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Exploring Ecodynamics of Coastal Foragers Using Integrated Faunal Records from Č̣́xwicən Village (Strait of Juan de Fuca, Washington, U.S.A.)

Virginia L. Butler

Sarah K. Campbell

Western Washington University, sarah.campbell@wwu.edu

Kristine M. Bovy

Michael A. Etnier

Western Washington University, mike.etnier@wwu.edu

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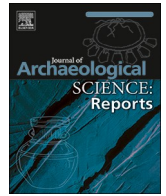
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journal homepage: www.elsevier.com/locate/jasrepExploring ecodynamics of coastal foragers using integrated faunal records from Číx^wicən village (Strait of Juan de Fuca, Washington, U.S.A.)Virginia L. Butler^{a,*}, Sarah K. Campbell^b, Kristine M. Bovy^c, Michael A. Etnier^b^a Portland State University, Department of Anthropology, 1721 SW Broadway, Portland, OR 97201, United States of America^b Western Washington University, Department of Anthropology, 516 High Street, Bellingham, WA 98225, United States of America^c University of Rhode Island, Department of Anthropology, 507 Chafee Building, 10 Chafee Road, Kingston, RI 02881, United States of America

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ABSTRACT

Extensive 2004 excavation of Číx^wicən (pronounced *ch-WHEET-son*), traditional home of the Lower Elwha Klallam Tribe in northwest Washington State, U.S.A., documented human occupation spanning the last 2700 years with fine geo-stratigraphic control and 102 radiocarbon samples. Remains of multiple plankhouses were documented. Occupation spans large-magnitude earthquakes, periods of climate change, and change in nearshore habitat. Our project began in 2012 as a case study to explore the value of human ecodynamics in explaining change and stability in human-animal relationships on the Northwest Coast through analysis of faunal and geo-archaeological records. Field sampling was explicitly designed to allow for integration of all faunal classes (birds, fish, mammals, and invertebrates), thus facilitating our ability to track how different taxa were affected by external factors and cultural processes. With over one million specimens, the faunal assemblage represents one of the largest on the North Pacific Coast. Invertebrate records reveal striking changes in intertidal habitat that are linked to the formation of the sheltered harbor and catastrophic events such as tsunamis. Analysis suggests a high level of consistency in the structure of resource use (evenness and richness) across 2150 years of occupation, despite increase in intensity of human use and a shift to plankhouse occupation. Trends in fish and invertebrate representation do not correspond to changing ocean conditions, while changes in abundance of herring, salmon, burrowing bivalves and urchins are consistent with impacts from tsunamis. Comparison of resource use between two well-sampled houses before and after one tsunami suggests that while both households were resilient, they negotiated the event in different ways.

1. Introduction

We are in the midst of a paradigm shift in our conception of human-environmental relationships and explanatory models for cultural change on the north Pacific coast of North America. At the time of European contact, relatively large concentrations of people lived in substantial plankhouses, participated in elaborate ceremonies, and were organized into ranked social units—attributes generally associated with agriculturalists. Until recently, anthropologists viewed the hunter-fisher-gatherer peoples of the Pacific Northwest as atypical foragers. Accounting for this outlier status became the focus of attention. Explanations first emphasized inherent abundance of resources such as salmon, then the spatial and temporal patchiness of resources and the importance of technological and social means of increasing productivity (Ames and Maschner, 1999; Matson and Coupland, 1995). Competition among social groups for prestige, recruitment, resource rights, and

control of storable commodities, exchanged through feasting or trade, were viewed as key factors in driving changes in social organization and subsistence adaptation (Coupland, 1985; Hayden, 1995). Changes in the use of animals were routinely used to explain many of these trends, for example, increased use of salmon (*Oncorhynchus* spp.) or marine mammals in some locations has been used as an explanation for observed changes in artifact distributions and/or household organization (Matson, 1992; Matson and Coupland, 1995).

Several shifts have occurred to challenge this thinking and research focus. The limits of simple models of resource intensification on resources like salmon are exposed empirically by close comparative analysis of faunal assemblages demonstrating the breadth of resources used (Butler and Campbell, 2004), and further by the great environmental diversity in the region (Moss, 2012). Increased use of fine-mesh screens has demonstrated the importance of a range of small-bodied fishes such as herring (*Clupea pallasii*) that had previously been

* Corresponding author.

E-mail address: virginia@pdx.edu (V.L. Butler).<https://doi.org/10.1016/j.jasrep.2018.09.031>

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overlooked (McKechnie et al., 2014; McKechnie and Moss, 2016). As well, there has been an increased appreciation for the role of plants in Northwest Coast lifeways—based on ethnohistoric records, archaeological evidence, and on-going practices (Deur and Turner, 2005 and references therein). Most striking, people were engaged in a range of activities such as transplanting plants and amending soils, which constitute gardening, blurring the line between “foragers” and “farmers” (Deur and Turner, 2005; Smith, 2005). In effect, this understanding has upended views that Northwest Coast peoples were atypical at all, because it challenges the validity of the dichotomy between hunter-gatherers and agriculturalists. Both terrestrial and nearshore landscapes were deliberately manipulated to increase habitable area (Grier, 2014) or in the case of clam gardens, to increase shellfish productivity (Groesbeck et al., 2014). As archaeologists collaborate more with Indigenous knowledge holders, they are learning that animals and plants hold a range of values beyond subsistence, further expanding our conception of human-environmental connections (Lepofsky et al., 2017; Moss et al., 2016).

To a large extent, scholars are shifting from seeking region-wide, unifying economic or environmental explanations for cultural changes or complexity, what Moss (2012) has termed ‘master narratives’—to a greater emphasis on understanding the role of local historical process and human agency in accounting for cultural changes (e.g., Hopt and Grier, 2018). Economic and environmental constraints are still relevant and require attention (e.g., Hutchinson et al., 2018, in this issue; Prentiss et al., 2018), but how these manifest in local settings must be considered.

The developing scholarly area known as *Human Ecodynamics* (H.E.) captures many of the ideas and methods that are part of this paradigm shift. Such scholarship joins concepts from historical ecology, resilience theory, human behavioral ecology, and Indigenous archaeology to explore the complex and dynamic relationships between *physical* (e.g., climate change, natural hazards), *ecological* (e.g., nutrient cycling, predator-prey relations), and *social* (e.g., economic, technological, organizational, ideological) processes (e.g., Fitzhugh et al., in this issue; Kirch, 2007). The need to consider historical contingency and human agency is integral to H.E. research.

The Northwest Coast is an appropriate place to apply the H.E. framework. The western edge of the North American continent, located on a plate boundary, is tectonically and volcanically active and has been subject to glaciation and sea level change, as well as dynamic patterns of ocean circulation. Cascade Subduction Zone (CSZ) earthquakes (of magnitude 8.0 and greater), and shifts in ocean productivity (Hutchinson et al., 2018, in this issue; Monks, 2017a) are of particular interest for our project. The region is characterized by multi-household villages with long-duration households, offering the opportunity to study social changes in the context of a dynamic environment.

Our research project began in 2012 as a case study to explore the value of H.E. in explaining change and stability in animal-human relationships on the Northwest Coast at the site of Čix^wicən¹ (pronounced *ch-WHEET-son*). The site is a traditional village of the Lower Elwha Klallam Tribe (LEKT) and is located on the southern shore of the Strait of Juan de Fuca (SJDF), on the northwest coast of Washington State (U.S.A.) (Fig. 1). Large-scale excavations in 2004 yielded enormous faunal samples associated with plankhouses, extramural activity areas, and midden deposits. Detailed geoarchaeological field recording of deposits and 102 radiocarbon ages have produced a high-resolution view of changes in the socio-ecological system over the past 2700 years (Campbell et al., 2018b). *In situ* records suggest the site was overtopped by multiple tsunamis. Thus, the site and faunal record provided an opportunity to study ways Indigenous people altered resource use in

response to external drivers of change; and how social forces mediated animal use in the context of potentially catastrophic events.

Our project focused on faunal remains for their potential to contribute to understanding resilience in human adaptive strategies in the face of a range of environmental and social changes, focusing on the past 2150 years of occupation. Faunal remains are more directly linked to resource use areas and environments than many other artifact types, and have been central to explanations for cultural change in our region. Field sampling was explicitly designed to allow for integration of all faunal classes (birds, fish, mammals, and invertebrates), thus addressing a common limitation with Northwest Coast faunal sampling, where remains of different faunal classes are retained and studied from different site matrix and volumes (Butler and Campbell, 2004).

Several central questions that drove the larger research project are the subject of this paper:

- Are there changes in the faunal record that indicate local landform evolution?
- Are there changes in resource use that correspond to the transition to plankhouse occupation?
- Are there changes in animal representation that correspond to changes in ocean conditions?
- To what extent did earthquakes affect nearshore habitats, animal populations, or cultural procurement?
- Did the degree of communalism in animal use vary across households? If so, how resilient was this social structure in response to an earthquake?

Although they are set in the specific context of the Čix^wicən project, analytic frameworks and methods we employ are applicable to a range of contexts beyond the Pacific Northwest, where scholarship seeks understanding of the complex and interacting factors that account for changing socio-ecological systems (e.g., Fitzhugh, 2018; McGovern et al., 2007; Morrison and Addison, 2013; Rick et al., 2013; Sandweiss et al., 2001; Zangrando, 2009).

2. Background to the environment

Čix^wicən is located near the eastern edge of the SJDF, which is part of the Salish Sea (which also includes the waters of Puget Sound and the Strait of Georgia) (Fig. 1). The SJDF is a deep (to 200 m), narrow, glacially-carved channel trending east-west between the Olympic Peninsula of Washington State and Vancouver Island, British Columbia (Canada).

Several attributes made Čix^wicən's location attractive to human settlement. With an intermediate location between the exposed outer coast of the Pacific Ocean and the inner waters of the Salish Sea, Čix^wicən is situated on or near the migratory paths of numerous marine species such as herring, salmon, fur seals (*Callorhinus ursinus*), gray, minke, and humpback whales (*Eschrichtius robustus*, *Balaenoptera acutorostrata*, and *Megaptera novaeangliae*, respectively), murre (*Uria* spp.) and other seabirds and waterfowl. Resident animals include bottom fishes such as sculpin (Cottidae) and greenling (Hexagrammidae), and California sea lions (*Zalophus californianus*), and harbor seals (*Phoca vitulina*) (Gaydos and Pearson, 2011; Therriault et al., 2009). Thus, the site is situated in an area that can capitalize on an abundance of migratory and resident marine life.

The richness of animal life along this corridor is linked to productivity of the Strait, owing to distinctive oceanographic conditions. Relative to inner waters of the Salish Sea, the SJDF is characterized by conditions that are more influenced by the open ocean. Colder, more saline water and greater wave energy from winds and tides support biota associated with open rocky shorelines of the Pacific coast, such as California mussel (*Mytilus californianus*), giant kelp (*Macrocystis pyrifera*), and red sea urchin (*Strongylocentrotus franciscanus*); none of these occur in the inner waters of Puget Sound. Perhaps the most significant of these is giant kelp, the predominant canopy-forming kelp along the

¹ An alternative spelling for the site name, Tse-whit-zen, has been used in some previous reports and publications. The Klallam language spelling, Čix^wicən (Montler, 2012), is preferred by the Lower Elwha Klallam Tribe.



Fig. 1. Map showing location of Čixʷicən. Dashed line outlines the Salish Sea watershed. (Figure drafted by Kendal McDonald.)

Pacific coastline (Pfister et al., 2018). This algae not only dominates many Pacific coastal habitats in terms of biomass, but is a foundational species. Kelp forests are structurally complex, biogenic habitats found in cool to cold marine waters of the high latitudes around the world. Guilds of macroalgae form multi-layered canopies rising high above the sea floor and are responsible for net primary productivity that is among the highest of any known ecosystem (Schiel and Foster, 2015). Invertebrates and fish that directly consume kelp or kelp detritus form the next trophic level of the food web. Canopy layering facilitates habitat and resource partitioning, contributing to high biodiversity at this, and higher, trophic levels. Čixʷicən is located just east of a broad marine reef with an optimum depth for giant kelp and other canopy forms (Fig. 2); thus, people had ready access to this ecologically rich and productive habitat.

The site is also located adjacent to one of only two natural harbors found along the ~150 km (95 mi) long southern shore of the Strait, which provided protection from heavy surf and access to a range of

resources. Port Angeles harbor is formed by the 5.5 km (3.4 mi) long Ediz Hook, which began to form as early as 5000 years ago (Galster and Schwartz, 1990) or possibly not until ~3000 years ago, not long before site occupation began (Campbell et al., 2018b). In addition, Čixʷicən was situated adjacent to a large tidal lagoon, which provided anchorage for boats and supported fish and waterfowl (Fig. 2). Based on bathymetry and substrate, eelgrass (*Zostera* spp.) beds ringed at least part of the harbor in the past. Such beds are ecologically important nurseries for a range of fishes as well as home for invertebrates; and important substrate for herring to spawn. Several springs flowed from the bluffs ringing the harbor, including some close to the village. Six small streams emptied into the harbor, which supported spawning populations of salmonids before 20th century industrialization (Elwha Dungeness Planning Unit, 2005). A short 8 km (5 mi) west of Čixʷicən is the Elwha River, which, apart from a ~100 year period during which the river was dammed, supported large runs of multiple salmonid species. A range of intertidal invertebrates were available both on the

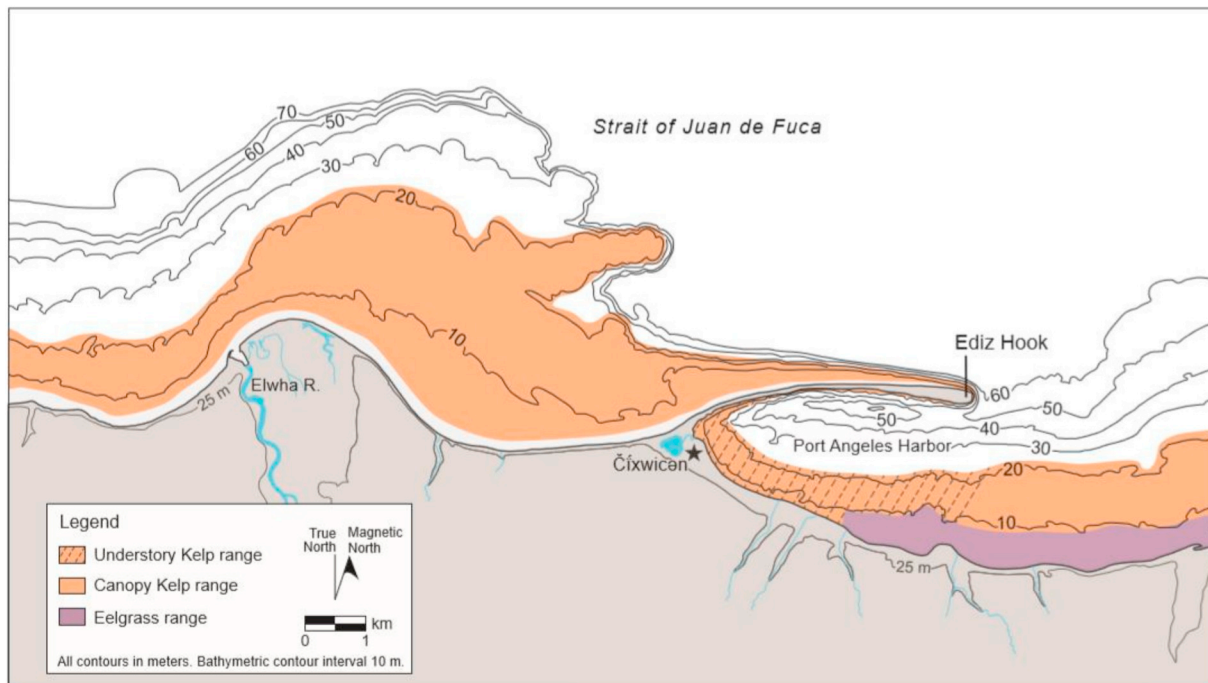


Fig. 2. Map of marine habitats and bathymetry in vicinity of Číxwícən. Bathymetry contours from NOAA 1990 Bathymetric Fishing Map. Terrestrial contours from ESRI USGS Topographic Basemap. Kelp and eelgrass range is based on ecological preferences (depth, substrate); given industrialization of the harbor, modern records of distribution are poor approximations of past conditions.

(Figure drafted by Adrienne Cobb.)

shore of the SJDF as well as in the protected waters of the harbor (e.g., butter clam [*Saxidomus gigantea*], little neck clam [*Leukoma staminea*], mussels [*Mytilus* spp.] and sea urchin [*Strongylocentrotus* spp.]). Terrestrial resources (e.g., wapiti [*Cervus canadensis*], blacktail deer [*Odocoileus hemionus*]) were available in the uplands south of the harbor.

3. Materials and methods

In 2004, as part of a large-scale mitigation for a proposed development, Larson Anthropological Archaeological Services (LAAS) and members of the LEKT excavated the village site using a modified isolated block technique. This approach provided vertical and horizontal control and allowed for excavation by fine stratigraphic divisions. Excavation units totaled 518 m² in area, and 261 m³ of sediment were excavated (see Fig. 3 inset for overall site area). Butler et al. (2018b) summarize the history of site excavation; Campbell et al. (2018b) provide an overview of geo-chronology and landform history.

Field sampling was explicitly designed to allow for integration of all classes of faunal data (Reetz et al., 2006), and simple calculation of matrix volume. Matrix was excavated from each uniquely defined deposit 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) or in some cases to 1/8" (3.2 mm) mesh (Kaehler and Lewarch, 2006) (Table 1). Most buckets from a given micro-stratum were screened to 1/4" and called *Sample* or 'S' buckets. Invertebrate shell was not retained from S buckets. A minimum of one bucket was processed from each stratum of each 1 m² grid unit and screened to 1/8" mesh. All faunal remains were retained from such buckets labeled *Complete* or 'C' buckets. A change in field protocols partway through the excavation meant that for some 10 L buckets originally collected as C buckets, the 1/8" residue was not saved. For our project, we labeled such samples as 'CX' buckets. Finally, relatively large remains were recorded *in situ* during excavation and referred to as 'E' samples. After excavation, faunal remains were sorted into four main animal groups (fish, bird, mammal, invertebrates) by

LAAS personnel; and all materials were curated by the Burke Museum of Natural History and Culture (Seattle, Washington).

Given the large scale of excavation, the enormous quantity of faunal remains recovered, and the impracticality of studying the entire collection, we needed to develop a sampling strategy that would allow us to examine representative faunal samples from a range of spatial and temporal contexts. We devised a sampling strategy targeting seven different excavation blocks (Fig. 3), which included remains from activity areas, extramural middens, and at least two house structures (in Areas A4 and A1). We used radiocarbon ages from the 2004 mitigation report to identify deposits that were among the oldest and youngest on the landform, which allowed us to obtain samples from as full a range of human occupation as possible.

Given our interest in exploring patterning for all the fauna simultaneously, we prioritized our faunal analysis on the C and CX buckets from seven different excavation areas (Fig. 3), because all classes of remains were retained in this sample type. Basing our study on the C buckets with screening to 1/8" mesh insured that we obtained samples from small-bodied fish and invertebrates (and fragmentary remains from all fauna).² We included the CX buckets to increase the volume of matrix studied. To increase the volume sampled for the mammal and bird remains, which were much less common than invertebrate and fish remains, S buckets from some site areas were also studied.

Remains from each main animal type from the targeted excavation blocks were sent to our respective laboratories for study: birds, KMB (University of Rhode Island); fish, VLB (Portland State University);

² Much research (Butler and Schroeder, 1998; Gobalet, 1989; Moss et al., 2017) demonstrates that remains of extremely small fish taxa (and small elements of larger fish) are lost when 1/8" mesh screens are used. Only a limited number of small volume bulk samples were retained in the 2004 mitigation project, which limited our ability to study the impact of this bias on fish representation.

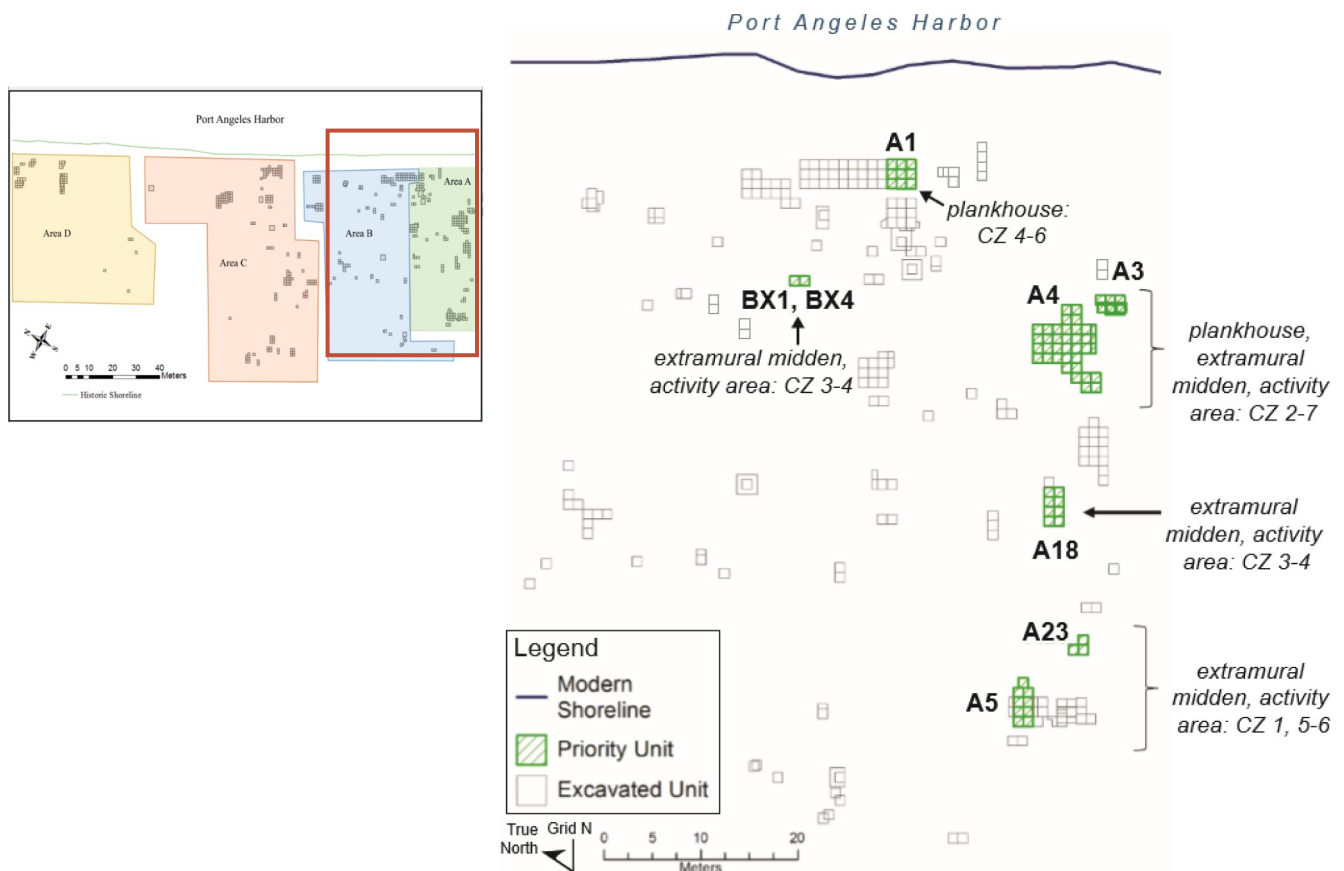


Fig. 3. Map showing areas targeted for geo-zooarchaeological analysis, chronozone (CZ) represented, and cultural activity indicated (“priority units”). (Figure drafted by Kristina Dick.) Inset map shows all areas excavated in 2004 mitigation, with red outlined box indicating focus of current research project. (Figure drafted by Laura Syvertson.)

Table 1
Summary of field sampling methods and sample types at Çikwícən, including number of bucket samples included in current project.

Sample code	Cu meters	Sample description and fauna collected	Analyzed current research ^a	
			Num. buckets	Liters
C	4.57	10 L bucket, to 1/8" mesh, all faunal types	457	4570
CX	3.63	10 L bucket, to 1/4" mesh, all faunal types	363	3630
S ^b	18.64	10 L bucket, to 1/4" mesh, mammal, bird, fish	1864	18,640
E		Recorded <i>in situ</i> , typically larger specimens, all faunal types	–	–

^a Samples from excavation areas A1, A3, A4, A18, A23, A5, BX1/BX4.

^b Because of relatively small numbers of specimens that could be identified to taxon in the C/CX buckets, mammal remains from S buckets from A4 and A5 were studied; bird remains from A5/A23 were studied, but are not further considered in this paper.

mammals, MAE (Western Washington University); and invertebrates, SKC (Western Washington University). Remains were identified to the finest taxon possible using reference skeletons or tests, and quantified using number of identified specimens (NISP) and other measures. We recorded specimens that could not be assigned beyond animal type (e.g., fish, invertebrates, mammal, bird, or vertebrate) as ‘unidentified specimens’ that were joined with NISP to create NSP (number of specimens) for some comparisons. We also documented the presence of

distinctive taphonomy (e.g. burning, cut marks, bone fragmentation) that indicate cultural processing or post-depositional processes, which Bovy et al. (in this issue) review in detail.

While each of the individual fish, mammal, and bird specimens was examined and attributes were recorded, given the enormous quantity of invertebrate remains, Campbell used ‘sampling to redundancy’ following Van der Veen and Fieller (1982) to estimate the quantities of specimens (taxa, elements) in 185 out of a total of 820 10 L buckets (see Campbell et al., 2018a). Invertebrate remains were recorded using both NISP and specimen weight. Element and portion, including landmarks were recorded as well, which were used to estimate minimal animal unit (MAU). MAU is similar to minimum number of individuals (MNI), but without taking side into account (see Table 2, for the main invertebrate taxa and major landmark/portion used for MAU calculations). For several invertebrate analyses in this paper, we rely on MAU, which addresses the concern that taxonomic representation would be biased by differences in fragmentation and identifiability across taxa (e.g., Claassen, 2000; Mason et al., 1998).

Several measures were used to explore variation in faunal representation across contexts within and between households, and over time. To measure the extent resource use was more specialized or generalized, we calculated Shannon’s evenness index (H)

$$H = - \sum_{i=1}^k p_i \ln p_i$$

where k is the number of categories and p_i is the proportion of the observations found in category i (Zar, 1984). To assess significance in change in proportional representation of taxa, we used chi square analysis, in particular adjusted standardized residuals (Everitt, 1977). We used the Brainerd-Robinson (B-R) similarity coefficient (Robinson,

Table 2
Background information on dominant invertebrate genera at Čix^wicān.

Genus (common name)	Element used in MAU calculation	N of elements in individual	Habitat association
<i>Strongylocentrotus</i> (urchin)	Hemipyramid	10	Kelp
<i>Balanus</i> (barnacle)	Body plate	6	Rocky
<i>Cryptochiton</i> (gumboot chiton)	Medial plate	6	Rocky
<i>Katharina</i> (chiton)	Medial plate	6	Rocky
<i>Nucella</i> (whelk)	Anterior canal	1	Rocky
<i>Semibalanus</i> (acorn barnacle)	Body plate	6	Rocky
<i>Mytilus</i> (mussel)	Hinge	2	Rocky
<i>Clinocardium</i> (cockle)	Hinge	2	Soft sediment
<i>Leukoma</i> (little-neck clam)	Hinge	2	Soft sediment
<i>Macoma</i> (macoma)	Hinge	2	Soft sediment
<i>Saxidomus</i> (butter clam)	Hinge	2	Soft sediment
<i>Tresus</i> (horse clam)	Hinge	2	Soft sediment

1951) to quantify degree of similarity in faunal representation between households, which we suggest reflects degree of communalism in resource use (see Section 4.6). To examine changing intensity of animal use through time or across contexts, we calculated an *accumulation rate*, by dividing the faunal frequency (e.g., NSP, NISP, or MAU) by excavation volume (N buckets × 10 L) and time unit duration. Many scholars have used faunal density (e.g., frequency of bone/volume) to infer intensity of resource use across a region; but as Jerardino (2016a) has shown, adding duration provides a more accurate indication of deposition practices or intensity of resource use than does density alone.

The materials we studied span occupation from 2150 cal BP to 150 cal BP. To establish chronological control, Campbell and Sterling defined seven chrono-stratigraphic zones, hereafter ‘CZs’ based on use of 59 radiocarbon ages and analysis of depositional sequences of field-identified strata (Table 3) (Campbell et al., 2018b). While 102 radiocarbon ages were obtained from Čix^wicān overall, 59 dates are from the site areas targeted for our faunal-geoarchaeological project. Through this process, all unique field-documented strata and associated samples (C, CX, S buckets and *in situ* E specimens) were assigned to one of the seven CZs, from CZ 1 (2150–1750 cal BP) to CZ 7 (300–150 cal BP). CZs range in duration from 150 years (CZ 7) to 450 years (CZ 5) (Table 3).

Our current research project did not include deposits from the oldest portions of Čix^wicān documented from the 2004 mitigation dated to as old as 2700 cal BP (Campbell et al., 2018b). Samples from CZ 7 (300–150 cal BP) are limited as well (Campbell et al., 2018b). LEKT knowledge and historic records show that Čix^wicān was a substantial village during the 18th–19th century in the time of European contact (Butler et al., 2018b), but unfortunately, faunal samples from this era are limited.

Fig. 3 shows the distribution of CZs across the excavation blocks targeted for our research. As seen, one area, A4, contains occupation

Table 3
Chronozones (CZs) and associated age ranges for Čix^wicān deposits.

Chronozone	Number of associated radiocarbon dates ^a	Age range (cal BP)	Mid-point (cal BP)
CZ 7	3	300–150	225
CZ 6	13	550–300	425
CZ 5	11	1000–550	775
CZ 4	12	1300–1000	1150
CZ 3	5	1550–1300	1425
CZ 2	8	1750–1550	1650
CZ 1	7	2150–1750	1950

^a 102 radiocarbon ages were obtained from the site overall; 59 are from areas targeted for our faunal-geoarchaeological project.

Table 4
Overview of samples included in the current Čix^wicān project (note: 1 cu m = 1000 L). (Excavated volumes from Reetz et al., 2006: 4–30, 4–62).

Area	Chronozones represented	Volume excavated (m ³)	C buckets ^b		CX buckets ^c	
			Liters excavated	% total excavated	Liters	% total excavated
A1	CZ 4–6	10.21	450	4.4	540	5.3
A3	CZ 3–5	6.90	240	3.5	80	1.2
A4	CZ 2–7	33.16	3170	9.6	2620	7.9
A5 ^a	CZ 1, 5–6	5.94 ^a	370	6.2	290	4.9
A18	CZ 3–4	1.53	40	2.6	40	2.6
A23	CZ 1, 5–6	1.90	90	4.7	30	1.6
BX1/BX4	CZ 3–4	0.85	210	24.7	40	4.7

^a Calculated excavation depth from field forms for the 11 1 × 1 m units from A5 included in current research project.

^b ‘C’ refers to complete buckets that were screened to 1/8” mesh and which provided invertebrate, fish, bird and mammal remains.

^c ‘CX’ refers to buckets that were screened to 1/4” mesh and which provided invertebrate, fish, bird and mammal remains.

from CZ 2 to CZ 7, but most areas have more limited time periods represented. Likewise, A4 provided the largest volume of excavated matrix and in turn volume of samples studied (Table 4); thus summary records for the site are heavily influenced by the A4 samples. Besides using CZs for chronological control, we were able to study finer-scale temporal change in A4 house deposits, where we had clear sequences of floors and fill (Campbell et al., 2018b).

4. Results

4.1. Overview of faunal assemblage

As shown in Table 5, over 1.2 million faunal specimens were documented in the C and CX bucket samples in our study. Specimen frequency is highly uneven across faunal type. Based on number of specimens (NSP), invertebrates represent 1.13 million specimens, over an order of magnitude more specimens than fish, which is an order of magnitude more abundant than mammal and bird. The scaled pattern of abundance generally holds for number of identified specimens (NISP), except that the mammal NISP is almost an order of magnitude less than bird (Table 5). The low frequency of identifiable mammal remains relates to the disproportionate fragmentation of mammal remains at the site, reasons for which Bovy et al. (in this issue) explore in detail. To increase the size of the mammal assemblage, Etnier analyzed additional matrix, 1864 S bucket samples (18,640 L). Even with the substantial increase in volume, only an additional 875 mammal remains (NISP) were identified minimally, to order (Table 5).

Table 5
Overview of faunal remains from C and CX buckets^a, by main faunal type. C buckets were screened to 1/8” mesh; CX buckets to 1/4” mesh.

Faunal type	NSP	NISP ^b	N Order	N Family	N Genus
Mammal ^c	5911	358	5	12	12
Aves	5627	2224	11	13	16
Fish	93,299	47,251	9	18	28
Shell	1,131,585	653,608	14	25	25
Vertebrate ^d	17,000	–	–	–	–
Total	1,253,422	703,441	39	68	81

^a Represents a total of 820 10 L buckets, or 8200 L, from A1, A4, A23, A5, A18, BX1, BX4 (includes ≥ 1/4 and ≥ 1/8”) assigned to chronozones (CZ 1, 2, 3, 4, 5, 6, 7).

^b Specimens identified to at least order.

^c An additional 875 out of 10,808 mammal specimens were identified to at least order from 1864 S buckets (18,640 L). The number of orders, families, and genera for mammals reflect this larger sample size.

^d Primarily from bird and mammal that could not be differentiated.

The fauna is extremely rich, with 39 orders, 68 families, and 81 genera represented. To highlight the main taxa in each faunal type, we have plotted the proportional representation of each family in descending order of NISP (Fig. 4; see Bovy, 2018; Butler et al., 2018a; Campbell et al., 2018a; and Etnier, 2018 for full details of taxonomic identifications). For invertebrates, Mytilidae (mussel) and Strongylocentrodidae (sea urchin) dominate, followed by venus clams, Veneridae (cockle); an additional 21 families are present that represent < 1% of the total shellfish NISP. Notable rare taxa include Dentalliidae (tusk shell), used for ornaments and trade, and Coronulidae (whale barnacle), obligate commensals of baleen whales.

Among fish, herring (Clupeiformes) dominates, constituting 53% of the assemblage overall (Fig. 4). The high herring abundance conforms to recent regional syntheses that emphasize the importance of this small-bodied forage fish in coastal archaeological sites (McKechnie et al., 2014; McKechnie and Moss, 2016). Cottidae (sculpin), second in abundance, is comprised of a large group of spiny fishes, including staghorn sculpin (*Leptocottus armatus*), buffalo sculpin (*Enophrys bison*), and great sculpin (*Myoxocephalus polyacanthocephalus*) that are typically associated with the bottom of both nearshore and relatively deep water, including kelp habitat. Gadidae (cod) is third in abundance, represented by Pacific cod (*Gadus macrocephalus*) and tomcod (*Microgadus proximus*), that are also bottom fishes. The fourth most abundant fish family is another bottom fish, Anoplopomatidae (sablefish or black cod), which is extremely rare in coastal sites in the Pacific Northwest (Nims and Butler, 2018; Nims and Butler, 2018). Nims and Butler (2018) establish that Čix'wicən fishers were targeting juvenile sablefish, between 20 and 40 cm in length, which reside in nearshore waters between 20 and 60 m deep. Salmonidae (salmon and trout) is fifth in abundance.³ Prior to 20th century habitat loss, anadromous salmonids would have been easiest to capture when they migrated into harbor streams or the Elwha River. The remaining families include Squalidae (dogfish shark), Hexagrammidae (greenlings and lingcod), flatfishes (Pleuronectiformes) and others.

Bird bones are relatively abundant at Čix'wicən compared to many other Pacific Northwest sites (Butler and Campbell, 2004). The bird assemblage is dominated by Alcidae (Fig. 4), primarily murre. There is a “spectacular influx” of common murres (*Uria aalge*) in the fall, when they leave their breeding grounds on the outer Pacific coast and enter the SJDF (Wahl et al., 1981: 7). Anatids (ducks, geese) are second in abundance, and were prized both for food and as a source of down for weaving (Suttles, 1951; Swan, 1870). Ducks were caught using hanging, submerged and hand nets. Hanging nets were often placed on strategic locations on sandspits (Suttles, 1951); Paul Kane observed hanging nets at Port Angeles in 1847 (Gunther, 1927: 205). Laridae (gulls, 11%), Gaviidae (loons, 9%), Podicipedidae (grebes, 6%) are also relatively abundant at the site. Diving ducks (such as scoters, *Melanitta* sp.), murres, loons and grebes all roost offshore at night (Manuwal et al., 1979, cited in DePuydt, 1994: 243; Wahl et al., 1981), and may have been hunted from canoes with spears or arrows, using torches or fires to blind and confuse the birds (e.g., Cooper and Suckley, 1859: 261; DePuydt, 1994: 242; Swan, 1870: 25). Also present at Čix'wicən are shearwater/fulmar (Procellariidae) and albatross (Diomedidae), which are far more abundant in offshore habitats of the outer coast, though some species are occasionally observed in the SJDF (Angell and Balcomb, 1982; Wahl et al., 2005).

The mammal assemblage is dominated by terrestrial forms, with Cervidae (black-tail deer and wapiti) the highest ranked family. Second

in abundance is Canidae, primarily represented by dog (*Canis lupus familiaris*). Marine mammals are well represented. Otariidae (northern fur seal and Steller sea lion [*Eumetopias jubatus*]), is the third-ranked family, with a mix of adult, sub-adult, and young-of-the-year fur seals represented. It was not possible to derive exact age estimates for the young-of-the-year fur seals, so it is unclear if they represent newborn pups taken locally or individuals that migrated from distant rookeries (see Etnier, 2004, 2018 for more details). The whale order is represented primarily by the fourth-ranked family Phocoenidae (dolphins/porpoise); unidentified whale is also present. Phocid seals (harbor seal) are ranked fifth. The mustelid family, ranked seventh, is primarily represented by sea otter (*Enhydra lutris*), but also includes small frequencies of mink (*Neovison vison*), and river otter (*Lontra canadensis*). Notable rare taxa include black bear (*Ursus americanus*, n = 2) and orca (*Orcinus orca*, Family Delphinidae), represented by a single tooth. Orca remains are exceptionally rare in North Pacific coastal sites (Etnier, 2003), despite their prominence in Northwest Coast cosmology and iconography (Drucker, 1951).

The Čix'wicən fauna reflects the site's intermediate location between the outer coast and the inner waters of the Salish Sea. The prominence of deer and wapiti is consistent with sites in the Puget Sound and Gulf of Georgia where terrestrial game dominate (Butler and Campbell, 2004); but 22% of Čix'wicən's mammal fauna are marine taxa (including a range of pinnipeds, whales, and sea otter) more typical of outer coast sites (McKechnie and Wigen, 2011). Čix'wicən's location near the eastern boundary of giant kelp meant that people were part of the complex kelp forest ecosystem that supported a diverse range of fish, red sea urchin, and sea otter, the latter of which is scarce in inner waters of the Salish Sea (Hanson and Kusmer, 2001; McKechnie and Wigen, 2011). California mussel, which prefers heavy wave action to calm waters, are well represented in the assemblage.

4.2. Are there changes in the faunal record that indicate local landform evolution?

In line with H.E. research, we sought to map out the history of the local landform, given its role in constraining long-term socio-environmental processes. Campbell et al. (2018b) provide a detailed overview of landform history, drawing on the site's geo-chronological records. Here we use Čix'wicən faunal remains to infer habitat changes related to landform history. The invertebrates are particularly useful for near-shore habitat reconstructions, given specific habitat or food requirements of many taxa and their limited mobility (Claassen, 1998). Epi-faunal taxa (e.g., barnacles, mussels, chiton, dog whelks) are closely associated with rocky beaches. Infaunal species (clams) are adapted to burrowing in soft sediments. The primary food for sea urchin is macroalgae (kelp), which requires bedrock or cobbles on which kelp holdfasts attach in lower intertidal and subtidal areas. In the Salish Sea, kelp is the dominant species when solid substrate is present (Mumford, 2007). Thus, in archaeological contexts, the presence and abundance of invertebrates that are linked to rocky beaches, soft sediment beaches or kelp habitat provide a basis for establishing the extent of these habitats near camp and village locations. Using the record in this way makes the assumption that invertebrate harvest intensity drops off with distance, thus the bulk of the invertebrates deposited at the site would have been harvested within the harbor, or outside the spit.

To reconstruct nearshore habitats in the vicinity of Čix'wicən, we relied on the C bucket samples (screened to 1/8" mesh), which provided 738,053 invertebrate NISP (identified to at least genus). Twelve genera that represent 99% of the total assemblage were easily assigned to habitat group: five genera of burrowing clams, six genera linked to rocky beaches and one genus, urchin, associated with kelp (Table 2). We estimated taxonomic abundance for each genus in each of the seven CZs using MAU (see Table 2 for element used/taxon) and illustrate temporal trends first using proportional representation (Fig. 5).

The Čix'wicən invertebrate record shows striking changes through

³ The relatively modest representation of salmonids is consistent with Butler and Campbell's (2004) synthesis of faunal records in the Salish Sea. They found that salmonid representation tended to be low in coastal settings, while high for site locations on rivers, a key location to dispatch fish migrating to spawning grounds.

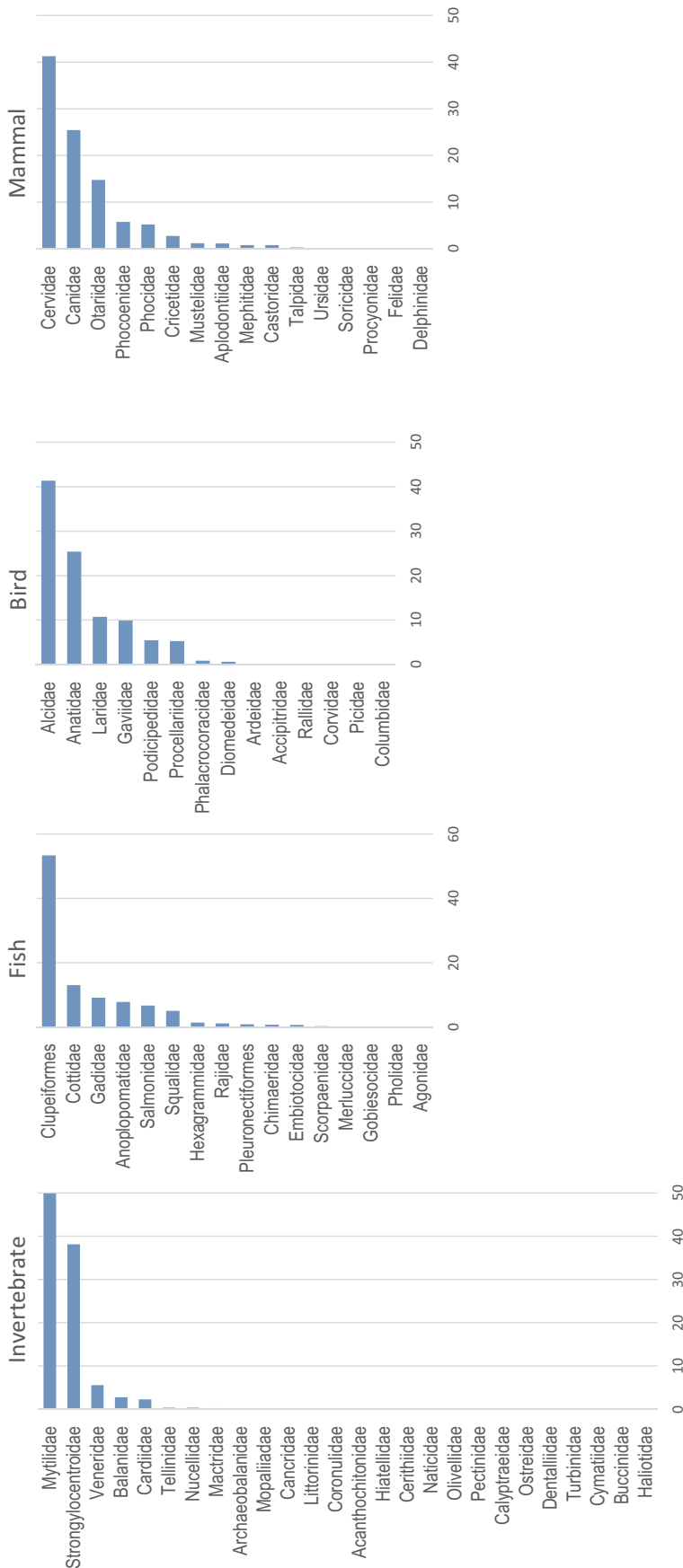


Fig. 4. Proportional representation (% NISP) of family for each faunal type. Samples included: Invertebrates & Fish, C/CX Buckets, $\geq 1/8''$; Bird, C/CX/E bucket and sample types, $\geq 1/8''$; Mammal, C/CX/S/E bucket and sample types, $\geq 1/8''$. (Note, for fish, herring, anchovy, and sardines are reported at the order level (Clupeiformes) because the elements of the otic series could not be identified to the family level with confidence. Given their numerical dominance, Clupeiformes specimens likely are from Pacific herring (*Clupea pallasii*). Flatfish are reported at the order level (Pleuronectiformes) because skeletal elements from member families Paralichthyidae and Pleuronectidae cannot always be distinguished.).

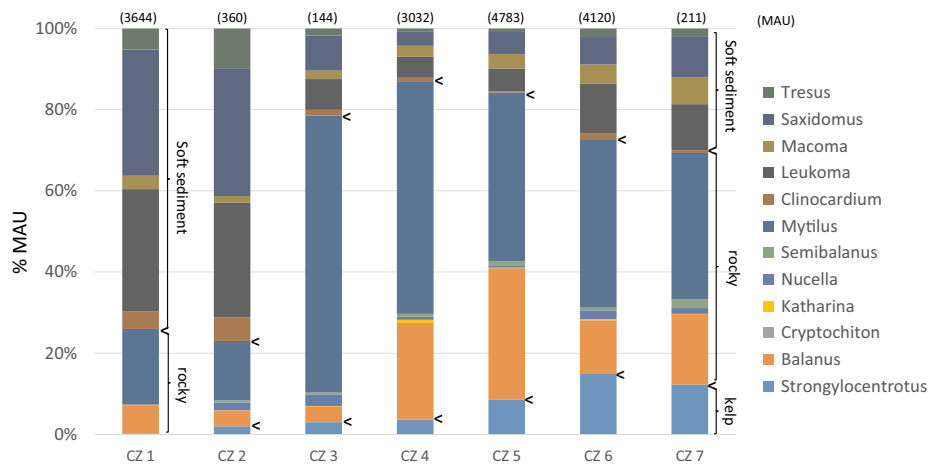


Fig. 5. Relative frequency (% MAU) of primary invertebrates by main habitat type and chronozone (CZ) arranged from oldest (left), CZ 1 (2150–1750 cal BP) to youngest (right), CZ 7 (300–150 cal BP). See Table 3 for all CZ temporal ranges. Caret separates habitat type. Samples included: C buckets, $\geq 1/8''$.

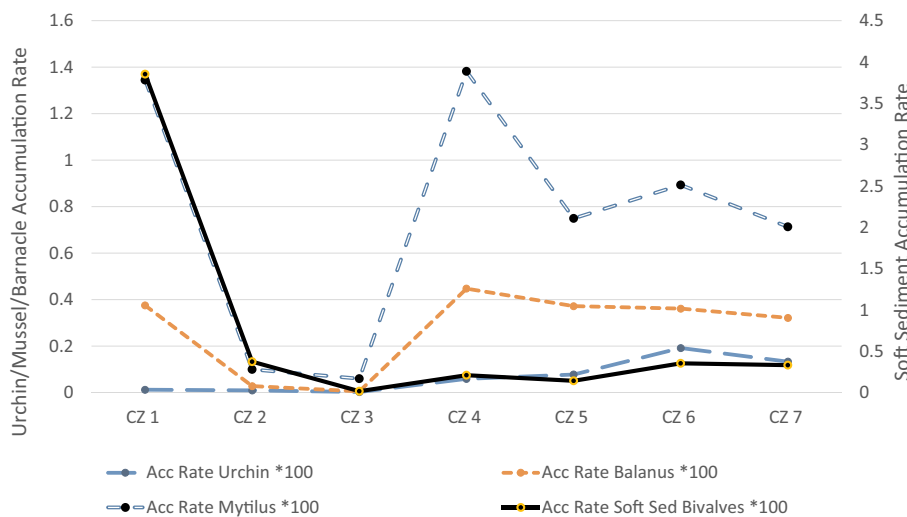


Fig. 6. Accumulation rate (MAU/Volume/Duration) of primary invertebrate genera and soft sediment bivalves by chronozone (CZ) arranged from oldest (left), CZ 1 (2150–1750 cal BP) to youngest (right), CZ 7 (300–150 cal BP). See Table 3 for all CZ temporal ranges. (Note, soft sediment bivalves are plotted on the right axis with a higher scale to accommodate their high abundance in CZ 1). Samples included: C buckets, $\geq 1/8''$.

time (Fig. 5). The oldest two CZs, CZ 1 and CZ 2, are dominated by burrowing bivalves found in soft sediment, especially *Saxidomus* (butter clam) and *Leukoma* (littleneck clam) (Fig. 5). Rocky beach genera (mainly *Mytilus* [mussel]) are relatively uncommon; and urchin is < 1% of each of the oldest assemblages. Faunal representation shifts dramatically in CZ 3, as rocky beach taxa (especially *Mytilus*) dominate; soft sediment bivalves decline in abundance until CZ 5 when they increase. Urchin increases gradually through time after CZ 2. In CZ 6 and CZ 7, urchin represents over 10% of the assemblage.

Accumulation rate (MAU/Volume/CZ Duration) plotted for the three main shellfish genera and soft sediment bivalves as a group, supports these trends, yet tells a somewhat different story (Fig. 6). The shift from soft sediment bivalves in the oldest CZs towards rocky beach substrate taxa is still evident. However, the accumulation rate suggests this main shift takes place in CZ 4, rather than CZ 3, when *Mytilus* and *Balanus* (acorn barnacle) reach their zenith, then decline. The trend for kelp and soft sediment habitat to increase from CZ 5 to CZ 6, tapering off in CZ 7, is generally consistent with changes in proportional representation.

In short, these trends suggest striking changes in nearshore habitat over the past ~2150 years. During CZ 1 (2150–1750 cal BP) and CZ 2 (1750–1550 cal BP), soft-sediment habitat dominates. Then there was a major loss of burrowing clam substrate in the area by CZ 3 (1550–1330 cal BP). Colonization of an exposed rocky substrate by epifauna would have been underway, as soft substrate was lost, and a substantial population of rocky beach taxa was established by CZ 4

(1300–1000 cal BP) when accumulation rates increase. After ~1000 years ago (beginning of CZ 5), the proportions of rocky species decreases steadily, while soft substrate bivalves increase, but never to the levels seen in CZ 1 (around 15% in CZ 7 compared to 75% in CZ 1). The changing representation of urchin, associated with kelp forests, is harder to interpret; it generally parallels the epibenthic rocky substrate taxa, which is not surprising since kelp prefers cobble substrate. The loss of soft sediment clam habitat by CZ 3 is likely tied to the long-term evolution of the spit and harbor, while the increase in such habitat after CZ 5 possibly results from deposition following catastrophic events such as tsunamis (Campbell et al., 2018b).

4.3. Are there changes in resource use that correspond to the transition to plankhouse occupation?

In order to set the context for understanding impacts from changing ocean conditions (Section 4.4), from earthquakes (Section 4.5), or social conditions at Čix'wicən (Section 4.6), we must first reconstruct trends in human occupation history. We explore occupational history in two ways. First, we use changing accumulation rates of all the fauna over the 2150-year occupation sequence to build a picture of changing human occupational intensity. Second, there is independent evidence that Čix'wicən residents began to build plankhouses on the landform at the beginning of CZ 4 (1300–1000 cal BP) (Campbell et al., 2018b); we investigate whether this social-cultural change in settlement was accompanied by changes in the structure of resource use.

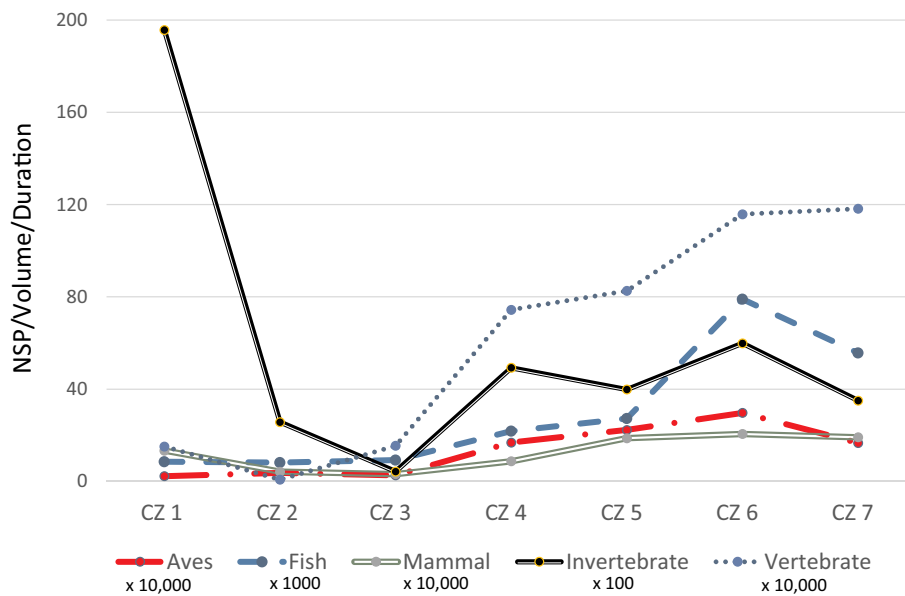


Fig. 7. Accumulation rate (NSP [number of specimens]/Volume/Duration) of all faunal types by chronozone (CZ) arranged from oldest (left), CZ 1 (2150–1750 cal BP) to youngest (right), CZ 7 (300–150 cal BP). See Table 3 for all CZ temporal ranges. The vertebrate category is mainly bird and mammal bone that could not be distinguished (Note the different multipliers used for faunal types, given the widely different absolute abundances). Samples included: C buckets, $\geq 1/8$ ".

Trends in accumulation rate across taxa are a crude indicator of occupation intensity. Higher accumulation rate could reflect the same number of people spending more of a year at the location, or more people spending the same amount of time, or some combination of these. The high accumulation rate for shellfish in CZ 1 followed by a severe decline across all the shellfish taxa (Fig. 6) suggests a major decline in site use. Accumulation rate remains low for CZ 2 and CZ 3, suggesting that there was limited shellfish collecting overall during this period. In CZ 4, accumulation rate dramatically increases for the rocky beach *Mytilus* and less so for *Balanus*. Notably, this general pattern, low accumulation rate in CZ 2 and CZ 3 followed by an increase in CZ 4, is repeated for all faunal groups (Fig. 7). Beginning in CZ 4, frequency of all animal types increases, generally reaching their high point in CZ 6 before tapering off in CZ 7.

This overall pattern suggests that human activities in CZ 1 focused on shellfishing (esp. for burrowing clams), followed by limited use in CZ 2 and 3. CZ 4, which as noted, also holds evidence for plankhouse construction, marks more intensive human occupation continuing until CZ 6. For discussion below, we label the pre-CZ 4 occupation as "camp" and occupation after CZ 3 as "village."

Does resource use change with the shift to plankhouse village occupation? Our expectation was that if the early, pre-house occupation was a logistical camp that was visited as part of a seasonal round, that the faunal record would show use of fewer, and seasonally restricted resources. If the later plankhouses were occupied all year as a permanent village, the faunal record would show a wider range of resources taken from throughout the year. We expected a shift from a less even, and more focal pattern in CZ 1–3, to a more even and richer animal fauna in CZ 4 and afterwards. To evaluate these expectations, we calculated Shannon's diversity index and determined richness for the main animal groups (invertebrate, fish, mammal, bird) for each CZ based on family level records. Because herring abundance is extremely high in several CZs and we wanted to assess evenness in the fishery independent of herring, we calculated evenness including and excluding this taxon. When sample size for a faunal type in a given CZ was < 30 specimens, evenness was not calculated (see Supplementary File 1).

Our expectations were not met (Fig. 8). Evenness does not increase with CZ 4 as expected for any of the animal types. The shift to plankhouse occupation did not result in broader use of animals. Evenness for fish (herring excluded) is remarkably consistent from CZ 1 to CZ 7. When herring are included, evenness declines greatly in CZ 6, which suggests a focal fishery on herring at this time. For shellfish (overall and for bivalves alone), evenness actually declines after CZ 2 and remains

relatively low for the rest of the occupation. Shellfish use was actually broader earlier, in CZ 1 and CZ 2, during the so-called camp phase than in the later occupation. For mammals and birds, samples sizes are too small for evenness calculation for CZ 1–3 (Supplementary File 1), so we cannot use this measure to track change from the camp to the village for them.

Taxonomic richness at the family level *does* increase after CZ 3 for all faunal groups except fish (Table 6), which supports the idea that with more permanent occupation, a greater variety of resources were procured and brought back to the village. However, there is often a high positive correlation between richness and sample size, which makes it difficult to determine if, for a given context, the number of taxa present is independent of sample size itself (Grayson, 1984). At Čix'wicən the correlation between sample size and richness is high and significant for fish, birds, and mammals (p values of 0.017, < 0.001, and 0.002, respectively) and is marginally significant for invertebrates ($p = 0.083$) (see Supplementary File 2). To mitigate this challenge, we divided the seven CZs into sub-populations, CZ 1–3 and CZ 4–7, corresponding to the camp and village occupations (following Grayson and Delpech, 1998; Nagaoka, 2002), to see if the relationship between sample size and richness was different for the two sub-populations. When considered as different sub-populations, the relationship between sample size and richness is only significant for "bird/camp" and both sub-populations of mammals (Supplementary File 2). However, the slopes for the two sub-populations are not significantly different for any of the faunal types, thus we are not able to separate out the effects of sample size on taxonomic richness for the camp vs. village occupation periods (Supplementary File 2). That is, although there are higher numbers of families of invertebrates, birds, and mammals in the "village" phase than there are in the "camp" phase, we cannot rule out the possibility that this is strictly a function of sample size (i.e., how many bones and shells were recovered from each CZ).

To consider more specifically the animal taxa people used during the camp and village occupations, we plotted the presence/absence of each family for each occupation type (Table 7). For both shellfish and mammals, a few taxa were present in the camp occupation but absent in the village occupation. As expected given larger sample sizes, several new taxa were added during the village occupation. Importantly, these additional taxa represent extremely small sample sizes, emphasizing their rarity in the village occupation (Table 7). For example, for shellfish, the six families present only in the village occupation contributed only 40 NISP, or 0.006% of the NISP of the village occupation. Thus, even if we could make the case that the faunal assemblage in the village

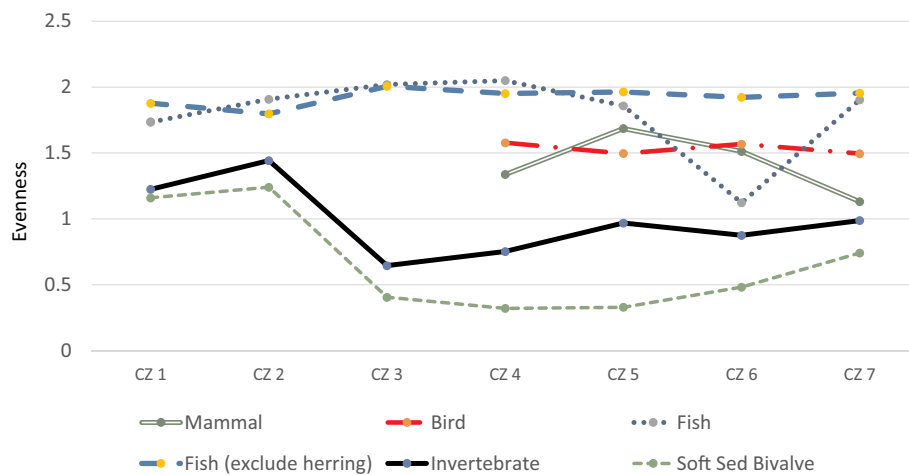


Fig. 8. Plot of Shannon's evenness for each faunal type by chronozone (CZ) arranged from oldest (left), CZ 1 (2150–1750 cal BP) to youngest (right), CZ 7 (300–150 cal BP). See Table 3 for all CZ temporal ranges. Values based on NISP of family. For fish, calculated two measures including and excluding herring; and for invertebrate, one for all families and one for soft sediment bivalves alone. Index not calculated for mammal and bird in CZ 1–3 given small sample sizes. Samples included: Invertebrate & Fish: C buckets, $\geq 1/8''$; Bird: C/CX buckets, $\geq 1/8''$; Mammal: C/CX/S/E bucket and sample types, $\geq 1/8''$.

Table 6

Taxonomic richness (N Family) and number of identified specimens (NISP) by family for faunal types, Čixwīcān. Samples included: Mammal, C/CX/S/E bucket and sample types, $\geq 1/8''$; Bird, C/CX, $\geq 1/8''$. Invertebrate/Fish, C buckets, $\geq 1/8''$.

	Chronozone	Invert NISP	Invert N Fam	Fish NISP	Fish N ^a Fam	Bird NISP	Bird N Fam	Mammal NISP	Mammal N Fam
Village	CZ 7	9966	13	836	12	43	6	38	5
	CZ 6	260,269	15	29,059	15	991	12	567	12
	CZ 5	128,234	16	8765	13	762	10	409	9
	CZ 4	138,493	15	3191	12	322	8	194	7
Camp	CZ 3	6380	13	1023	12	28	5	26	5
	CZ 2	5315	14	225	12	16	5	8	3
	CZ 1	62,946	13	274	10	16	5	59	8

^a The orders Clupeiformes and Pleuronectiformes are counted as *family* for this tally, see caption Fig. 4.

occupation is richer (independent of sample size), the overall impact on lifeways, subsistence, or ritual, appears to be slight.

Comparing the seasonal availability of animals present in the camp vs. village phases suggests that in both, occupants were spending much or all of the year at the location. Prominent birds in both occupation periods, alcids (murre) and anatids (ducks, geese), are most common between October and March (Wahl et al., 1981), while procellariids (shearwaters) are most common in summer. Herring are most abundant when they move into nearshore waters to spawn in late winter and spring. Salmonids are most accessible during their spring, summer and early fall spawning runs. Pacific cod (a prominent gadid in both periods) is easiest to procure when it enters nearshore shallow waters in winter (Bowers and Moss, 2001). Shellfish were likely taken throughout the year, with fewer taken during summer (e.g., Cannon and Burchell, 2017). Beyond seasonality, the presence of large terrestrial mammals such as deer and wapiti in both periods indicates that remains of terrestrial mammals were being transported to the coastal settlement whether it was a “camp” or a plankhouse “village.”

All this suggests that the earliest occupation reflects a central residential base that was occupied for extended periods of the year, rather than a stop on a seasonal round or a logistical camp. During the camp occupation, people were spending extended periods of the year at the site, collecting, processing and consuming foods procured from marine and terrestrial habitats. The sharp increase in accumulation rate at 1300 cal BP (CZ 4) (Fig. 7) with the shift to plankhouse occupation, suggests more people were spending more time at the location than previously; but the structure of animal use (as measured by evenness and richness) is remarkably consistent for the 2150-year period.

4.4. Are there changes in animal representation that correspond to changes in ocean conditions?

A core aspect of human ecodynamics research concerns ways socio-

ecological systems are affected by changing environment (e.g., McGovern et al., 2007; Nelson et al., 2016). Of particular concern in our research is how changing ocean conditions affected animal abundance or foodwebs, and in turn human lifeways (Jerardino et al., 2008; Jones et al., 2017; Monks, 2017a, 2017b). As noted previously, H.E. is especially interested in considering not just environmental impacts on fauna (and in turn people), but ways humans negotiated their response to such changes, distinguishing this scholarship from environmental determinism.

For Čixwīcān records, Hutchinson et al. (2018, in this issue) identified striking trends in human occupational history at the site, which they suggest are linked to changing marine productivity and possibly to impacts of tsunamis. Briefly, Hutchinson et al. created a summed probability density function based on 102 radiocarbon ages, which they used as a proxy for occupational intensity. They highlighted several peaks and troughs, which correspond to peaks and troughs in abundance of fish remains in a sedimentary marine core from Saanich Inlet, Vancouver Island (Tunncliffe et al., 2001), which the authors argue is a proxy for changing ocean productivity and food web responses (Fig. 9). In particular, Hutchinson et al. suggest warmer sea surface temperatures (SSTs) associated with the Roman Warm Period and the Medieval Warm Period (MWP) led initially to increased primary productivity, especially an increase in forage fish such as herring. The authors suggest that, in time, this would have led to increased competition or increase in predators; and these ‘top down’ drivers along with cooling temperatures associated with the Late Antique Little Ice Age (LALIA) or Little Ice Age (LIA) would then cause fish abundance to decline. Their work highlights the complex relationship between SSTs, ecosystem processes, and fish abundance (see Maschner et al., 2009 and Monks, 2017a for additional views). Alignment with other climate proxies, particularly advances and retreats in alpine glaciers and globally recognized climate eras such as the LALIA, the MWP, and the LIA (Fig. 9; Hutchinson et al., 2018, in this issue) support the interpretation that

Table 7

List of family represented by main animal type for the camp (CZ 1–3) vs. village (CZ 4–7) occupations. Samples used: Fish/Invertebrates: C buckets $\geq 1/8''$; Birds: C/CX/E $\geq 1/8''$; Mammal: C/CX/S/E, $\geq 1/8''$.

Shellfish	CZ 1–3	CZ 4–7	Fish	CZ 1–3	CZ 4–7	Bird	CZ 1–3	CZ 4–7	Mammal	CZ 1–3	CZ 4–7
Archaeobalanidae	x	x	Anoplopomatidae	x	x	Alcidae	x	x	Aplodontiidae	x	x
Balanidae	x	x	Bothidae	x	x	Anatidae	x	x	Canidae	x	x
Cancriidae	x	x	Chimaeridae	x	x	Gaviidae	x	x	Cervidae	x	x
Cardiidae	x	x	Clupeidae	x	x	Laridae	x	x	Cricetidae	x	x
Cerithiidae	x	x	Cottidae	x	x	Podicipedidae	x	x	Delphinidae	x	x
Littorinidae	x	x	Embiotocidae	x	x	Procellariidae	x	x	Mustelidae	x	x
Mactridae	x	x	Gadidae	x	x	Accipitridae	x	x	Otariidae	x	x
Mopaliidae	x	x	Hexagrammidae	x	x	Ardeidae	x	x	Phocidae	x	x
Mytilidae	x	x	Pleuronectidae	x	x	Columbidae	x	x	Phocoenidae	x	x
Nucellidae	x	x	Rajidae	x	x	Corvidae	x	x	Soricidae	x	
Strongylocentroidae	x	x	Salmonidae	x	x	Diomedidae	x	x	Talpidae	x	
Tellinidae	x	x	Scorpaenidae	x	x	Phalacrocoracidae	x	x	Procyonidae		x
Buccinidae	x	x	Squalidae	x	x	Picidae	x	x	Castoridae	x	x
Hiatellidae	x		Agonidae	x	x	Rallidae	x	x	Felidae	x	x
Naticidae	x		Engraulidae	x	x	Total NISP add'l taxa added	55		Mephitidae		x
Acanthochitonidae		x	Gobiesocidae		x				Ursidae		x
Coronulidae		x	Merluccidae		x				Total NISP add'l taxa added		26
Dentalliidae		x	Pholidae		x						
Ostreidae		x	Total NISP add'l taxa added		13						
Pectinidae		x									
Turbinidae		x									
Total NISP add'l taxa added		40									

trends in the marine sediment core reflect changing ocean conditions.

Do we detect any change in animal representation in Čix^wicən faunal records that corresponds to these environmental trends? We might approach this question with Čix^wicən records by comparing faunal representation by CZ against the records for environmental change. Given that the duration of CZ 4 and CZ 5 spans hundreds of years, such a comparison would be very coarse. For example, the most pronounced peak and trough in the fish remains core highlighted by Hutchinson et al. (2018, in this issue), falls *within* the period of CZ 4 (1300–1000 cal BP). CZ 5 encompasses part of the MWP and also the LIA (Fig. 9). We sought a finer-grained approach, which was feasible because of the series of discrete fill and floor deposits in the A4 plankhouse, spanning CZ 3 – CZ 7 (Table 8). Using the superposition of deposits, we created a temporal order that allows us to consider change *within* CZ 4, 5, and 6. To graphically display faunal records on a time series that could be compared with trends in Hutchinson et al. (2018, in this issue), we estimated an absolute age for each deposit using either the beginning of a CZ or its midpoint.

We studied temporal trends for the dominant fish and invertebrate taxa using density (NISP or MAU/volume sampled).⁴ Not only do we expect their abundance to be more directly related to changing ocean conditions than birds and mammals, but they also offer relatively large sample sizes. A trade-off in using the finer-stratigraphic contexts is that sample sizes of mammal and bird remains from the discrete deposits were too small to provide meaningful comparisons for the sequence.

As shown in Fig. 9, changing density for fish and invertebrate groups do not correspond to the fish core record for fish abundance or the MWP or LIA. We expected spikes in abundance in the MWP and declines in the LIA, but patterns in fish and shellfish representation are much more complex. One common theme in the records is for density of the fish and shellfish groups to increase through time, which could indicate more about increase in occupational intensity than anything specific about ocean conditions. Beyond this though, we are struck by the lack of consistency in density across groups through time suggesting that single drivers such as changing SST are not behind the patterns. For example, urchin, soft sediment bivalves and mussels show an offset pattern of peak abundance and decline (Fig. 9), suggesting local

⁴ We calculated density rather than accumulation rate because faunal records were assigned to a single time slice rather than a duration.

environmental change or cultural use patterns have more to do with faunal trends than ocean conditions. For the fish, trends in herring density, including a high spike in density between 600 and 400 cal BP, are unlike the records for salmon, rockfish and allies (Scorpaeniformes), and cods, which, after 1000 cal BP, show a relatively consistent representation. Overall, trends in marine taxa faunal density at Čix^wicən do not correspond to changing ocean conditions.

4.5. To what extent did earthquakes affect nearshore habitats, animal populations, or cultural procurement?

Understanding ways people responded to natural hazards is of central interest to H.E. research (e.g., Fitzhugh et al., 2016; Harrison and Maher, 2014). Čix^wicən is located ~220 km east of the plate-boundary for the CSZ, which has ruptured as many as seven times over the past 3200 years, resulting in “great” earthquakes (8.0 magnitude or greater) (Atwater et al., 2004; Atwater and Griggs, 2012). Northwest Coast Indigenous oral traditions describe major consequences (including loss of life) resulting from landslides, subsidence, uplift, and tsunamis (Losey, 2007; Ludwin et al., 2005; McMillan and Hutchinson, 2002; Phillips, 2007; Swan, 1870; Younker, 2007). Hutchinson et al. (2018, in this issue) suggest the principal threat was tsunamis. Walsh et al. (2002) predict complete inundation of the shoreline of Port Angeles in the event of a tsunami. Modeling impacts of tsunamis on the landform hosting Čix^wicən suggests that if tsunamis occurred at high tide, impacts would have been considerable. Campbell et al. (2018b) point to evidence for possibly five tsunamis at Čix^wicən which are linked to four named CSZ events, S, U, W, and Y, and to Event 2, a tsunamigenic deposit identified in Discovery Bay, ~50 km east of Čix^wicən, but which has not been linked to a rupture at the plate margin so likely has a local origin (Table 8).

Our project examined the impact of tsunamis on the socio-environmental system in two main ways. In this section, we consider how nearshore habitats, animal populations and cultural procurement were affected. In Section 4.6, we turn specifically to ways social entities at Čix^wicən negotiated animal resource use after such an event, through changes in social organization and collective action; and whether some households gained control over resources, or changed patterns in resource use because of changes in resource patches that households regularly used.

As part of a pilot study of a small sample of Čix^wicən fish remains

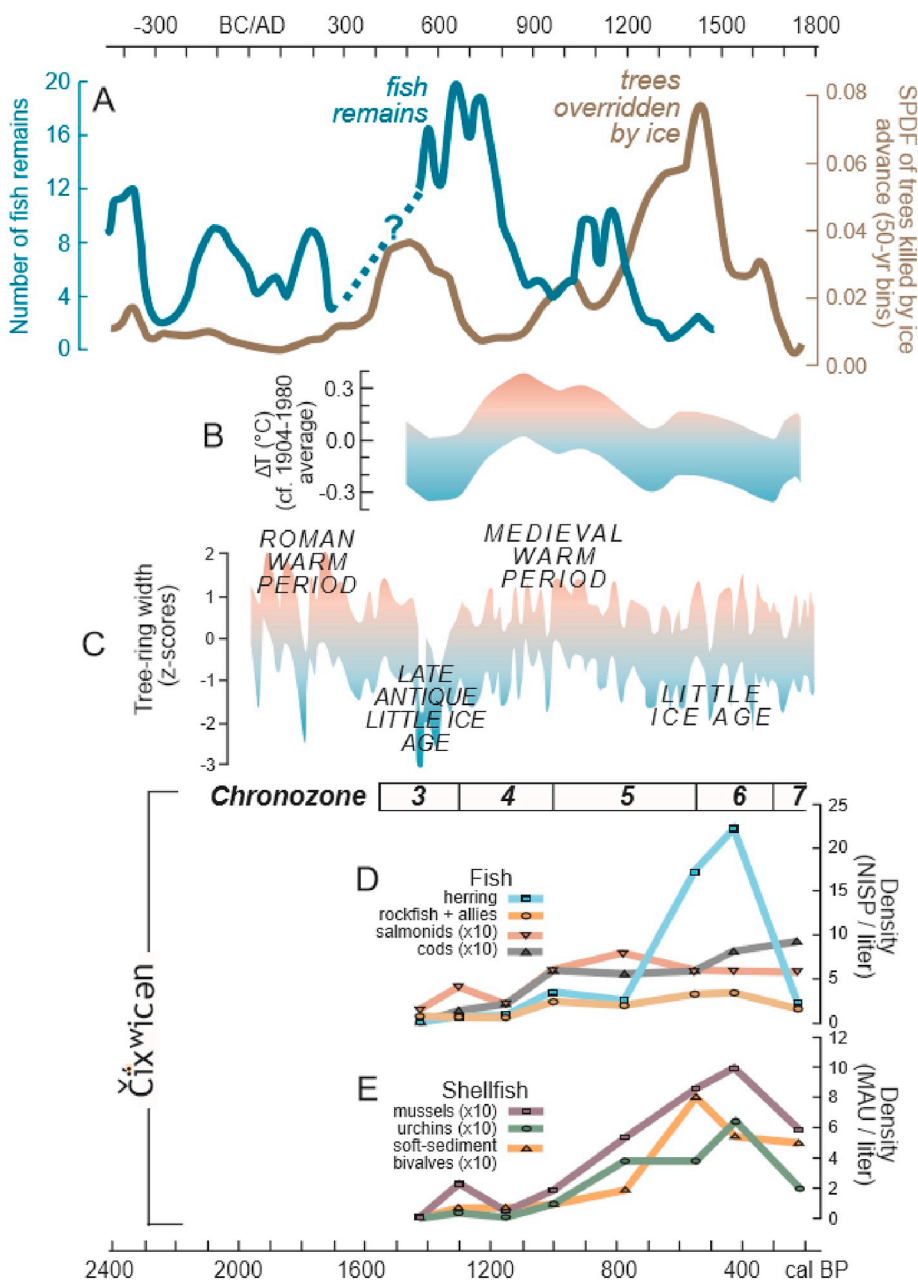


Fig. 9. A) Number of fish remains (3-sample means) in ODP (Ocean Drilling Program) core (Tunncliffe et al., 2001) and calibrated summed probability distribution (SPDF) of trees killed by glacial advances in southwest British Columbia and adjacent areas of Washington State (Hutchinson et al., 2018, in this issue); B) Paleotemperature indices from western North America (redrawn from Trouet et al., 2013); C) Eurasia (redrawn from Büntgen et al., 2016); D) Density of fish remains from dominant taxa in floor-fill sequence in A4 (this study); E) Density of shellfish remains from dominant taxa, floor-fill sequence in A4 (this study). Samples included: Invertebrates & Fish, C buckets, $\geq 1/8''$. (Figure drafted by Ian Hutchinson; Fig. 9a–c appears as Fig. 6 in Hutchinson et al., 2018, in this issue.)

and drawing on work by Losey (2005, 2007), Mohlenhoff and Butler (2017) highlight ways nearshore habitats and animal populations could be directly and indirectly affected by tsunamis (Table 9). Habitat (and associated food webs) could be degraded through erosion or deposition. As tsunamis move onshore they can scour nearshore habitats and lower reaches of streams, which could result in a decline in shellfish populations and salmon spawning habitat. As floodwaters recede—slowing waters deposit sediment, which, depending on context and matrix, could create new habitat for some fishes and burrowing invertebrates, or could be detrimental for other plants and animals. Kelp habitat could be negatively affected by both erosion and deposition. Scouring could undermine substrate supporting the holdfasts and defoliate the kelp itself. Bull kelp does not tolerate being covered by silt (Mumford, 2007); and increased seawater turbidity and sediments can negatively affect kelp either by reducing sunlight or directly by the particulate matter (Watanabe et al., 2016). Canopy kelp forests that are reduced by severe storms show reduced resilience to urchin herbivory (Filbee-Dexter and Scheibling, 2012).

The two main nearshore habitats, eelgrass beds and kelp forests, are

expected to show different levels of resilience to tsunami impacts. Eelgrass beds, which are preferred spawning habitat for herring, are expected to be more resilient as research shows they are capable of losing 75% of their biomass annually due to grazing, yet rebound (Schultz, 1990, cited in Losey, 2002). Kelp forests would be less resilient to disturbance associated with major tsunamis. The fish and invertebrates associated with these main habitats would be expected to respond similarly. For example, herring and nearshore fish that rely on eelgrass beds would be less affected and the animals associated with the kelp food web (larger sculpins, Pacific cod, urchin, sea otter) would be more affected (Table 9).

Because of their sessile nature and the high potential for change in nearshore habitats resulting from tsunamis, shellfish would be most affected by tsunamis, and fish less so, given their mobility. Higher trophic feeders and mobile creatures like birds and marine mammals would be least affected given their mobility. On the other hand, if coastal habitats were severely degraded, food webs could be disrupted, which could affect local abundance of all the creatures in that web.

In addition to direct impacts from tsunamis on habitats and animals,

Table 8

A4 house deposits in stratigraphic sequence with estimated ages and temporal relationship to four known earthquakes events. A fifth event, S, pre-dates the house in A4; impacts of this tsunami not considered. Volume of matrix analyzed by chronozone (CZ) and deposit type listed for C buckets screened to 1/8" mesh; and CX buckets screened to 1/4" mesh.

Chronozone	Deposit	Volume (liters)	Age Assigned	Earthquake (age range)	Comment
CZ 7	Extramural	300	225 BP	Event Y (250 cal BP) ^a	Mid-point of CZ 7
CZ 6	Post-house	1260	425 BP		Mid-point of CZ 6
	Floor 4	540	550 BP	Event 2 (650-560 cal BP) ^b	Beginning of CZ 6
CZ 5	Fill	470	775 BP		Mid-point of CZ 5
	Floor 3	590	1000 BP	Event W (910-790 cal BP) ^c	Beginning of CZ 5
CZ 4	Floor 2	240	1150 BP		Mid-point of CZ 4
	Floor 1	260	1300 BP	Event U (1260-1230 cal BP) ^c	Beginning of CZ 4
CZ 3	Pre-house	600	1425 BP		Mid-point of CZ 3

^aHistorically documented event, January 26, 1700 (Atwater et al., 2005).

^bGarrison-Laney, 2017. Note: Mohlenhoff and Butler (2017) refer to this dated tsunami deposit in Discovery Bay, as "T-2", a label, "T", typically linked to turbidites that occur in the deep sea and are thought to result from massive earthquakes. Garrison-Laney suggests the tsunami sand in Discovery Bay results from a local rather than a subduction zone boundary event.

^cAtwater et al., 2004; Atwater and Griggs, 2012.

Table 9

Summary of tsunami-related drivers and associated impacts on habitats or cultural procurement.

Driver-process	Expectation
Habitat loss (erosion)	
Intertidal shellfish beds	Decrease in soft sediment bivalves?
Eel grass beds	Fast recovery: herring/nearshore fish, minimally affected
Kelp beds	Long recovery: associated fish/sea urchin more affected.
Salmon stream spawning habitat ^a	Decline in salmonids
Soft sediment habitat increase (deposition)	
Intertidal shellfish beds	Increase in soft-sediment bivalves?
Kelp beds	Decline in kelp forests and creatures closely tied to kelp forest habitat (urchin)
Salmon stream spawning habitat ^a	Decline in salmonids
Loss of boats/nets/other gear	Offshore resources decline; mass capture resources decline Decline in marine mammals, offshore birds; increase in terrestrial mammals/nearshore birds

^a Port Angeles Harbor streams are short. Prior to industrialization and loss of habitat, salmon likely would have spawned relatively close to stream mouths; thus any tsunami run-up would have degraded salmon spawning habitat.

such events could result in disruption to the social sphere: loss of human life, destruction of houses and loss of equipment required to dispatch animals (canoes for hunting and fishing of marine creatures; gear such as nets and poles, hook and line). Offshore resources that require canoes (marine mammals, offshore birds) would decline while nearshore resources would not be as affected. The loss of canoes could also lead to a greater use of terrestrial resources and a decline in marine mammals (Table 9). Losey (2005) notes that loss of boats (and their crews) from the 2004 Indian Ocean earthquake led to great declines in marine fisheries in the region (see FAO, 2007).⁵

⁵ We note too that Northwest Coast canoes, mainly "dugout" forms made from western red cedar (*Thuja plicata*), ranged in length from over 10 m to 4 m, with the larger forms able to carry enormous loads (> 5 tons) (Ames, 2002). Given their importance for resource procurement and maintaining social networks, in the aftermath of an event when boats were lost, a community would likely make boat building a high priority. Nonetheless, construction of large canoes would have represented a substantial labor investment. Given such costs, it is reasonable to suggest that foragers may have shifted subsistence focus to nearshore resources if canoes were lost.

In testing for tsunami-related impacts on Čix^{wicən} animals, we needed a chronology of earthquake events that could be tied to the chronology of Čix^{wicən} deposits. Timing of earthquake events has been closely studied in coastal areas of Oregon, Washington, and British Columbia, through dating of buried subsided landscapes, tsunami sands, and liquefaction features (Atwater et al., 2004; Atwater and Griggs, 2012). Time estimates for the events range from 120 years (Event W) to one day (Event Y) (Table 8). To link these earthquakes to Čix^{wicən} chronology, we needed the most fine-grained temporal record possible, coupled with the need for robust faunal sample sizes. We turned to the floor and fill deposits from the A4 plankhouse, which extend from CZ 3 to CZ 7, as discussed in Section 4.4.

We arrayed the earthquake ages against the best age estimates for floor and fill deposits and used proportional representation of taxa from the deposits to characterize the status of animal populations 'before' and 'after' earthquake events. For example, to assess the impacts of Event 2 on invertebrates, we compared proportional representation of taxa between CZ 5 fill deposit (= 'before') to the CZ 6 floor deposit (= 'after') (Table 8, Fig. 10).

We recognize that our approach to assessing tsunami impacts has

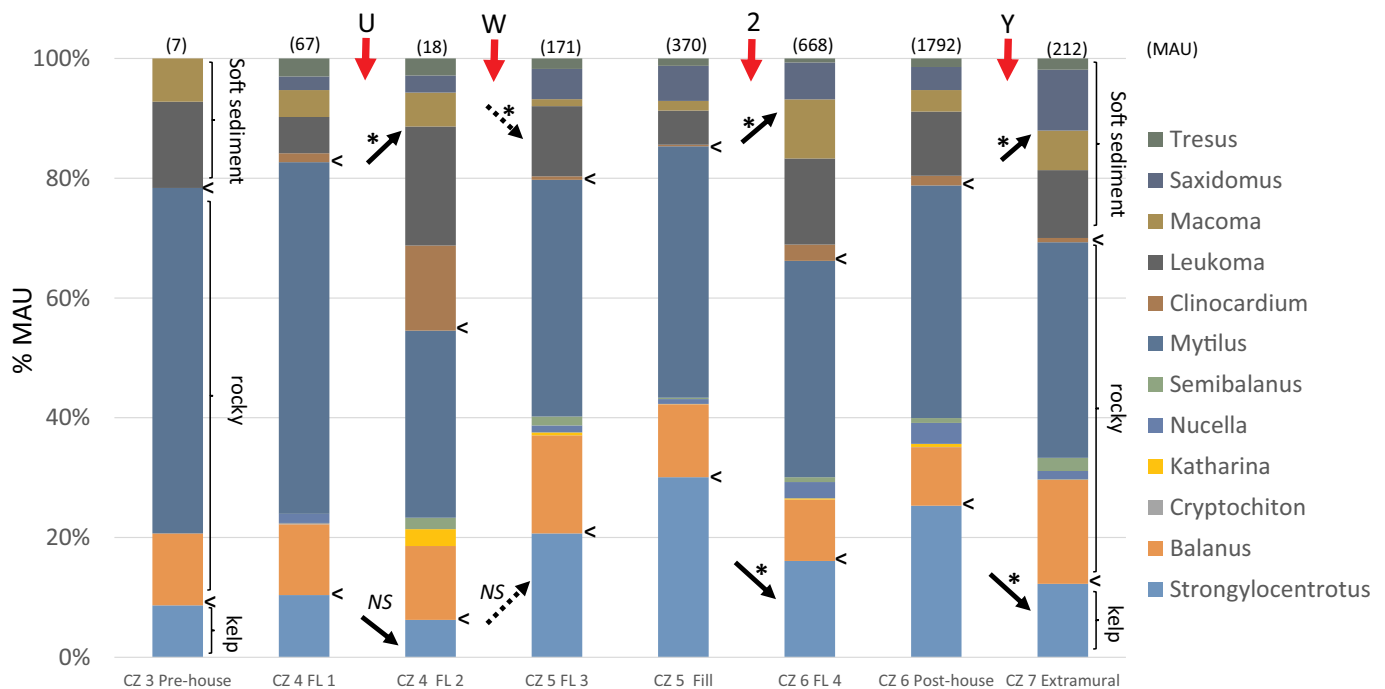


Fig. 10. Pct MAU of invertebrate genera within floor-fill sequence of A4 house, arranged from older (left) to younger (right). Temporal range of CZs in Table 3. Genera grouped by main habitat type, separated by caret symbol. Earthquake events (red arrow) indicated by letter or number. Solid arrows show trend in relative abundance of taxa-habitat type followed expectation; dotted arrows show trend contrary to expectation. Significant trends ($p = 0.05$) based on analysis of adjusted residuals indicated with *, NS = not significant. See Supplementary File 3 for statistics. Samples included: C buckets, $\geq 1/8''$.

weaknesses. This approach presumes that the earthquake events happened *before* or *after* our analytic components (e.g., CZ 4 Floor 2; CZ 5 Floor 3), when the event could have happened at some point over the period of time the deposit formed. Importantly, the separation of the CZs and floor-fill deposits can be directly tied to tsunami events for some contexts. For example, Campbell et al. (2018b) argue that Event 2 led to temporary abandonment of the A4 plankhouse. CZ 6 Floor 4 represents a rebuilding of the plankhouse with a slightly different footprint. Thus the deposits representing the ‘befores’ and ‘afters’ related to Event 2 are well-coordinated. We also recognize the challenge in gauging earthquake impacts, which are expected to be most profound in the few years following an event, with deposits that accumulated over decades if not centuries. In this way, our tests are conservative: given the time resolution, many impacts will not be detected, but substantial ones might be.

What impacts to animal populations do we see? To start with invertebrates (Fig. 10), after three events, Event U, 2, and Y, soft sediment burrowing bivalves increase in relative abundance, and urchin abundance declines, which follows if tsunamis tend to deposit soft sediment conducive to burrowing bivalves; and defoliate kelp, which would degrade kelp habitat for urchin. All but one these trends are statistically significant ($p = 0.05$) based on analysis of adjusted residuals (see Supplementary File 3). Note too that rocky species also decline after Event U, which would occur if coastal erosion was severe. On the other hand, after Event W, soft sediment bivalves *decrease*, also a significant trend; the increase in urchin after Event W is not significant, however (Fig. 10).

Regarding fish (Fig. 11), we focused attention on salmon and herring: salmon are expected to decline if scouring of spawning habitat occurred, while herring are expected to increase relative to other fishes given the premise that eelgrass, preferred spawning habitat for herring, would be more resilient to tsunami impacts than other nearshore habitat like kelp. As seen in Fig. 11, after Event U and Event 2, both expectations were met; the trends are significant based on adjusted residuals (Supplementary File 3). Neither of the trends after Event W are significant. After Event Y, neither expectation was met (salmon increase, herring decrease;

and both trends are significant). Beyond simple trend direction, the most striking pattern in fish representation across the house deposits is the huge spike in herring after Event 2 in CZ 6 (Fig. 11), which was noted earlier (Section 4.4) when reviewing effects of changing ocean conditions on marine resources (Fig. 9). In Section 4.6 we will consider shifts in the overall fishery between CZ 5 and CZ 6 and between contemporaneous households. Here we emphasize that differences in fish representation across most of the floor-fill sequence are relatively subtle except between CZ 5 and CZ 6; and CZ 6 and CZ 7.

For mammals, as seen in Fig. 12, after Event Y, relative abundance of marine mammal significantly declines, in line with the expectation that loss of boats or other gear led to reduced marine mammal use (while the minimal change after Event 2 is not significant).

For birds, the most striking trend is after Event W, when the abundance of offshore birds – alcids (murre), procellariids (shearwaters), and diomedeids (albatross) that would require watercraft to procure, *declines* as expected from tsunami impacts (Fig. 13). There is a slight but significant increase in offshore birds after Event 2, however, while there is no significant change after Event Y (Fig. 13).

These results suggest that invertebrates and fish were affected more than birds and mammals, which is in line with expectations that tsunamis should disproportionately affect less mobile creatures (shellfish) and those whose survival is closely tied to local habitats (shellfish/fish). Beyond this, our records may point to which tsunamis had the most impact on animal populations (Table 10). More of the expectations were met following Event U and Event 2 than Event W and Event Y. The impact of Event U on Čix'wicən residents was highlighted by Hutchinson et al. (2018, in this issue), who suggest that this tsunami at ~1260–1230 cal BP, caused severe declines in village occupation, if not abandonment. Our records for fish and shellfish support the notion that nearshore habitats and in turn marine creatures were also affected by this event. As noted previously, *in situ* evidence for Event 2 (650–560 cal BP), suggests that residents (and local environments and animals) had to cope with the aftermath of this tsunami as well. This second tsunami, Event 2, is especially relevant for our research project,

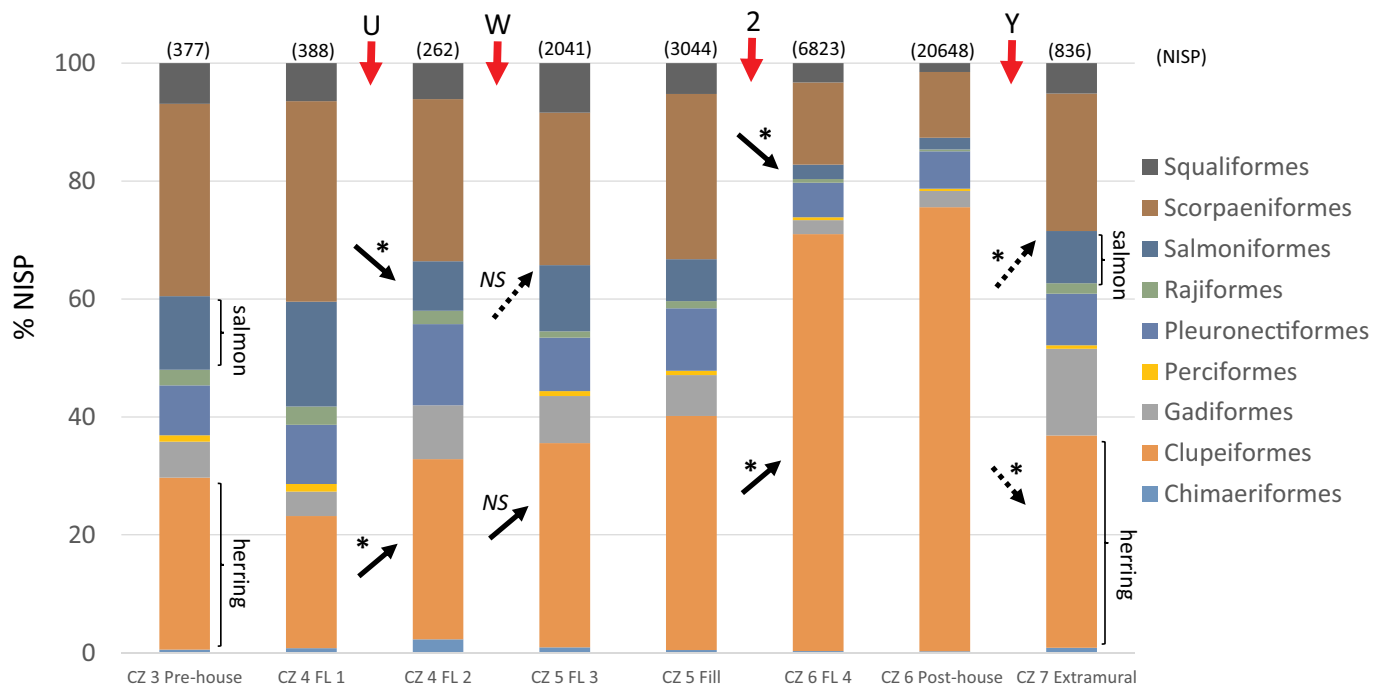


Fig. 11. Pct NISP of fish orders within floor-fill sequence of A4 house, arranged from older (left) to younger (right). Temporal range of CZs in Table 3. Earthquake events (red arrow) indicated by letter or number. Trends in herring and salmon highlighted. Solid arrows show trend followed expectation; dotted arrows show trend contrary to expectation. Significant trends ($p = 0.05$) based on analysis of adjusted residuals indicated with *, NS = not significant. See Supplementary File 3 for statistics. Samples included: C buckets, $\geq 1/8''$.

as we have samples from contemporaneous households before and after the event. Thus, we are able to examine ways different households negotiated abrupt environmental impacts.

4.6. Did the degree of communalism in animal use vary across households? If so, how resilient was this social structure in response to an earthquake?

A number of case studies (see papers in Cooper and Sheets, 2012; Grattan and Torrence, 2007; Reycraft and Bawden, 2000; Torrence and Grattan, 2002) have suggested linkages between the social structure of a society and the form of social response to major environmental stresses such as those caused by earthquakes or volcanoes. Different parts of society could be expected to react differently to stresses (Reycraft, 2000),

but intracommunity variation rarely has been explicitly studied. This is likely due to empirical challenges, as it requires known sequences of environmental change, sufficient control over site formation to isolate intracommunity social units of different ages, and faunal sampling that allows researchers to simultaneously compare uses of different classes of animals (birds, fish, shellfish, and mammals are rarely sampled comparably). As seen below, the Čixw'icən records meet these challenges.

In the Pacific Northwest, we can consider intracommunity response to major environmental impacts through study of archaeological records from households—the subject of much theoretical and empirical study in the region (Ames, 2006; Coupland et al., 2009; Grier, 2006; Prentiss et al., 2018; Samuels, 1991; Sobel et al., 2006). Households are a fundamental social, economic, and political unit across the varying

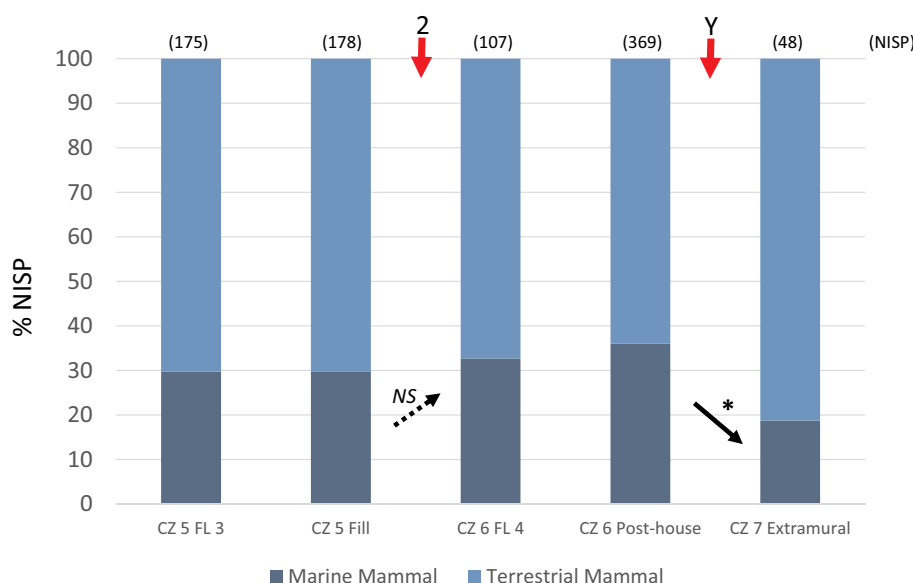


Fig. 12. Pct NISP of marine vs. terrestrial mammal remains in floor-fill sequence of A4 house, arranged from older (left) to younger (right). Temporal range of CZs in Table 3. Earthquake events (red arrow) indicated by letter or number. Solid arrows show trend follows expectation; dotted arrows show trend contrary to expectation. Significant trends ($p = 0.05$) based on analysis of adjusted residuals indicated with *, NS = not significant. See Supplementary File 3 for statistics. Samples included: C/CX/S buckets E bag, $\geq 1/8''$. Sample sizes < 30 NISP for CZ 3–4 contexts, excluded.

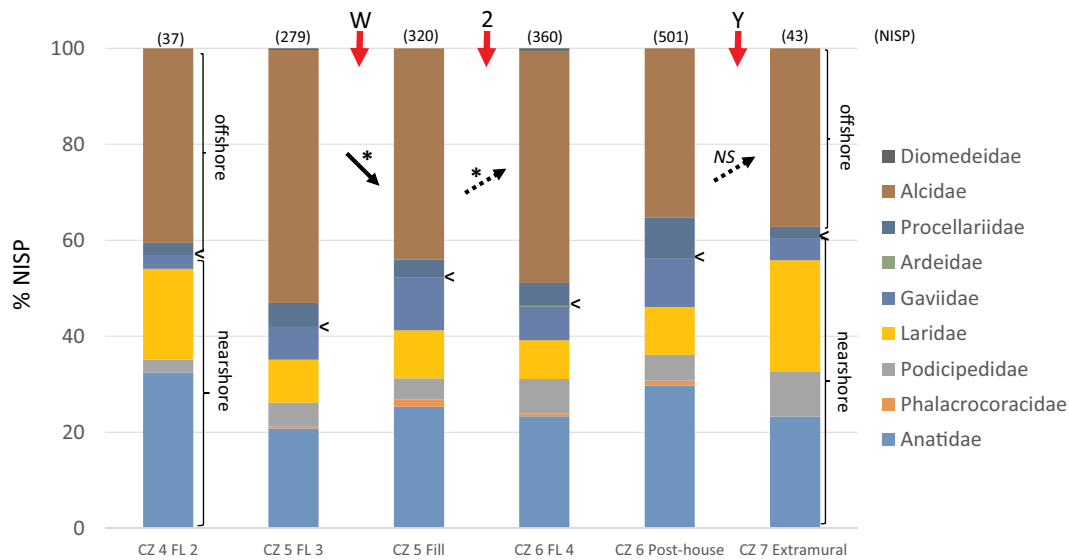


Fig. 13. Pct NISP of bird families within floor-fill sequence of A4 house, arranged from older (left) to younger (right). Temporal range of CZs in Table 3. Earthquake events (red arrow) indicated by letter or number. Bird families arranged by main habitat, separated by caret symbol. Solid arrows show trend follows expectation; dotted arrows show trend contrary to expectation. Significant trends ($p = 0.05$) based on analysis of adjusted residuals indicated with *, NS = not significant. See Supplementary File 3 for statistics. Samples included: C/CX bags, $\geq 1/8''$. Sample sizes < 30 NISP for CZ 3 pre-house, CZ 4, Floor 1 contexts, excluded.

Table 10

Summary of results related to expected tsunami impacts on animal abundance or cultural procurement. Dashes indicate sample sizes < 30 NISP; not included in test. (adjusted residuals: * = significant; + = not significant).

Faunal type	Event U	Event W	Event 2	Event Y
Invertebrate				
Burrowing bivalves ↑	Yes*	No** ^a	Yes*	Yes*
Urchin ↓	Yes ⁺	No ⁺	Yes*	Yes*
Fish				
Herring ↑	Yes*	Yes ⁺	Yes*	No*
Salmon ↓	Yes*	No ⁺	Yes*	No*
Mammal				
Terrestrial ↑	–	–	No ⁺	Yes*
Bird				
Nearshore ↑	–	Yes*	No*	No ⁺

^a Tsunami could also cause erosion as well and thus lead to a decline in burrowing bivalve habitat.

social-political systems in the Northwest Coast culture area from northern California to Alaska (Coupland, 1985; Coupland et al., 2009). Importantly, households are archaeologically accessible in the form of architectural features (walls, posts, hearths) and comparative study of contents of houses and extramural features, within a village or at a regional scale, allows for study of household dynamics.

Coast Salish, including the Central Coast Salish Klallam, are known for decentralized social organization, lack of strong social ranking, bilateral kinship, and resource control at the extended family level (Suttles, 1951, 1987). Coast Salish had highly flexible sociopolitical organization where individuals could choose the household with which they aligned. This capacity for individuals to shift affiliations helped prevent accumulation of material wealth and also managed risk (Angelbeck and Grier, 2012). This flexibility put a brake on the control house chiefs could hold over the household. Potlatches, including feasting and displays of wealth and largesse, helped re-distribute resources, but also served to limit wealth accumulation (Angelbeck and Grier, 2012). Among Coast Salish the most productive resource areas, salmon streams, dip-net locations, sites for raised duck nets, and sites for gathering specific types of clams such as butter clams or horse clams, were owned by extended families (Richardson, 1982). We have an expectation that use of some, if not all, resources would be socially mediated, with the degree of resource

ownership and sharing varying on a continuum from communalism to autonomy (Dolan, 2015).

Losey (2007), considering the north Pacific coast more generally, suggests a major tsunami could ‘level’ social status and undermine the existing social order through loss of material wealth. Depending on an individual’s gender, social position, and special skills, the resultant change in social status may have necessitated joining other houses to maintain access to subsistence resources. If family-owned resource areas were diminished following an impact, how would households negotiate this?

Turning to Čix’w’icən, we sought to study first whether households persisted after an earthquake; and if so, how households negotiated a major environmental challenge by comparing resource use before and after a known tsunami. In particular, we examined the extent two households were *autonomous* or *communal* in animal resource use—and ways this structure changed after a tsunami. On one side of the continuum, households could be operating independently—autonomously—acquiring/producing food to meet their group’s dietary and social needs. On the other end of the continuum, households could be acting communally, by sharing resource locations and cooperating to acquire and pool resources (Dolan, 2015). Would a high impact event lead households to “work together more” or become more independent? Did degree of communalism vary for different resources? In effect, we sought to understand whether degree of communalism affected a household’s ability to rebound after such an event.

We studied remains from two plankhouses, one in Area A1 and one in Area A4 that were contemporaneously occupied, in CZ 5 and CZ 6 (Campbell et al., 2018b). As noted above (Section 4.5), Event 2 overtopped the landform in the interval before CZ 6; collapsed walls in A4, and subsequent rebuilding of the house with a slightly different footprint, demonstrate that the household was substantially affected.⁶ During excavation, floor deposits were distinguished from each house for the two time periods (Campbell et al., 2018b). Thus, we can compare faunal representation between houses for each chronozone to consider where resource use falls along the autonomy-communalism continuum, and then track how organization of resource use *changed* between CZ 5 and CZ 6.

⁶ We lack similar detail for the A1 house, but assume the tsunami would have damaged that house as well.

Table 11
Example showing calculation of the Brainerd-Robinson coefficient of similarity.

Assemblage	Taxon 1	Taxon 2	Taxon 3	Taxon 4	Taxon 5	Total
House A4	10%	50%	5%	20%	15%	100%
House A1	20%	40%	10%	5%	25%	100%
Absolute difference	10	10	5	15	10	50

B-R coefficient = 200–50, or 150.

To operationalize the autonomy-communalism continuum, we built on work by Dolan (2015) who suggested that autonomous households would rely on different resource patches. By extension, we suggest that a household's record of animal use is a reflection of the resource patch used—and that we could assess degree of communalism between contemporaneous households using degree of similarity in proportional taxonomic representation between houses. If households are operating independently, the mix of resources used should be different and reflect that independence. If households are working collectively, taxonomic representation should show greater similarity. Collective or communal resource use could mean sharing harvested resources, sharing equipment, utilizing resource locations owned by the village at large, or extending invitations to family-owned resource locations.

To assess similarity in taxonomic representation between households and for each CZ, we calculated the Brainerd-Robinson (B-R) coefficient of similarity, which summarizes the degree of similarity in proportional representation of categories between a pair of assemblages (Table 11). Widely used in the 1950s by cultural historians to assess similarity in representation in artifact types in different sites or components within sites (Robinson, 1951), the approach involves identifying categories to be used in the comparison, counting the number of occurrences, and calculating the relative proportion of each class in the assemblage. The absolute difference between the percentages of each class in the two assemblages is determined, the differences are summed and then subtracted from 200 (Table 11). The higher the B-R coefficient, the more similar the two assemblages.

Importantly, the B-R is an index, not a statistic. We cannot determine the statistical significance of values. We calculated chi-squares to establish whether assemblages were significantly different from each other and they were for virtually all the tests we ran (see Supplementary File 4). To move beyond this uninformative result, we decided to employ the B-R coefficient to identify similarity in animal use between households and the extent to which they were consistent or not through time (Table 12). In the next sections, we discuss the B-R values for each animal type for the period *before* (CZ 5) and *after* (CZ 6) Event 2.

Besides measuring the degree of communalism, we were also interested in whether the social order shifted in the aftermath of a high impact event, building on Losey (2007). Did one household amass more resources—access high status resource surpluses? We studied this using accumulation rates, which provide different information than relative taxonomic representation and can be calculated for any taxonomic

Table 12
Contrasts in faunal similarity between Households A1 and A4 in two chronozones (CZs) as measured by Brainerd-Robinson (B-R) index and accumulation rate.

Faunal type	Faunal grouping within type	Samples	CZ 5 A1 vs A4	CZ 6 A1 vs A4	B-R Trend CZ 5 - 6
Fish (NISP)	Grouped by order	≥ 1/8" C	155	143	↓
	Large fish orders	≥ 1/4" C/CX	157	118	
	Rockfish & allies genera	≥ 1/8" C	188	127	
	Accumulation rate	≥ 1/8" C	Low & similar	A4 high & dissimilar	
Invert (MAU)	Grouped by genera	≥ 1/8" C	143	169	↑
	Burrowing bivalves genera	≥ 1/8" C	110	176	
	Accumulation rate	≥ 1/8" C	A1 high & dissimilar	High and similar	
Bird (NISP)	Bird family	≥ 1/8" C/CX	134	142	↑
	Accumulation rate	≥ 1/8" C/CX	Low & similar	A4 high & dissimilar	

grouping independently. Accumulation rates have been used as population proxies, but other variables, such as varying depositional rates of natural sediment can affect them. In this case, we assume the measure is partly tied to the number of people contributing to the accumulation i.e., household occupancy, as they are standardized by excavation volume and also by estimated duration of the period of accumulation. For our study, we calculated accumulation rate for the dominant taxa of fish and shellfish; and for birds overall. Mammal bone frequency was insufficient to warrant detailed examination.

4.6.1. Fish

While there are differences between the two households in the relative abundance of certain fish orders in CZ 5 (Fig. 14), the differences become more pronounced in CZ 6. In A4, herring becomes extremely prominent (71%) and other fish taxa decline. In A1, herring retains its predominance (43%), but several fish taxa become relatively more abundant: Gadidae (cod), Scorpaeniformes (sculpins, rockfish, sablefish, greenlings) and Pleuronectiformes (flatfish). The similarity between houses declines slightly as measured by the decrease in B-R coefficients from 155 in CZ 5, to 143 in CZ 6. The differences between CZ 5 and CZ 6 are even more pronounced when we examine samples that emphasize the large-bodied fish (≥ 1/4" mesh) and specific genera of Scorpaeniformes (see Supplementary File 5). In both cases, the B-R values decline substantially in CZ 6 (Table 12), indicating greater differences between households. The inhabitants of house A1 made use of greater proportions of cod and *Leptocottus* (staghorn sculpin) in contrast with the A4 household where herring and *Anoplopoma* (sablefish) are more common. The overarching trend is that A1 and A4 households are more similar to each other in CZ 5 than in CZ 6, suggesting a more communal fishery early and a more autonomous one later in time.

4.6.2. Invertebrate

Trends in communalism in use of invertebrates contrast with fisheries, with the two households showing greater differences in resource use in CZ 5 than CZ 6. In CZ 5, the A1 household shows a relatively even representation of the three main habitats, soft sediment (42%), rocky intertidal (35%), and kelp (24%) (Supplementary File 5), and *Macoma* (40%) and *Saxidomus* (36%) are the most common burrowing bivalves (Fig. 15). In the A4 household, rocky intertidal taxa (59%) greatly exceed the frequency of soft sediment taxa (20%). *Leukoma* (58%) dominates the burrowing bivalves (Fig. 15). Similarity in harvest strategies increase from CZ 5 to CZ 6 when all invertebrate genera are considered (B-R coefficient 143 to 169), and are even more pronounced (110 to 176) for burrowing bivalves alone (Table 12). Assuming the B-R is a good proxy measure for degree of autonomy, the two households harvested invertebrates more independently in CZ 5 and more communally in CZ 6.

4.6.3. Bird

The two households show striking and consistent differences through time in the abundance of offshore versus inshore birds. The A4 household favored 'offshore' birds especially Alcididae (murrens,

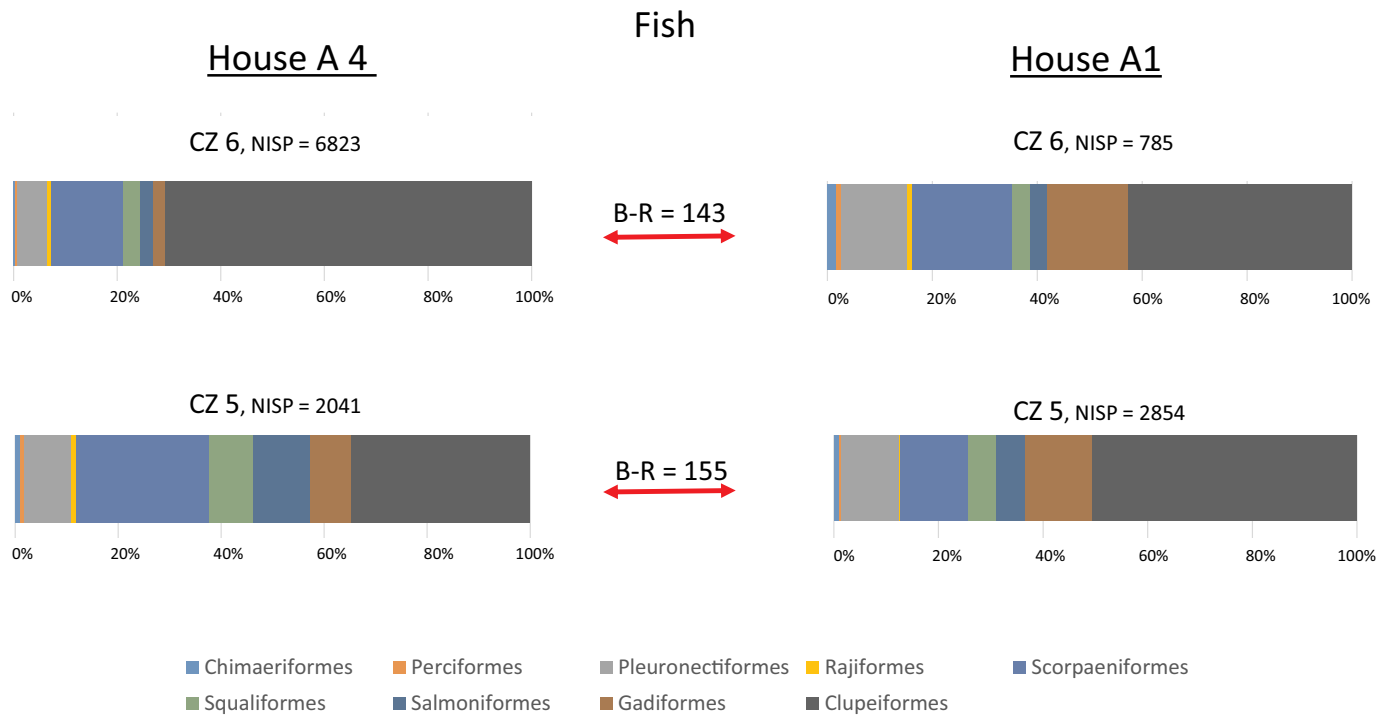


Fig. 14. Comparison of fish frequency (% NISP fish order) between Houses and Chronozones (CZ) from floor deposits. Samples included: C buckets, $\geq 1/8''$. B-R is the Brainerd-Robinson coefficient of similarity, where a value of 200 is perfect similarity and 0 is no similarity. CZ 5: 1000–550 cal BP; CZ 6: 550–300 cal BP. See Supplemental File 4 for sample volume analyzed.

guillemots, auklets) while the A1 household demonstrates a focus on 'inshore' birds and in particular Anatidae (ducks, geese, swans) (Fig. 16). While both families can be found inshore, alcids are common in habitats some distance from shore, which justifies our dividing the birds into these broad habitat types. Other taxa vary somewhat between houses and through time (Laridae [gulls] are prominent in CZ 5, A1; Gaviidae [loons] are more prominent in A1 in both CZs), but it is the

difference in alcid/anatid frequency that is most pronounced (Fig. 16). Considering the autonomy scale, the households become slightly more similar through time, with the B-R trending from 134 to 142.

4.6.4. Mammal

Because of small sample sizes, to identify contrasts in the ways households used mammals, we aggregated the identified specimens into

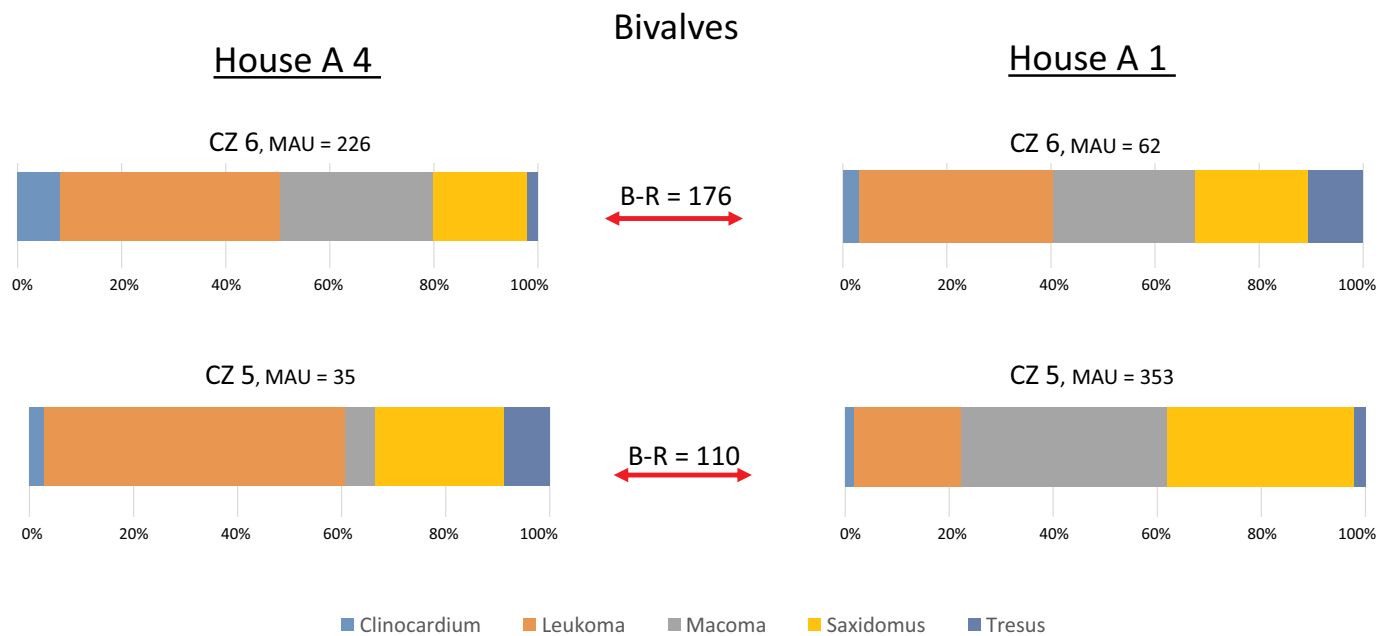


Fig. 15. Comparison of bivalve frequency (% MAU genus) between Houses and Chronozones (CZ) from floor deposits. Samples included: C buckets, $\geq 1/8''$. B-R is the Brainerd-Robinson coefficient of similarity, where a value of 200 is perfect similarity and 0 is no similarity. CZ 5: 1000–550 cal BP; CZ 6: 550–300 cal BP. See Supplemental File 4 for sample volume analyzed.

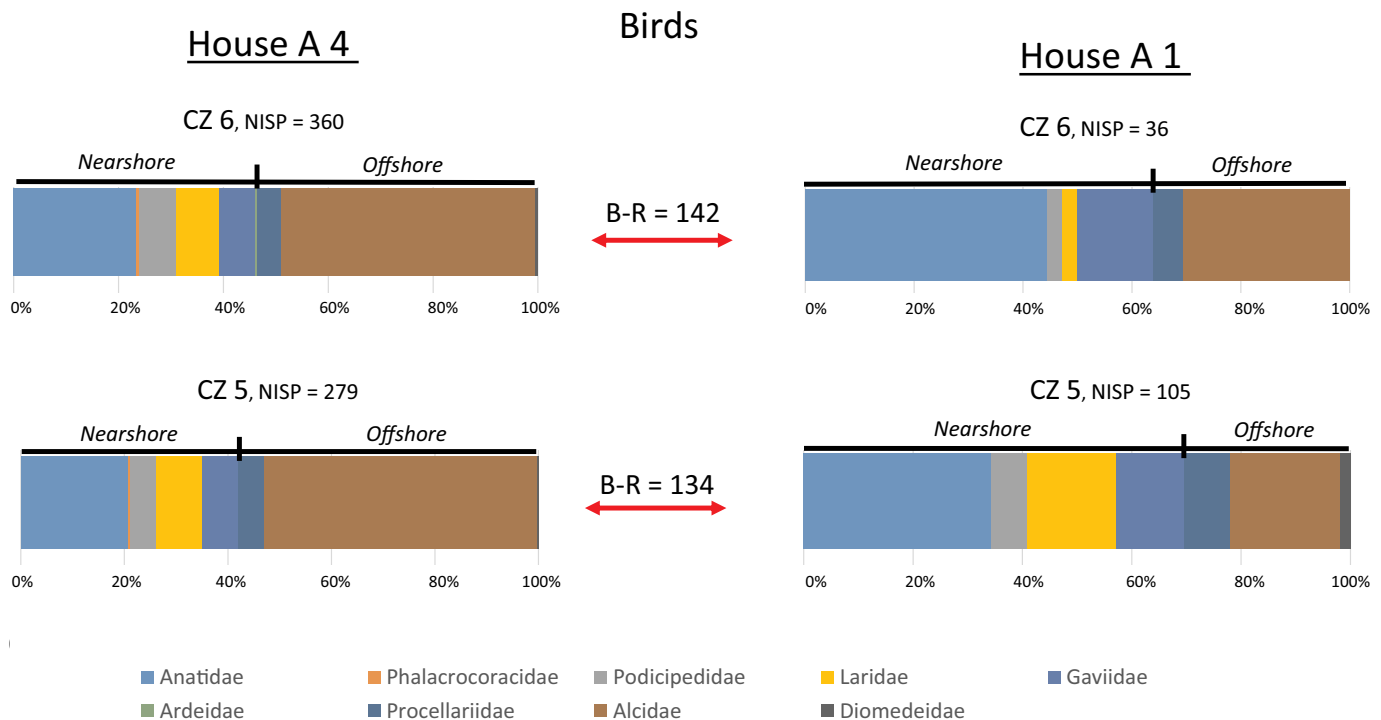


Fig. 16. Comparison of bird frequency (% NISP family) by Houses and Chronozones (CZ) from floor deposits. Samples included: C/CX buckets, $\geq 1/8''$. B-R is the Brainerd-Robinson coefficient of similarity, where a value of 200 is perfect similarity and 0 is no similarity. CZ 5: 1000–550 cal BP; CZ 6: 550–300 cal BP. See Supplemental File 4 for sample volume analyzed.

a 'marine' vs. 'terrestrial' category and considered differences at this broad scale of use (Supplementary File 5). No B-R coefficient was calculated. The two households show slight shifts through time before and after Event 2 in proportion of marine vs. terrestrial mammals present. In A4 proportion of marine mammals increased from 25% to 33% from CZ 5 to CZ 6; in A1, marine mammal percent declines from 33% to 21%. Neither of these shifts are significant based on analysis of adjusted residuals (see Supplementary File 4).

4.6.5. Accumulation rates

We see striking differences in accumulation rates both between households and through time for certain animal types. Bird accumulation is modest but relatively similar between A1 and A4 households in CZ 5, while in CZ 6 the accumulation rate for the A4 household accelerates and is four times greater than in A1 (Fig. 17d). Accumulation rates for three main fish orders (herring, rockfish and allies, salmonids) show similar trends (Fig. 17a–c). Fish accumulation rates are consistent between households in CZ 5, which suggests similar household size and intensity of fishing. In CZ 6, pronounced differences develop. In A4, accumulation rates for each fish group increased, with herring showing the most dramatic rise (Fig. 17c) resulting in accumulation rates in A4 that are more than twice the rate in A1 for all three fish groups.

Shellfishing intensity trends differ from those for fish and bird (Fig. 17e–g). Accumulation rates for two dominant genera (urchin and mussel), and the soft sediment bivalves, are quite different between the households in CZ 5 (3 to 15 times greater in A1 than in A4). The contrast diminishes in CZ 6; greater similarity in accumulation rates between households indicates more comparable intensities of shellfishing, although accumulation rates for A4 still outpace those in A1 (for all three comparisons).

4.6.6. Persistence and the role of social mediation in resilience

The main differences in animal representation and accumulation rates between house A1 and A4 during CZ 5 and CZ 6 are summarized in Fig. 18. During CZ 5, occupants of House A1 and A4 used similar fish

resources, indicating a communal fishery. In contrast, members of the A1 household devoted more time to shellfishing than A4, and gathered more burrowing bivalves, especially *Macoma* and *Saxidomus*. House A4 occupants focused on rocky intertidal species, and favored *Leukoma* when clamming. Bird use also differs between the houses in CZ 5, with ducks favored in A1 and murre in A4, suggesting an autonomous pattern.

During CZ 6, bird use is relatively unchanged (still autonomous), but fish and invertebrates show opposing trends; fishing practices become more autonomous between households and shellfishing becomes more communal. The A4 household increased their focus on herring and sablefish, while the A1 household accessed less herring and made greater use of cod and sculpin. Accumulation rates, which are a proxy for harvest rates, increase in CZ 6 House A4 for fish, birds, and slightly less so for invertebrates, suggesting that this household is supporting more people than before Event 2.

Given the higher accumulation rates for bird and fish and slightly higher rates for invertebrates in CZ 6, the A4 household membership may have rebounded more quickly, and with more members came more access to resource use rights, especially related to fishing. Based on Coast Salish practices, many types of resource locations were owned by individual families (e.g., salmon streams, herring use areas, bird netting areas, clam gathering spots, and accompanying gear). Perhaps the increased use of herring and salmon in A4 following the event (Fig. 17), points to this household's greater success in recruiting members of families that had access to these use areas after the tsunami, while A1 occupants may have lost access. In addition, if A4 was larger, it would have been able to field task groups to procure resources from distant/discrete patches, whereas A1, with fewer members, would have been more limited in this way. Patterns in use of sablefish between households and through time also indicate that the social order shifted after the tsunami. Sablefish, known for high prestige/ritual use during ethnographic times (Swan, 1887; Nims and Butler, in this issue), is similarly represented in both households in CZ 5, but the fish becomes prominent in the A4 household in CZ 6, suggesting this household's

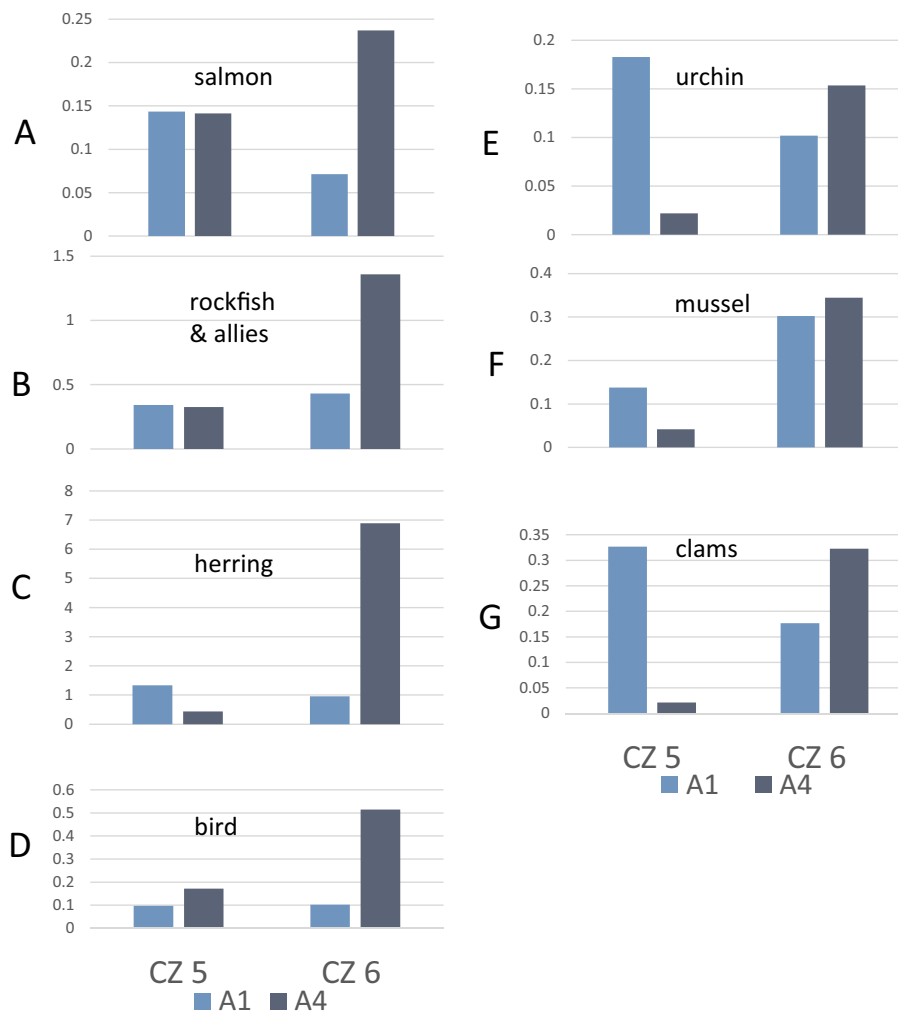


Fig. 17. Comparison of accumulation rate by taxon, floors of household A1 & A4, and CZ 5 & 6. Rate for Fish & Bird: $(NISP/Volume/Duration)*100$; Invertebrates: $(MAU/Volume/Duration*100)$. Samples included: Fish & Invertebrates, C buckets, $\geq 1/8''$. Birds, C/CX buckets, $\geq 1/8''$. A) salmon; B) rockfish & allies; C) herring; D) bird; E) urchin; F) mussel; G) soft sediment clams. CZ 5: 1000–550 cal BP; CZ 6: 550–300 cal BP. See Supplemental File 4 for sample volume analyzed.

rising stature.

At the same time, after Event 2, the A1 household in CZ 6 began taking more small inshore sculpins (staghorn, buffalo), probably through foraging the local shoreline, including the lagoon next to the village. Besides small fish, *Macoma*, a burrowing bivalve common in fine sediments of a lagoon, and ducks, which could be netted, are prominent in the A1 fauna after the tsunami. While in many ways, the A1 household appears to have been reduced after the event (fewer members, less access to favored resources, such as herring, salmon, sablefish), large-bodied Pacific cod, which was prominent before the tsunami, became even more prominent afterwards, which suggests the household retained the necessary knowledge, gear, or access to fishing grounds for this resource.

Invertebrate use in the two households becomes more communal after the event. Perhaps because of enhanced habitat for burrowing clams, there were fewer restrictions for access. This explanation is not completely satisfying given that both households are pursuing mussels and urchins as well. Shellfishing is a strongly gendered practice, especially linked to females based on ethnographic and on-going practices in the Pacific Northwest (Daniels, 2009; Moss, 1993) and globally (Jerardino, 2016b). Does the greater similarity in invertebrates used between the two households after the tsunami suggest that it is specifically the women who are working more collectively than they had been before?

Although sample sizes for mammals are small (and trends not statistically significant), increases in the proportion of marine mammal remains in A4 from CZ 5 to CZ 6 are consistent with greater access to marine resources than was possible for A1. This finding matches the

patterns observed for fish (especially sablefish). Mammal procurement differed between the houses beyond just the kinds of animals obtained. Bovy et al. (in this issue) found that mammal bones in A4 were more fragmented and more often burned in both CZ 5 and CZ 6 than those in A1, indicating people in A4 were consistently using bone as an additive to wood fuel and/or processing bones for grease, which could have been used for a variety of practical or ritual purposes.

Of all the resources, use of birds changed the least after the tsunami. The two households clearly had access to different patches and likely different expertise with the focus on alcids in the A4 household and anatids in A1. Type of bird use by household is particularly consistent through time, suggesting the social rules/practices related to birds were maintained after the tsunami. This is especially evident for A4 where the B-R coefficient comparing CZ 5 and CZ 6 is 188. For A1, the coefficient of similarity is not as high (B-R = 155) but the dominance of ducks in this household persists (Fig. 16). The higher accumulation rate for birds in the A4 household in CZ 6 suggests that residents were more intensively hunting birds than were people in A1. This picture for higher levels of bird hunting in the A4 household supports the scenario outlined above, that after the tsunami, the A4 household grew in household size and standing while the A1 household did not fare as well, but did maintain certain specialization on ducks.

We draw several conclusions from this analysis of ways two households negotiated a high impact event. First—both households ‘came back’ after the tsunami, so at the simplest level, both were resilient in the face of a catastrophic event. Notably, the households responded differently, and in complex ways, illustrating their agency. While the two households became more communal in shellfishing

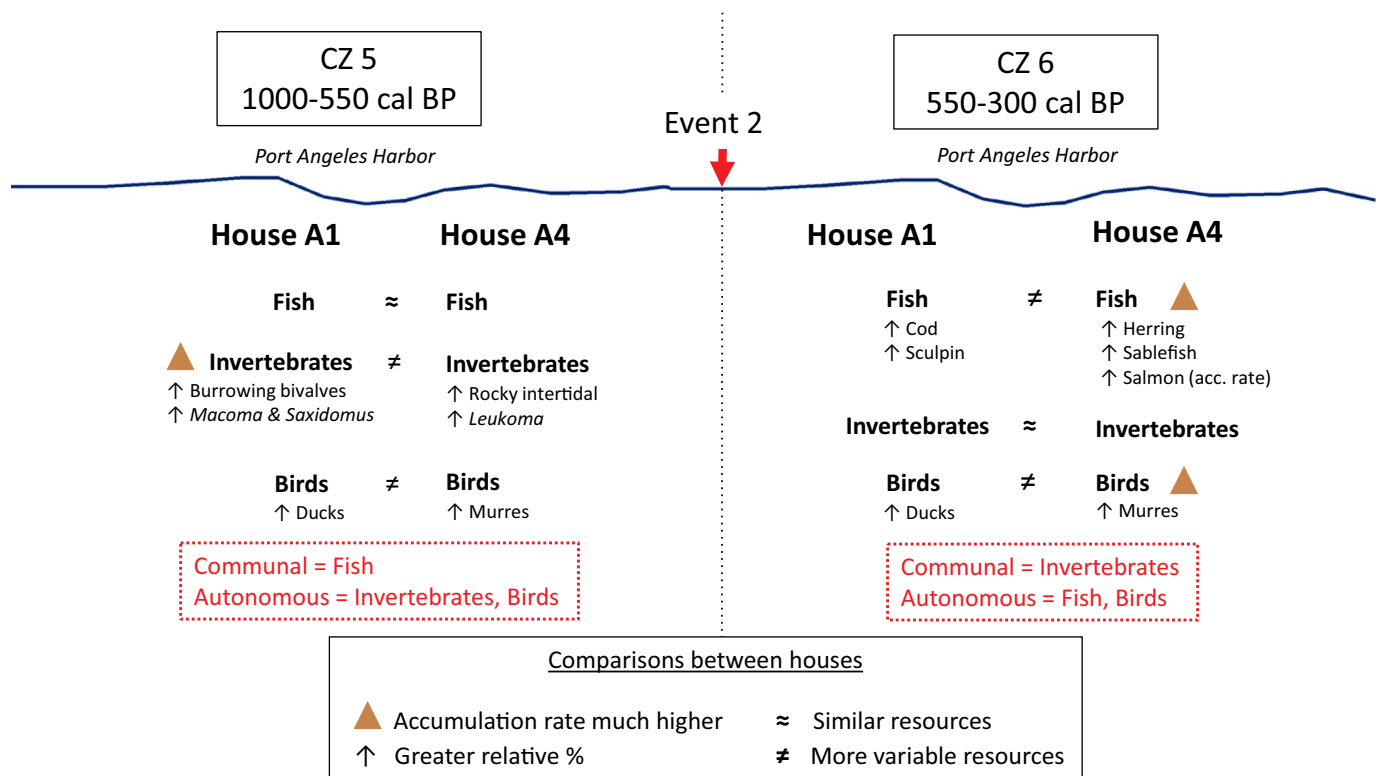


Fig. 18. Summary of main differences in animal representation in House A1 and House A4 floor deposits in CZ 5 (1000–550 cal BP) and CZ 6 (550–300 cal BP). See Figs. 14–17, Table 12 and Supplemental File 5 for supporting data.

activities, they became more independent in fisheries; the autonomy in bird use seen in CZ 5 was maintained in CZ 6. We hypothesize that the varied social response itself contributed to long-term resilience and persistence of each household and in turn the overall community.

Regarding Losey's (2007) suggestion that a high impact event could lead to a shift in the social order, our records are not clear. While there are indications that the A4 household amassed more members and gained access to more and different resources than the A1 household post-tsunami, we do not have control over the social position of the households *before* the tsunami, thus we do not know if the social position actually *changed*. On the other hand, the A1 household maintained use of one resource, ducks; and distinct patterns in resource use for birds and fish indicate the household was not dependent on the A4 household.

5. Conclusions

Our paper presents key findings from the Čix'wícən faunal analysis project. Drawing on the H.E. framework, we explored the long-term dynamic relationships between people, animals, and the environment at the traditional village of the LEKT, located in coastal Washington, U.S.A. Because of its wide-ranging scope, H.E. research is an ambitious undertaking (Fitzhugh et al., in this issue). Our complex, multi-pronged effort to integrate faunal records, high resolution geochronology and independent environmental data illustrate these ambitions. We hope the framework can serve as a model for future research on coastal foragers in the Pacific Northwest and beyond.

While there is evidence for occupation as early as 2700 cal BP, our project focused on the human story between 2150 cal BP and the contact era. Between 1300 and 1000 cal BP (CZ 4), people began to construct and occupy plankhouses. Over this lengthy period, people adjusted their lifeways to a changing coastline, varying ocean conditions, and several large-magnitude earthquakes. In line with H.E. research, a key task was to see how animals (and in turn people) were affected by

these external drivers; and whether settling into plankhouses altered ways people engaged with animal resources. Also commensurate with H.E., we looked beyond environmental determinism to explain changes, to examine how people responded to a high impact event such as a tsunami, through analysis of faunal remains from two households. Studying contrasts in household response to external drivers leads directly to insights on the role of human agency in negotiating external challenges.

Čix'wícən's immense invertebrate sample, especially useful for nearshore habitat reconstruction, highlights striking trends, from the early period favoring soft-sediment bivalves—then shifting to rocky shoreline and kelp habitat, then a return to soft sediment bivalves. Gradual coastal process, namely evolution of the harbor and sheltering spit, likely explains the loss of soft sediment clam habitat by CZ 3 (1550–1300 cal BP), while abrupt forces, a tsunami, may have contributed to deposition favoring soft sediment bivalves in CZ 5 (1000–550 cal BP) (Campbell et al., 2018b). Despite coastline changes, the overall diversity of bird, fish, and mammal use as measured by evenness and richness is similar through time.

This consistency is particularly striking given the changes in settlement organization (shift to plankhouse occupation) and likely reflects a stable adaptation to the local food web (Moss, 2012). Such findings are in-line with Hopt and Grier (2018) who highlight continuity in fisheries over a period between a Marpole (1500–1300 BP) and Late Period (1000–600 BP) occupation from coastal British Columbia. The great breadth in resource use across all the animal types and through time seen at Čix'wícən further challenge the overly simple notions that intensification on one or a few resources such as salmon account for developing cultural complexity on the Northwest Coast (Butler and Campbell, 2004).

Our analysis did not detect impact of changing ocean conditions on invertebrate or fish representation, which is in contrast to findings of Hutchinson et al. (2018, in this issue) who make a compelling case that changing ocean conditions affected human occupation intensity at

Čix^{wic}ən. We see several limitations with our test. Besides selective human procurement, archaeological sampling and temporal resolution limits our ability to establish clear “cause and effect” relationships. Other studies of archaeological faunal records on the outer coast of Vancouver Island (Monks, 2017a) and central California coast (Jones et al., 2017) support the idea that coastal animals and, in turn, human populations were affected by changing ocean conditions, especially associated with the MWP and LIA. Future geochemical analysis of Čix^{wic}ən fauna (otoliths, bivalves) could provide a finer-grained link to ocean-animal interaction than faunal abundances alone (e.g., Andrus et al., 2002).

On the other hand, earthquakes and in particular tsunami impacts were pronounced. The faunal project suggests that invertebrates and fishes were the most affected. Geoarchaeological analysis of Čix^{wic}ən site records points to evidence that possibly five tsunamis overtopped the site over the past 1600 years (Campbell et al., 2018b). Analysis of radiocarbon records indicates severe decline in occupational intensity caused by one tsunami (Hutchinson et al., 2018, in this issue). Perhaps the simplest takeaway message here is one of resilience in the socio-ecological system. After each event, people returned, rebuilt, and adapted to changed environmental and social circumstances. The latter we directly explored through comparing/contrasting faunal records from two contemporaneous households, for which we had records before and after a tsunami. As discussed, most striking is the complexity in response between households and for different animals and resource patches.

While our project focused on faunal remains to study intracommunity response to tsunamis, given our broader interest in human-animal relationships, other material culture (e.g., tools) and architecture would provide an independent line of study and more directly address how gear was shared and owned. Breaking down the animal resources used to finer taxonomic levels and relating them to habitat patches would provide further insights into the strategies of the two households adopted. These are but two examples of numerous research projects that could be explored in the future with Čix^{wic}ən materials.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jasrep.2018.09.031>.

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