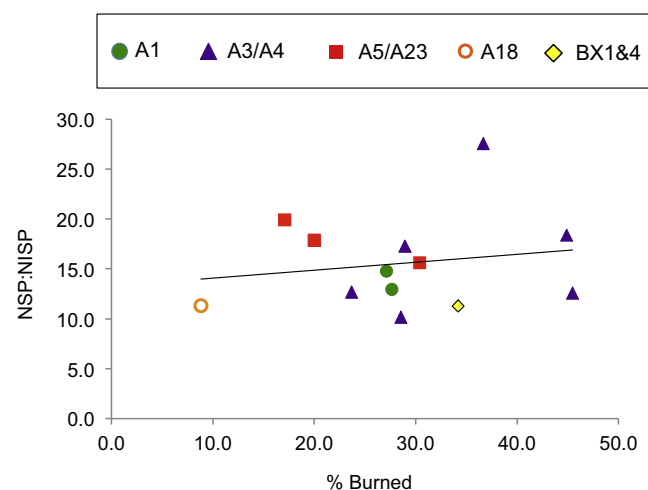
Fig. 7. Mammal identifiability (NSP:NISP) and burning rate for each Area and CZ pairing. The slope coefficient is not significant ($r^2 = 0.02992$; $p = 0.57201$). Samples included: C/CX only; ≥ 1/4″ mesh screen.

additional test implications (Table 2).[3] First, we would expect mammal bones to be preferentially selected over bird bones for use as a bone fuel additive, due to the inherent differences in fat and grease content. We explore more detailed comparisons of mammal and bird burning patterns, to determine whether these two types of animals were treated differently at the site. As with mammal, bird bones are also more burned on occupation surfaces than secondary contexts (Fig. 6), but the identifiability of bird bones is comparable in both cases (Fig. 5). If we look at burning by screen size for mammals vs. birds, we again see a difference. Burned unidentifiable mammal fragments dominate the smaller screen sizes (Fig. 8), while burned and non-burned bird bones are roughly equal in identifiability in all screen sizes (Fig. 9). The overall burning rate for unidentified mammals is much higher (40%)

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[2] In our experience, the burning rates for the Čḯxʷicən mammals are high compared to other shell midden sites; in contrast, non-shell midden sites may be dominated by small fragments of burned or calcined bone due to preservation issues (e.g., Etnier and Bovy, 2010; Prince, 2007; Seitsonen et al., 2017).
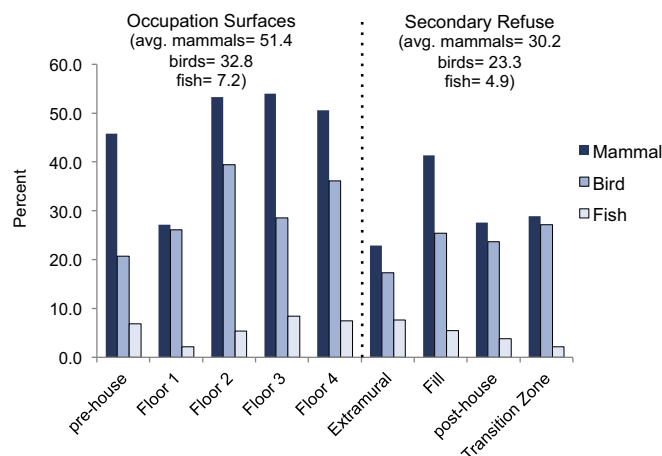
[3] While researchers have looked at the relative proportion of shafts vs. epiphyses as an argument for or against bone fuel use (e.g. abundant shafts indicate trash disposal rather than bone fuel use; Yravedra and Uzquiano, 2013), we do not do so here, since the assemblage is so fragmented that the resulting numbers would be quite small (for example, only 10 pinniped femora were recovered from the entire assemblage). Also, the test is equivocal; if people are choosing epiphyses to put in the fire, they may be more likely to fragment and would be less identifiable and less abundant.
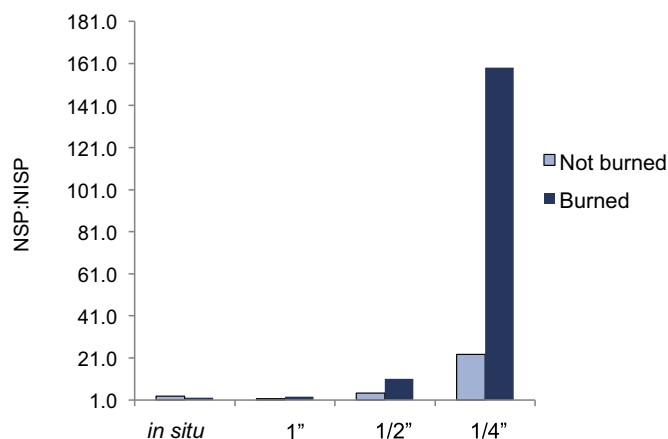
Fig. 8. Identifiability (NSP:NISP) by screen size for burned and non-burned mammal bone for Areas A4 & A5. All sample types included.
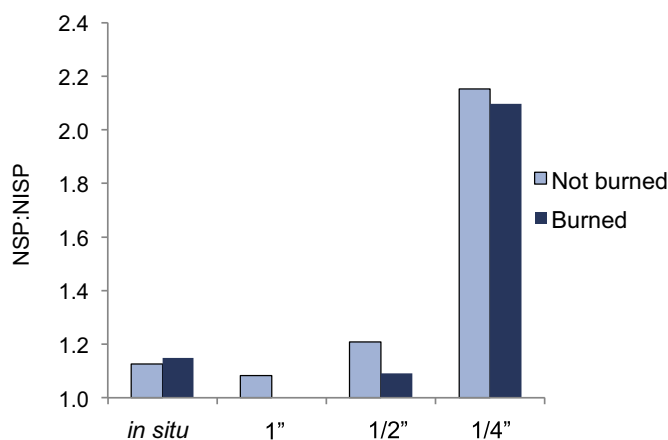

Fig. 9. Identifiability (NSP:NISP) by screen size for burned and non-burned bird bone for Areas A4 & A5. Samples included: C, CX, E.

than for artiodactyls (15%) and pinnipeds (9%), reinforcing the conclusion that burned specimens were more fragmented and less identifiable. Patterns of bird burning vary in other ways as well. For example, 10% (n = 81) of the bird humeri recovered are systematically burned along the broken shaft (indicative of roasting), and in some areas of the site, bird burning rates are much higher than for mammals (A3, CZ5 = 70% birds, 40% mammals; BX1/BX4, CZ4 = 63% birds, 34% mammals). Overall, the patterns in burning of bird bone do not match those of mammals, which points to different taphonomic life history trajectories for the two classes of animals.

Second, if mammal bones were being used for either fuel or trash disposal, we expect burned mammal bones to be found in contexts near hearths or burning activity areas (Costamagno et al., 2002). To test this, we compared the overall abundance and burning rates for selected thermal features in A4 (Table 6). Only a small proportion of mammal bones from A4 were recovered from thermal features (1.8%), which in itself is problematic for the fuel hypothesis. In addition, burning rates did not differ for mammal bone found in thermal features versus all other contexts in A4 ($\chi^2 = 1.55$, p = 0.213). Perhaps as part of routine hearth maintenance, remains were emptied and deposited elsewhere on the site.

Finally, if the bone fuel hypothesis were correct, we would expect to find evidence for the use of dead or dry wood at Čʼíxʷicən, since bone fuel use increases the efficiency of deadwood fires. We have information on 409 charcoal samples, which were analyzed by Shaw (2018) in order to find suitable AMS dating samples. Nearly half (49%; n = 75) of the samples that could be identified to at least genus were Douglas fir (*Pseudotsuga menziesii*), which is a high-ranked fuel, well suited for high heat

Table 6
Frequency of burned mammal bones in A4 thermal features and all other contexts. All sample types included; ≥ 1/4″ mesh screen. There is no significant difference between bones found in thermal features and other contexts ($\chi^2 = 1.55$, p = 0.213).

	Thermal features			All other contexts		
	Burned	Not burned	Total	Burned	Not burned	Total
NSP	116	180	296	5848	10,537	16,385
% Burned			39.2			35.7

activities like heating and cooking (Shaw, 2008, 2012). Other woods represented at Čʼíxʷicən, in order of decreasing abundance, include: alder (*Alnus*), spruce or larch (*Picea/Larix*), willow (*Salix*), elderberry (*Sambucus*), oceanspray (*Holodiscus*), and twelve additional genera each with < 2% of total NISP. Although Čʼíxʷicən inhabitants appear to have harvested firewood broadly from the trees and shrubs of the lush Pacific Northwest Coast forest, bone fuel may still have been useful for increasing fire efficiency. At Čʼíxʷicən, at least four charcoal specimens exhibiting fungal hyphae[4] are present in Area A4, suggesting that deadwood or driftwood may have been used occasionally as fuel (Shaw, 2018).

The high frequency of burned mammal bone, the differences between burning patterns for mammals and birds, and the presence of deadwood use at the site, provide some support for the hypothesis that mammal bones were intentionally burned for fuel. Secondarily, the burned bones appear to have been fragmented further due to mechanical pressure after deposition.

5.3. Bone marrow extraction

The importance of artiodactyl bone marrow as a source of fat has long been noted (e.g., Binford, 1978), stimulating an extensive literature on bone fragmentation and the identification of marrow extraction in the archaeological record (e.g., Blumenschine, 1988; Jones and Metcalfe, 1988; Lyman, 1994; Outram, 2001). Binford's initial work ranked skeletal elements of Dall sheep (*Ovis dalli*) and caribou (*Rangifer tarandus*) based on the efficiency with which marrow could be extracted, measured as ml of marrow yield per minute of effort. The major limb elements (femur, tibia, humerus, and the radio-cubitus [=fused radius + ulna]) consistently ranked high in extractive efficiency; metapodials ranked intermediate; and phalanges ranked low (Binford, 1978). Binford's informants told him that phalanges, while they did contain some marrow, were only ever utilized for marrow during the leanest of times (Binford, 1978). Initial attempts to recognize bone marrow production relied on marrow utility indices (Binford, 1978; Jones and Metcalfe, 1988); however, factors such as transport costs and differential preservation posed analytical problems (Wolverton, 2002). Given that relatively little fragmentation is needed to extract marrow (versus extraction of grease), the extent of fragmentation of individual marrow bearing bones, measured as % whole, has frequently been used instead (Lyman, 1994, 2008; Munro and Bar-Oz, 2005; Nagaoka, 2005; Todd and Rapson, 1988; Wolverton, 2002). For example, Munro and Bar-Oz, 2005, tested for marrow exploitation at an Epipalaeolithic site in Israel, by comparing the % complete long bone shafts of gazelle (marrow rich), with hares (less marrow) and partridges (no marrow), and found significantly lower percentages of whole bones for gazelle. They also compared the relative completeness of juvenile and adult gazelle bones, with the assumption that adults will be preferentially chosen for marrow extraction (since juvenile bones contain less marrow), and found that the adult bones were more fragmented. Finally, percussion marks or impact scars on limb bones are used to identify marrow extraction (e.g., Blumenschine, 1988; Lyman, 1994).

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[4] Shaw did not systematically look for evidence of fungal hyphae in the assemblage, since this was not relevant to her goal of finding suitable radiocarbon samples. Future analyses could be conducted at Čʼíxʷicən or other sites to evaluate the presence of deadwood.

Table 7

Extent of long bone fragmentation (% Whole) for artiodactyls, canids, pinnipeds, and birds.[a]

Element	Artiodactyls		Canids		Pinnipeds		Birds	
	Counts	% Whole	Counts	% Whole	Counts	% Whole	Counts	% Whole
Femur	0 of 22	0.0	3 of 7	42.9	4 of 10	40.0	30 of 225	13.3
Humerus	0 of 9	0.0	4 of 11	36.4	1 of 6	16.7	13 of 739	1.8
Metapodial/tarsometatarsus	4 of 73	5.5	7 of 16	43.8	13 of 30	43.3	36 of 255	14.1
Phalanx	17 of 52	32.7	61 of 63	96.8	24 of 55	43.6	92 of 129	71.3
Radius	0 of 8	0.0	1 of 4	25.0	2 of 11	18.2	30 of 327	9.2
Tibia/tibiotarsus	0 of 26	0.0	3 of 7	42.9	1 of 4	25.0	14 of 432	3.2
Ulna	0 of 13	0.0	1 of 5	20.0	2 of 6	33.3	61 of 653	9.3

[a] % Whole includes any element that was approximately 90% complete or greater (e.g. contained both distal and proximal portions). Includes all sample types, areas, and CZs; ≥1/4″ mesh screen.

To test for marrow extraction at Číx̌ʷicən, we compared the extent of fragmentation of artiodactyl bones to animals with less marrow (canids) and no marrow (pinnipeds, birds). Only six of the artiodactyl bones could be securely identified to age class, so we could not compare fragmentation values between adults and juveniles. Impact scars, which would likely occur during the marrow extraction process, were systematically recorded during the analysis.

Table 7 shows the raw counts and % whole long bones for artiodactyls, canids, pinnipeds, and birds, from the entire Číx̌ʷicən assemblage (all areas and CZs). Artiodactyls are consistently more fragmented than canids, pinnipeds and birds for every element. Consistent with Binford's marrow index rankings, none of the major limb bones (femur, tibia, humerus, radius/ulna) of artiodactyls in the entire assemblage were complete; artiodactyl metapodial survivorship was low (5.5%), and survivorship of artiodactyl phalanges (32.7%) is consistent with only occasional marrow extraction. Indeed, phalanges were the most complete element for all animal types (Table 7). The range of values for % whole elements (excluding phalanges) is 20% (ulnae) to 44% (metapodials) for canids, 17% (humeri) to 43% (metapodials) for pinnipeds, and 2% (humeri) to 14% (tarsometatarsus) for birds. While these contrasts are striking and certainly support the hypothesis that bone marrow extraction contributed to artiodactyl bone fragmentation, only one impact fracture was noted in the mammal assemblage. We suggest that such fractures were destroyed as the mammal bones were further processed (see Section 5.4).

5.4. Boiling bones: bone grease rendering and soup or stew making

Bone fragmentation could result from bone grease rendering, soup production, or both. Ethnoarchaeology and cross-cultural ethnographic comparisons (e.g., Binford, 1978; Vehik, 1977) have highlighted the importance of bone grease as a "concentrated energy source" (Vehik, 1977:172) and the dietary benefits are often stressed, including use as a base for soup, constituent of pemmican or suet cakes, or condiment. Bone grease may also be used as a food preservative or candle fuel, as an agent for waterproofing skins or canoes, tanning hides, or treating bowstrings, and in soap production (Heinrich, 2014; Morin and Soulier, 2017; Outram, 2001; Prince, 2007; Vehik, 1977). The importance of fat to Northwest Coast people is shown in Drucker's ethnography of the Northern and Central Nootkan (Nuu-chah-nulth) First Nations people of the west coast of Vancouver Island:

There was a tremendous emphasis on fats—oils and greases—in the dietary patterns…Fat parts of salmon, fat meats, whale and seal blubber, the oily skins of ducks and geese, even heavy, soggy deer tallow, were all considered choice and delicious (though the last, deer tallow, was admitted to be a pretty low-grade delicacy, and was used extensively only by the upriver Muchalat.)

(Drucker, 1951:62–63)

Support for the value of bone grease can be found at the well-preserved Ozette site, 125 km to the west by sea from Číx̌ʷicən. Despite the lack of ethnographic evidence for bone grease extraction for the Makah,

Huelsbeck (1994:282) describes 'hack' marks on whale vertebrae, which he suggests indicate attempts to penetrate the oil-rich bones and obtain chunks of bone for grease rendering. The possibility of bone grease rendering at the site is even more interesting because, based on estimated quantities of consumable whale oil, people living at Ozette likely had a surplus of whale oil to trade to neighboring groups (Huelsbeck, 1994:297).

In his comparison of Medieval Norse and Paleo-Eskimo sites in Greenland, Outram (1999) found that land mammal bone, including domesticated livestock (cattle, sheep, goats) and caribou, were highly fragmented compared to those of seals in both cultures, and concludes the land mammal bones were processed for grease, while the seals were not. Outram found no ethnographic examples of seal bone used for grease rendering and provides two explanations for this difference (Outram, 1999:115–16). First, he suggests that due to the low melting point of seal oil it would not rise to the surface of hot water, which is how bone grease is usually collected when rendered. Secondly, he reasons that the glut of fat from blubber during the sealing season would make bone grease rendering superfluous. Lyman et al. (1992) and Nagaoka (2006) have also argued that the extraction of bone grease or oil would be less likely for seals, given that so much grease is readily available in the blubber. We question both of these premises. First, seal oil has a specific gravity of about 0.93, and is non-soluble in water (Andés, 1898); therefore it will float. Second, seal oil preserves well (Stopp, 2002), so there may be incentive to store it for later use. Therefore, the effort of extracting seal oil from bones may be worthwhile, even when there are fresh supplies of oil available.

Besides grease rendering, bone might also fragment as part of soup production (Heinrich, 2014). Soup or stew making is similar to bone grease rendering, but the grease is incorporated into the broth along with other ingredients. In the Pacific Northwest, stone boiling (using hot stones) is frequently mentioned as one of the main ways to cook meat (Barnett, 1955:60; Curtis, 1913:57; Gunther, 1927:209; Haeberlin and Gunther, 1930:23; Jenness, n.d.:31). Swan (1870:25), for example, mentions that ducks were "thrown promiscuously into a kettle" and boiled. Importantly, bone fragmentation or condition associated with grease or soup making would not be easily distinguished.

Researchers have used experiments to test assumptions about the costs and benefits of breaking bone into fragments to increase grease production, as well as to develop taphonomic criteria for recognizing it in the archaeological record. In cultural settings lacking vessels that could be put directly on a fire, grease rendering typically involves the use of hot stones placed into waterproof fiber or wooden baskets.[5] This

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[5] Ethnoarchaeological work has indicated that, in some cases, bones might need to be chopped to fit into cooking containers (e.g., Yellen, 1977:292). There is little direct archaeological evidence of cooking containers in the Pacific Northwest; presumably they were in the lineage of the baskets and bentwood boxes used for cooking by stone boiling in historic times. The flexible construction technology allowed for varying sizes of cooking containers and it is unlikely the extreme mammal bone fragmentation at Číx̌ʷicən is due to constraints on container size alone.

would heat the water to the boiling point, after which the grease could be extracted from the vessel. Church and Lyman (2003) showed that for deer bone, fragments smaller than 5 cm long did not yield more grease, while Janzen et al. (2014) found that breaking bones into smaller fragments (≤5 cm) reduced the amount of water and fuel needed for grease production. While the amount of time needed to boil bone for grease may vary by animal (Lupo and Schmitt, 1997) and size of bone fragments (Janzen et al., 2014), Church and Lyman (2003) found that 80% of grease was released in the first 2–3 h of simmering (for fragments ≤5 cm). In short, if the goal is to generate grease, people may have broken up bones into fragments of various sizes, depending on constraints on fuel or water. The empirical expectations for soup making would be similar, although bone fragments may be larger and used multiple times (Heinrich, 2014; Morin and Soulier, 2017).

Beyond measuring the size and weight of the fragments themselves, scholars have sought signatures of bone grease, considering freshness of breaks, location of chop marks (Heinrich, 2014; Outram, 1999) and contextual evidence such as the presence of fire-cracked rock, and association with hearths, although many such traits are equivocal. Several scholars have noted that low rates of burning would be expected with bone grease production (Gifford-Gonzalez, 1993; Heinrich, 2014; Morin and Soulier, 2017; Vehik, 1977) but some bone could burn if close to a fire either during the rendering process (Outram, 1999) or after discard. Also, given that the epiphyseal ends are richer in grease, would one expect to find more in the archaeological record when grease rendering has occurred, or fewer because they were processed beyond recognition (Prince, 2007:18)? In an attempt to find unambiguous signatures of grease rendering, Morin and Soulier (2017) recently proposed intensive analysis of morphological patterning, crushing and tear marks, and micro-inclusions of hammerstone or anvil debris adhering to the bone matrix.

Our expectations for either grease rendering or soup making at Čḯxʷicən are that the bone fragments should be smaller (≤5 cm or 2 in) than breakage for bone marrow extraction alone. We examined the percentages of bones retained in the 1″, 1/2″ and 1/4″ screens (and those recorded *in situ*) to assess the scale of fragmentation at the site. The vast majority (90%) of all mammal fragments were smaller than 1″ (Fig. 10). In addition, ~17,000 'non-fish vertebrate' fragments were recovered in the 1/8″ screens from 'C' samples (Table 4); minimally half (but likely more) of these are mammal rather than bird. A comparison of the screen size distribution by mammal type (Fig. 10) shows similar fragmentation rates for both artiodactyls and pinnipeds; in both cases 41% of these identified bones were < 1″ in size.

In addition, we might expect bones to be associated with thermal features, and anvil stones, for processing bone fragments, should also be present (Table 2). As discussed above (Section 5.2), relatively few mammal bones were directly associated with thermal features in House A4 (Table 6), though bone from grease rendering may have been discarded elsewhere at the site. Two anvil stones were recovered from House A4, which is consistent with bone breakage, but not enough to test association.

In conclusion, we believe the high degree of fragmentation in the Čḯxʷicən mammal bone assemblage, for both terrestrial mammals and pinnipeds, is consistent with bone grease rendering or soup making. This finding differs from others (Lyman et al., 1992; Nagaoka, 2006; Outram, 1999) who have assumed sea mammal bones would not be selected for bone grease rendering. In addition, greater post-depositional attrition may have occurred as a result of boiling, although boiling times may have been significantly shorter than the 9-h threshold for diagenesis noted in experimental studies by Roberts et al. (2002; see Section 5.1).

5.5. Bone tool production

Bone and antler tools were an extremely important part of the technological inventory of Northwest Coast people. Čḯxʷicən is no
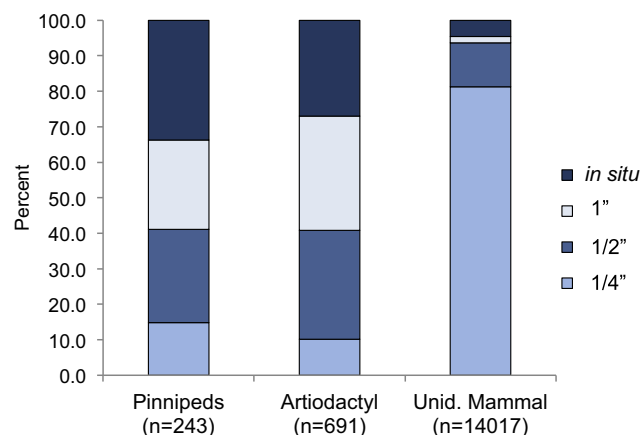
Fig. 10. Screen size distribution (percent) for remains of pinnipeds, artiodactyls and unidentifiable mammals for Areas A4 & A5. All sample types included.

exception; excavation finds[6] included awls, spindle whorls, combs, chisels, wedges, points and barbs for harpoons, herring rake tines, and other fishing gear, which played important roles in basketry construction, personal adornment, weaving, wood working, and subsistence pursuits. In locations where manufacture of these tools took place through systematic reduction and shaping of various skeletal elements, we would expect considerable bone fragmentation (Table 2). At Čḯxʷicən, catalogued artifacts and technological byproducts in the midden samples demonstrate that bone and antler tools were not only used, broken, and discarded, but were also manufactured there (Table 8; and see discussion of bone tool production locus in A18 in Campbell et al., this issue).

During analysis of faunal remains from midden samples, 663 specimens exhibiting modifications related, or likely related, to tool production were encountered (Table 8). The first category, percussion impacts, is included here because it could derive from the rough shaping of bone fragments for tool production, but it could also derive from marrow extraction (not mutually exclusive with the former), or reducing bones for grease extraction or soup making (Heinrich, 2014). The 48 bone flakes reflect hard hammer percussion; they show bulbs of percussion and radial fissures analogous to lithic flakes. Another 11 specimens display the negative flake scars of percussion impact. The reduction sequence byproducts include 472 bone chips. These were removed with an edged tool such as an adze, and show distinctive curls and step-fractures along the length of the curl analogous to wood chips (Fig. 11). They are unlikely to result from any kind of processing other than intentional shaping. Other modified specimens tabulated as reflecting varied reduction methods such as chopping, incising, snapping, grinding and drilling, are stages in the process of producing finished bone tools. A total of 41 finished tools and tool fragments were found in the midden samples although the protocol during original laboratory analysis following excavation was to remove these and catalog them separately. Importantly, mammal bones are disproportionately represented compared to birds in virtually all of the categories of modification and formal tools. Furthermore, within mammals, artiodactyls are more commonly identified among the modified bones than are cetaceans and carnivores. The vast majority of the modified specimens cannot be identified further than mammal (575) or vertebrate (20) because reduction has eliminated diagnostic features.

Taxonomic identifications were also attempted for a selected sample of catalogued artifacts, as shown in the final line in Table 8. Bird represent 9% of these catalogued artifacts, as opposed to only comprising

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[6] No formal analysis of the vast artifact assemblage from Čḯxʷicən has yet been conducted (Butler et al., this issue a). The bone objects listed here were pictured and/or discussed in excavation records.

Table 8

Bone fragments with evidence for tool production observed during the Čḍxʷicən zooarchaeological analysis by major taxonomic category. All sample types, areas, CZs, and screen sizes included.

	Bird	Artiodactyl	Cetacea/Carnivora	Unid. mammal[a]	Vertebrate (non-fish)	Total
NSP from faunal samples[b]	9848	717	769	15,803	19,139	46,138
Percussion impacts[c]						
Bone flake		1		47		48
Flaked/split	1	9		1		11
Reduction sequence byproducts						
Bone chip/shaving[d]		11	1	455	5	472
Incised and snapped	1	3		1		5
Incised		5		3		8
Ground	2	7	1	31	2	43
Drilled				1		1
Chopped	2	19		13		34
Finished tools/tool fragments[e]						
Fabricators		4		2	3	9
Points				16	10	26
Harpoon gear		1		5		6
Total manufacturing from faunal samples	6	60	2	575	20	663
From sample of catalogued artifacts[f]	8	6	1	52	19	86

[a] Unidentified mammal includes 77 rodent and 5 shrew/mole specimens, none of which were modified.

[b] Specimen counts from Area A3 are included here; these were excluded from Table 4, since the fish bones from A3 were not analyzed.

[c] Percussion impacts could be from marrow extraction or tool production.

[d] Many of the bone chips/shavings were recovered in the 1/8″ screens (n = 115); the total number of bone chips/shavings would be greater if a larger sample of the 1/8″ material had been analyzed.

[e] Finished tool categories are as follows: fabricators: awls, wedges, needles, ulna knife; points: unipoints, bipoints; and harpoon gear: barbed harpoon point, composite toggling harpoon valve.

[f] Taxonomic identifications were attempted for 86 of the 133 catalogued artifacts from select units in Area A4 (Units 1–3, 5–6, 9–16). See Table 9.
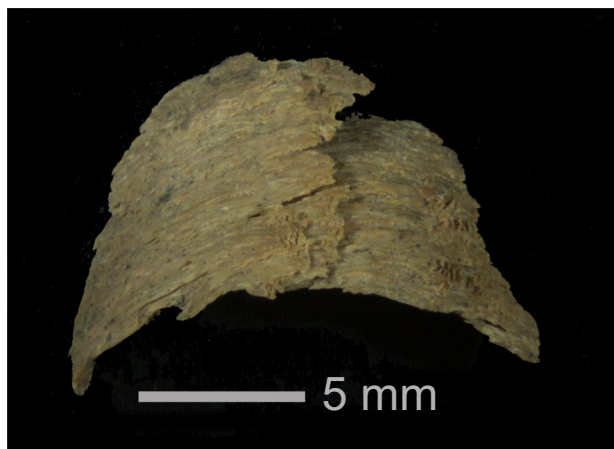

Fig. 11. Bone chip/shaving from Čḍxʷicən, a byproduct of bone tool production. Photograph by Anthony Hofkamp. Courtesy of the Washington State Dept. of Transportation, catalog number 10825.04.01.

1% of the overall midden sample. Although some of the catalogued specimens tended to be larger, there was little difference in the taxonomic identification rate for catalogued mammal specimens (7/59 = 12%) compared to those from the midden samples (62/637 = 10%). Many of the unidentifiable mammal specimens are made from the walls of dense, straight-grained long bone (consistent with terrestrial mammals) and have been worked on all sides, obscuring anatomical features. A wedge fragment, likely made from whalebone, is the only formal tool identified as coming from marine mammal bone.

In order to obtain a more realistic assessment of how bone tool production contributed to mammal bone fragmentation at the site, we combine data from our faunal samples and the catalogued bone assemblage (Table 9). Analysis of the entire assemblage of catalogued bone and antler artifacts was outside the scope of our project, but Campbell and Etnier examined all of those from 13 1 × 1 m units in Area A4, assigning them to functional categories and making taxonomic identification. For this selected area we have a comparable sampling volume for all modified and unmodified bones—those that were catalogued and those from the faunal samples, from all water-screen buckets and all *in situ* samples.

Not surprisingly, the catalogued mammal bone artifact sample includes the majority of end products and some of the intermediate products and debitage. Tools and tool fragments dominate (96%), while these are rare in the faunal samples (4%; Table 9). Sixteen pieces of debitage in the catalogued sample exhibit early stages of reduction such as percussive fracture, adze marks, coarse striations, or longitudinal sawing, with no evidence of secondary shaping or surface finishing. Adding the 185 reduction sequence byproducts from the faunal samples from the same excavated matrix, which includes a large number of bone and antler chips or shavings (n = 157), radically changes our impression of the types and intensity of manufacturing activity.

The combined modified bone assemblage can be directly compared to the lithic assemblage derived from the same excavation units and sample volumes (Sparaga, 2017) giving us a yardstick for the importance of bone technology relative to stone technology. Bone tools and manufacturing byproducts actually outnumber stone tools and manufacturing byproducts (Table 9), demonstrating that bone tool manufacture was not an incidental or minor activity at Čḍxʷicən.

Although bone and antler is comparable in importance to stone as raw material for manufacturing tools, only a small fraction of the overall mammal bone sample can be identified as debitage or tools, indicating that bone tool manufacturing accounts for only a minor amount of the fragmentation observed in mammal bones. Further, site occupants were selective in terms of which animals were preferred, therefore, bone tool manufacture cannot account for the overall fragmentation of the assemblage. It seems unlikely that bone tool manufacturing was more intense at Čḍxʷicən than other coastal sites, although direct comparisons are difficult because bone manufacturing byproducts are under-reported from many sites, and when they are, constant-volume sampling is rarely, if ever, a part of that analysis (Butler et al., this issue b).

5.6. Summary of mammal bone fragmentation at Čḍxʷicən

In the previous sections we have demonstrated that the 'life history' of the mammal bones at Čḍxʷicən was distinct from that of birds and

Table 9

Comparison of bone and lithic technology from a comparable volume sample (Area A4, Units 1–3, 5–6, 9–16) at Čḯxʷicən. Frequencies shown by tool and debitage category and sample type (catalogued artifacts vs. midden samples). See Table 8 for finished tool categories.

Grouping	Catalogued modified bone[a]	From faunal samples[b]	Total modified bone	Lithics
	N (% total bone)	N (% total bone)	N	N
Tools and tool fragments				
Mobillary art: incised, painted stones				42
Fabricators	9	1	10	6
Specialized tools	75	3	78	56
Ground shaft fragments, unclassified[c]	25		25	
Total tools and tool fragments	109 (96%)	4 (4%)	113	104
Reduction sequence byproducts[d]	16 (8%)	185 (92%)	201	185
Total manufacturing products	125	189	314	289

[a] Excludes 8 bird specimens.
[b] Includes all sample types, CZs, and screen sizes.
[c] The ground shaft fragments are portions of finished tools exhibiting complete shaping, fine striations and polish, but not complete enough to classify functionally.
[d] Bone flakes and impact fractures excluded.

fish. While this is not necessarily surprising, given that mammal bones may be expected to undergo greater processing (Fig. 2), the number of processes affecting the mammal bone at the site is notable. Fig. 12 summarizes the possible factors affecting mammal bones at Čḯxʷicən through time, and gives our assessment of the importance of each.

From our review, we argue that both marrow extraction (for artiodactyls) and boiling for grease or soup (all mammals) were of major importance at Čḯxʷicən. There were very few complete artiodactyl bones, both in an absolute sense and relative to pinnipeds and canids, which supports the argument that these were broken for marrow. The high degree of fragmentation for unidentifiable mammal fragments (90% < 1″ in size, excluding the 1/8″ sample), and similar percentages (41%) of smaller (< 1″) fragments for both artiodactyls and pinnipeds, suggests different kinds of mammals may have been boiled for grease rendering or soup making. Future taphonomic studies, using more intensive analysis methods (e.g., direct measurement, micro-inclusions, crushing or tear marks), could be conducted to test this hypothesis further.

In addition to these major factors, artiodactyl bones were also chosen to produce tools such as awls and points, and one wedge was made from a sea mammal bone. The high frequency of burning in the mammal assemblage provides support for the possibility that a variety of mammal bones were mixed with wood and used for fuel. The burning also increased the likelihood of fragmentation due to mechanical pressure, such as trampling, after deposition; while we acknowledge this post-depositional effect, we believe it to be of modest importance in causing fragmentation compared to the intentional actions of site occupants. Finally, intentional burning for trash disposal, carnivore gnawing (before or after deposition), surface weathering, chemical breakdown and indirect (post-depositional) heating are likely of negligible importance in structuring the Čḯxʷicən mammal bone assemblage.

In sum, a large range of different factors, most notably marrow and grease extraction, along with tool production, bone fuel use, and post-depositional mechanical pressure, appear to have acted in concert to produce the highly fragmented Čḯxʷicən mammalian assemblage.

6. Human ecodynamics at Čḯxʷicən

Now that we have described and attempted to identify the processes that contributed to mammal bone fragmentation at Čḯxʷicən, we explore the higher-level social and economic drivers at play. Why might people have been using bone as fuel? Why were they rendering mammal bone grease? To address these questions, we now expand our analyses to add the temporal dimension to assess changes in bone fragmentation and burning through time, and include comparisons of different houses within the site to better understand culturally-

mediated behaviors. We consider the choices people made about processing mammal carcasses in relation to changing environmental and social conditions at the site.

6.1. Bone fuel use: why use bone fuel in a productive coastal forest?

Availability of firewood was a critical need for pre-industrial peoples, and may have been an important factor, along with water and defense, in the selection of locations for Northwest Coast village sites (Heizer, 1963:189). Use of bone for fuel may not be surprising in situations where people are fuel limited (e.g., Grayson, 1991; Marquer et al., 2010), but why might people living in a productive forest use bone fuel? In her study of bone fuel use at the Abri Pataud rock shelter, an Aurignacian site in southwestern France, Théry-Parisot (2002) debunked the common misconception that bone is used for fuel only when wood is scarce or unavailable.

The underlying assumption of the bone fuel literature is that an efficient, productive fire is desirable (see Section 5.2), which may have been especially important during the winter (for warmth or light) or during climatic downturns. As mentioned above (Section 5.2), bone fuel may have improved the longevity of deadwood fires (Théry-Parisot, 2002). Deadwood is a desirable fuel, since it already has low moisture content, often comes in a manageable package size, and may immediately be tossed on a fire. Scholars recognize that fuel collection around a habitation site will preferentially target deadwood before moving on to wood requiring seasoning (Théry-Parisot et al., 2002). In addition to helping deadwood combust more slowly, bone fuel produces high flames and rapid extinction of embers and, therefore, it is useful for activities requiring radiation and convection, such as lighting, cooking, drying, curing, and heating (Théry-Parisot, 2002). It is not useful for activities requiring conduction, such as transforming raw material.

Given this complexity, would we expect bone fuel use to have increased through time at Čḯxʷicən as the village became larger and/or more sedentary and local availability of wood fuel decreased? Or might we expect bone to have been more important as a fuel additive earlier in the occupancy of the site, when deadwood was more plentiful? Either argument could be made. Fig. 13 shows the percentage of burning of mammal bones through time at the site, extending from CZ 1 (2150–1750 cal BP) through CZ 7 (300–150 cal BP). The percentage of burned mammal bones generally increases through the occupation (Cochran's linear trend, chi-square = 12.35, p < 0.001), although burning rates peak in CZ 3 (40%) and CZ 5 (45%), and decline to 20% in CZ 7 (the latest occupation).

Perhaps more telling than the trend through time is a comparison between two households, as documented in the plankhouses represented in Area A1 and Area A4. In comparing the two houses, we
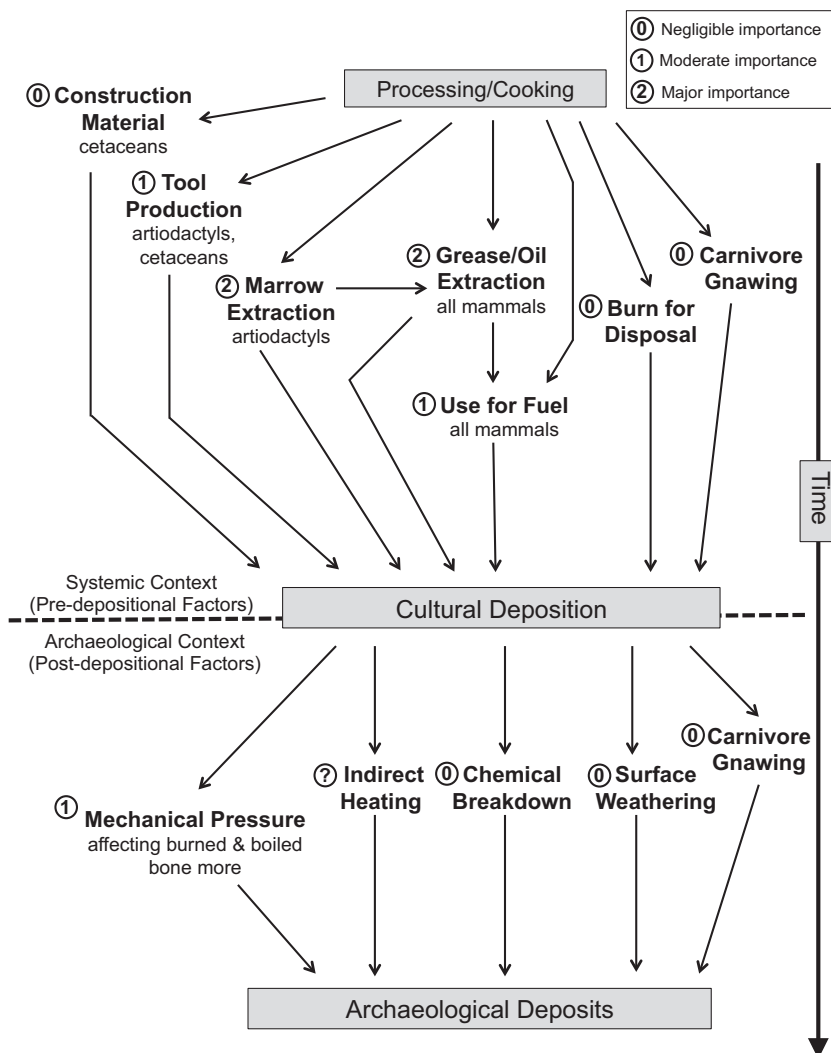
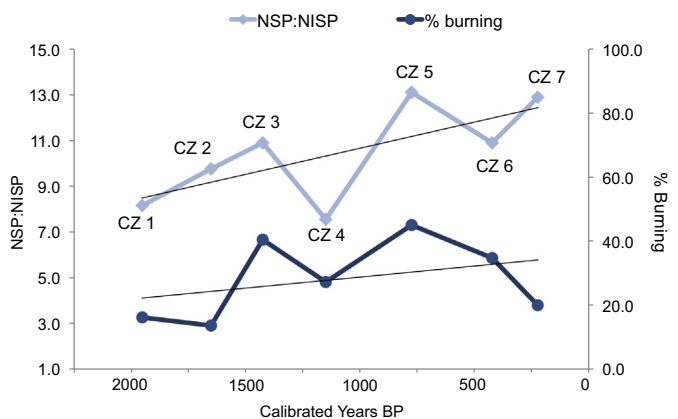**Fig. 12.** Relative importance of factors affecting mammal bone fragmentation at Číxʷicən.

Fig. 13. Burning rates and mammal bone identifiability (NSP:NISP) plotted by midpoint of each CZ for Areas A4 & A5. All sample types included; ≥1/4″ mesh screen. Regression lines have been included for visual reference only. Cochran's Linear Trend for identifiability, $\chi^2 = 11.22$, p = 0.001; Cochran's Linear Trend for burning, $\chi^2 = 12.35$, p < 0.001. (NSP values: CZ 1 = 473; CZ 2 = 117; CZ 3 = 359; CZ 4 = 1494; CZ 5 = 5395; CZ 6 = 6961; CZ 7 = 644).

event ('Event 2'), one of four tectonic events documented at Číxʷicən (Campbell et al., this issue), occurred at 630–560 BP (Garrison-Laney, 2017). Earthquake 'Event 2' appears to have caused the collapse of walls and the roof in House A4 (Campbell et al., this issue). Comparing CZ 5 and CZ 6 allows us to explore potential impacts of this external event.

Both houses would be equally affected by the availability of fuel wood, in general, or deadwood, in particular.[7] However, strategies of bone fuel use may differ between households if bone was chosen for fuel use for other reasons, such as lighting, drying, or curing. Fig. 14 shows that the mammal bones are much more frequently burned in House A4 than House A1 in both CZ 5 (53% vs. 28%) and CZ 6 (48% vs. 28%). There is little difference before and after the 'Event 2' earthquake. The occupants in the A4 house may have added bone fuel to their fires to produce a particular kind of fire needed for a given task, such as drying or smoking fish. The burning could also be related to ritual use, as mentioned in ethnographies of more northerly groups (Prince, 2007).

focus on the occupation during CZ 5 (1000–550 cal BP) and CZ 6 (550–300 cal BP) for two reasons. First, the occupation of Area A1 is restricted almost entirely to these two CZs. Secondly, a local earthquake
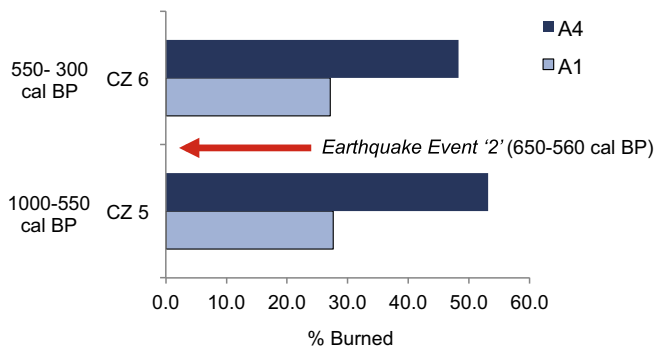
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[7] While we are not aware of any ethnographic reference for Northwest Coast people controlling drift wood supply or forest stands for firewood supply, such management is certainly plausible given the huge range of resources which were carefully managed (e.g., Deur and Turner, 2005).

Fig. 14. Comparison of mammal bone burning for floors in House A4 and House A1 during CZ 5 (1000–550 cal BP) and CZ 6 (550–300 cal BP). Samples included: C/CX only; ≥1/4″ mesh screen.

Fig. 15. Comparison of mammal bone identifiability (NSP:NISP) for floors in House A4 and House A1 during CZ 5 (1000–550 cal BP) and CZ 6 (550–300 cal BP). Samples included: C/CX only; ≥1/4″ mesh screen. (NSP values for A4: CZ 5 = 845; CZ 6 = 572; A1: CZ 5 = 246; CZ 6 = 177).

6.2. Bone grease rendering: feast or famine?

Extreme bone fragmentation is frequently viewed as an indication of efforts to extract maximum caloric value in situations of severe resource stress (e.g., Outram, 1999, 2001, 2003, 2005) or even starvation (Ellis et al., 2011; Heinrich, 2014), given the presumed high costs associated with processing the grease (after Binford, 1978). However, the Pacific Northwest Coast is well known for the abundance of available food, and this rich environment is often viewed as a factor in the atypical development of social complexity among these foraging peoples (e.g., Ames and Maschner, 1999; Matson and Coupland, 1995). In his study of bone fragmentation in interior sites in British Columbia, Prince (2007:21) questions the assumption that bone grease rendering must be due to resource stress, arguing that bone grease may have been "valued in its own right," as the fats were essential for long term food preservation and were a rare and socially valuable commodity. Rather than seeing bone grease as a starvation food, Prince argues that the production of bone grease may have occurred when preferred sources, such as eulachon oil (from the fish *Thaleichthys pacificus*), were unavailable via trade due to increased social tensions or territorial disputes.

Beyond the economic importance of bone grease, others have suggested that extreme bone fragmentation and/or bone grease or oil production may indicate feasting or ritual activity (Coupland, 2006; Coupland et al., 2003; Hayden, 2004; Heizer, 1963; Prince, 2007). Coupland (2006) found extreme mammal bone fragmentation and burning, compared to fish and bird bone, in House O at the McNichol Creek Site (Rupert Harbor, BC), which is believed through independent contextual and physical evidence to have been the house of a chief. House O contained more mammal bones than any other context at the site, and was the only location with sea mammal bones, which he interprets as prestige food. Coupland (2006:91) argued that this difference in the treatment of mammal bones in House O indicates these bones were "intentionally returned to the fire after the meat had been cooked and removed from the bone, a practice that may be associated with ritual feasting."

Citing ethnographic studies (e.g., Daly, 2004:112–113; Halpin and Seguin, 1990:271; Ksan, 1980:49–50), Prince (2007:21) notes that

> Grease in general, foods preserved in grease, and anything requiring intensive labor to produce, were valued feast foods for the Gitksan... Animal greases can also be considered symbols of wealth and power, being used to lubricate holes during totem pole erection, to **flare fires during ritual performances**, and to entice mythological tricksters to perform services. [emphasis added]

If bone grease processing was related to resource stress at Č'íxʷicən, we might expect the need for bone grease rendering to increase as the village became more sedentary and circumscribed through time, which would affect all households at the site. Alternatively, if bone grease rendering was a valu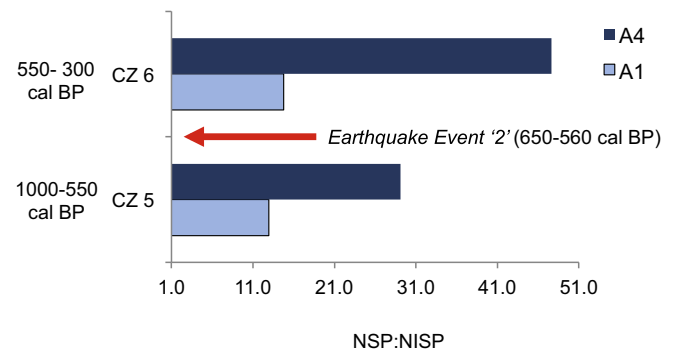ed activity at Č'íxʷicən, possibly even associated with feasting or rituals, we may see differences between households. Did one house intensify bone grease rendering more than another as a strategy for increasing or perhaps demonstrating wealth? Did one house have more feasts? We would also expect to find other contextual evidence for ritual.

Fig. 13 shows the identifiability of mammal bones through time. There is a significant trend (Cochran's linear trend, chi-square = 11.22, p = 0.001) towards decreased identifiability (and as we have argued, greater fragmentation), which could be related to increased processing for grease over time, supporting the resource stress hypothesis. Cursory inspection of Fig. 13 suggests some correspondence between identifiability and burning, such as the decline from CZ 3 to CZ 4, and increase to CZ 5. However, the curves are not similar at other points in time (CZ 2, CZ 7), and the two are not correlated overall (spearman's rho = 0.563, 0.50 ≥ p ≥ 0.20). This analysis supports our previous assertion (Section 5.2) that while burning influences identification rates in some contexts, burning is not the major driver behind mammal bone fragmentation at the site.

The spatial differences between the A1 and A4 houses at the site are more striking than the trend through time (Fig. 15). The A4 mammal bones are more fragmented than those in A1 in both time periods, which may indicate that occupants of the A4 house engaged in more bone grease rendering. As noted, the A4 mammal bones show higher frequency of burning than A1 specimens (Fig. 14), thus given the house floor context, some of the fragmentation in A4 could reflect post-depositional mechanical breakage. However, independent evidence supports the potential link between bone grease rendering and ritual use in House A4. House A4 occupants were obtaining greater amounts of sablefish (*Anoplopoma fimbria*), a known prestige item (Nims and Butler, this issue), and large deposits of sea urchins (*Strongylocentrotus* sp.) were also recovered in A4, which may have been used in feasts (Grier, 2012). Whatever the reasons for the different levels of mammal identifiability and burning between the houses, it appears that the households were acting independently and were resilient, with little change following the 'Event 2' earthquake.

7. Summary & conclusions

While we were initially dismayed at the high degree of fragmentation and low identifiability of the Č'íxʷicən mammal bone assemblage, which made it more difficult to assess use of specific mammal taxa through time and space (Butler et al., in press b), we now realize important insights may be gained from these small fragments. Mammal bones are significantly more fragmented than birds and fish at Č'íxʷicən. Clearly these differences indicate that mammal bones were systematically treated differently than either bird bones or fish bones prior to deposition into the midden deposits. Both terrestrial and marine mammals were recovered at Č'íxʷicən, and the assemblage is less

identifiable than all other sites in our comparative sample, especially those sites dominated by sea mammals. Artiodactyl bones appear to have been broken for marrow, grease rendering, and tool production. Seal bones were somewhat less fragmented (more complete bones) than artiodactyls, but are still frequent in smaller screen sizes, indicating they were also chosen for grease rendering and/or stewing. Rather than occurring as a response to food stress, the production of bone grease or oil may have been socially valuable as a source of wealth or prestige. Mammal remains in House A4 are consistently more highly fragmented and burned than in House A1, suggesting occupants in House A4 were using bone as an additive to wood fuel and/or processing the bones for grease or oil, which could have been used for a variety of practical and ritual purposes.

Our study is the first to explicitly highlight the possible role of bone grease and bone fuel for indigenous peoples of the southern Northwest Coast, and explore these strategies using a human ecodynamics perspective. We integrate multiple classes of animals in our analysis, which is helpful for identifying patterns in mammal bone fragmentation. We hope to see further taphonomic work to evaluate the role of bone fuel and grease or oil in this region and other coastal areas. We urge others to report and analyze smaller unidentifiable bone fragments, even from sites with abundant well-preserved faunal remains (e.g., Outram, 2001). Determining the full extent of the spatial and temporal variability in how mammal bones were processed will be a crucial aspect of determining why Čḱx̌ʷicən appears unique in this aspect. Future work is needed to assess whether grease rendering or bone fuel use was occurring at other sites in the region, and whether greater bone fragmentation is indeed typical of sites with more terrestrial mammals than sea mammals.

Acknowledgements

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