The sablefish (*Anoplopoma fimbria*) of Číxʷicən: Socioenvironmental lessons from an unusually abundant species

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ABSTRACT

We analyzed sablefish (*Anoplopoma fimbria*) remains from Číxʷicən (pronounced *ch-WHEET-son*), a 2700 year-old ancestral village of the Lower Elwha Klallam Tribe in northwest Washington state, U.S.A., to improve understanding of how this species was used by Native American/First Nations peoples in the past. Though sablefish are abundant at Číxʷicən, and limited ethnographic accounts indicate they were highly prized in northwestern North America, their remains are rare in regional archaeology. We present a body-size regression model for estimating the fork length (FL) of archaeologically represented sablefish and determining which habitats they were captured from (i.e. shallow, nearshore waters as juveniles or deepwater, offshore sites as adults). FL estimates for sablefish remains from Číxʷicən indicate the site occupants exclusively targeted inshore juveniles. Comparisons of sablefish abundances over time show juvenile sablefish were reliably and sustainably harvested over the duration of the site's occupation despite major environmental perturbation from regional climate change and tectonic disturbances. However, patterns of sablefish use differ in two Číxʷicən households, suggesting access to and consumption of sablefish was socially mediated.

1. Introduction

Analysis of archaeological fishbone from Číxʷicən (pronounced *ch-WHEET-son*), a large Native American village on the coast of Washington State, U.S.A. (Fig. 1), shows that sablefish (*Anoplopoma fimbria*, also commonly marketed as black cod), is the third most abundant fish taxon represented at the site (3209 NISP out of a total 44,763 NISP). Considering that sablefish are scarce or absent from all other archaeological sites in northwestern North America (Nims and Butler, 2018), we were initially perplexed that the species is so abundant at Číxʷicən. Now that we know more about the species, we seek to understand why it is not more common elsewhere. Today, sablefish occupies nearly every North Pacific habitat over the course of its life span, from the extreme depths of continental slopes to inshore waters, where young-of-the-year are easily caught by hand-jigging (Echave et al., 2013). The species is also extremely nutritious (U.S. Department of Agriculture, 2014) and we expect sablefish would have been sought after wherever they were available.

Ethnographic and historic evidence for sablefish capture in the region is lacking, with only a few exceptions. Available records show that adult sablefish were especially prized on Haida Gwaii (Fig. 1) where

Haida fished for them with specialized bentwood hooks (Blackman, 1990; Hobler, 1978; Swan, 1887). Further evidence for sablefish use among Haida was recorded in a story told by John Sky (in Swanton, 1905) that includes the expression, "Does the black cod stick you here?" According to Swanton (1905, p. 225), the question refers to the exclusive availability of 'black cod' on the west coast of Haida Gwaii, which was so highly regarded that visitors, including the story's main character, would delay departure from the region. Arima and Dewhirst (1990, p. 397) mention that groups of Nuu-chah-nulth and Ditidaht on the west coast of Vancouver Island (Fig. 1) captured 'sablefish' and 'lingcod' with lures and harpoons or dipnets from canoes. Finally, James Swan (1887) noted in the late nineteenth century that sablefish were highly valued by peoples living on the Strait of Juan de Fuca (Fig. 1), and that it was a common bycatch in European and Native American/First Nations commercial fisheries that was occasionally taken in large volumes. Swan (1887) also states that Native American/First Nations peoples along the Strait of Juan de Fuca only desired mature sablefish, which are typically captured at depths of 100 m to 1400 m and grow to over a meter in length (Head et al., 2014; Love, 2011; Pearson and Shaw, 2004). Thus, adults were pursued with longline fishing methods as luxury items for chiefs, but only infrequently
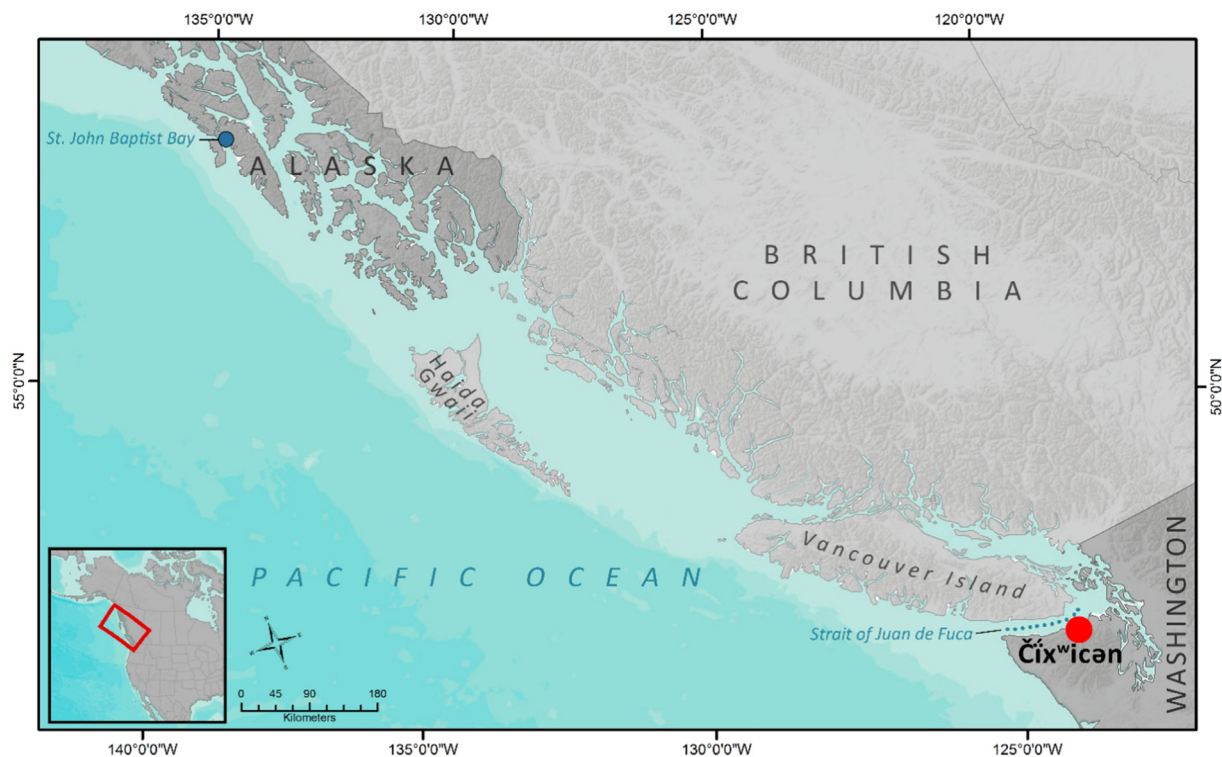
Fig. 1. Location of Číxʷicən in northwest Washington State, USA with locations mentioned in the text.

due to the difficulties associated with fishing in such deep waters (Swan, 1887).

While we have no information about traditional preferences for juvenile sablefish, young-of-the-year may have provided an attractive, low-cost alternative. Juveniles measuring 20 cm to 40 cm are commonly found in shallow bays and inlets throughout the Pacific Coast at depths of 20 m to 60 m, and they periodically become super-abundant. The occurrence of these "strong year classes" appears to correlate with primary productivity (Shotwell et al., 2014; Sogard, 2011) and have resulted in enormous commercial and recreational catches of juveniles (Cox, 1948; McFarlane and Beamish, 1983; Rutecki and Varosi, 1997a). Another important factor to consider is the high degree of spatial variability in juvenile sablefish abundances. A seven year survey of juveniles in southeast Alaska found sablefish in 11 bays and inlets, but they were only consistently present in large numbers at one location, St. John Baptist Bay (Rutecki and Varosi, 1997a). Why sablefish prefer some bays over others remains unknown, but Coutré (2014) suggests juveniles might be attracted to places with freshwater input and salmon offal, or that sablefish might be entrained in specific places as larvae.

As sablefish occupy different habitats at particular stages of their life history, we aimed to improve our understanding of the ecological contexts of sablefish capture in the past by studying the population structures of archaeological sablefish. Here, we present a method for estimating the body-size of sablefish from the size of their vertebrae and apply it to the Číxʷicən collection to explore the ecological contexts of sablefish capture. We also examine the patterns in sablefish abundances over time at Číxʷicən and in two separate households from the site to explore the socioenvironmental factors that affect sablefish representation. Finally, we apply insights from Číxʷicən to the question of sablefish's widespread scarcity in northwest North American archaeology.

2. Sablefish life history

Sablefish make two ontogenetic migrations during their early life history. First, larvae hatch from eggs on continental slopes in February or March and then migrate to the shoreline along the surface of the ocean during their first summer, developing into juvenile fish along the way (Kendall and Matarese, 1987; Mason et al., 1983; McFarlane and Beamish, 1983; Wing, 1997). Annual migrations of juveniles arrive in nearshore and inshore waters by September or October, where they reside for one or two years. Second, sablefish leave inshore waters after their second summer for the continental slopes and move progressively deeper as they mature and grow larger (Courtney and Rutecki, 2011; Maloney and Sigler, 2008; Rutecki and Varosi, 1997a, 1997b). These two migrations effectively separate sablefish life history into three distinct habitat regimes: offshore epipelagic (i.e. inhabiting the oceanic zone illuminated by sunlight), inshore demersal (i.e. bottom-dwelling), and offshore demersal.

Because sablefish body-size and growth rates are closely related to age, with rapid growth in the first few years of life followed by slow or zero growth after reaching maturity (Echave et al., 2012; Hanselman et al., 2015; Head et al., 2014), sablefish life-stage and habitat regime can be identified by body-size alone (Maloney and Sigler, 2008; Rutecki and Varosi, 1997b). Based on studies from southeast Alaska to California, juveniles arriving in inshore waters typically measure between 20 cm and 30 cm length (Bell and Gharrett, 1945; Edson, 1954) with average lengths of 21 cm to 23 cm in southeast Alaska (Rutecki and Varosi, 1997a). By the end of their first summer, when sablefish begin migrating to offshore waters, sablefish in the same region grow to average lengths of 35 cm to 39 cm (Rutecki and Varosi, 1997b, 1997a). From these observations, we classify any sablefish measuring between 20 cm and 40 cm as inshore demersal juveniles, with smaller fish falling into the offshore epipelagic category (Table 1). Though some juveniles measuring up to 60 cm may reside in inshore waters for an additional year or two (Rutecki and Varosi, 1997a), we classify any larger sablefish as offshore demersal.

Table 1
Sablefish life stages by habitat regime and body-size.

Life stage	Habitat regime	Fork length (cm)	Citation
Egg	Offshore pelagic	n/a	
Larvae	Offshore pelagic	< 3.5	Kendall and Matarese (1987)
	Offshore epipelagic	3.5–20	Rutecki and Varosi (1997a, 1997b)
Juvenile	Inshore demersal	20–40	
	Offshore demersal	40–54	
Adult	Offshore demersal	> 54[a]	Head et al. (2014)

[a] Length at which 50% of sablefish reach maturity.

3. Methods and materials

3.1. Sablefish body-size regression

To estimate sablefish body-size, we calculated linear regression models relating fork length (FL) to the height of vertebral centra. We used vertebrae for our regressions because these are the only skeletal elements of sablefish represented in substantial numbers at Čḯxʷicən, but this approach comes with two potential issues. First, if vertebrae from some fish survive in higher proportions than others they will be disproportionately represented in size-frequency distributions. We could control for this problem by estimating body-size with the atlas alone, but only 86 atlas specimens were identified among the 3209 sablefish specimens in the Čḯxʷicən fishbone collection (2.7% $NISP_{sablefish}$). This sample is large enough to provide an overall pattern of sablefish size frequencies, but it is too small to examine intra-site variation. Instead, we calculated separate regression models for the atlas and other vertebra types and used size-frequencies for the former to test whether there are any biases in the latter.

Second, teleost vertebral columns exhibit extensive morphological variability within individual skeletons, and the dimensions of the vertebral centrum are not consistent across all vertebrae in any individual. In other words, the size of any given vertebra could be a function of both its allometric relationship to body-size *and* its position in the vertebral column. Our observations of sablefish vertebrae suggest that centrum size is consistent for abdominal vertebrae, but not for caudal vertebrae – vertebrae that possess a haemal arch (Fig. 2) – which shows dramatic decreases in size towards the caudal end of the vertebral column. Therefore, we exclude caudal vertebrae from our analysis and focus on the atlas and abdominal vertebrae alone.

Our reference sample of modern sablefish consisted of 11 individual fish. While minimum sample sizes of 30 to 40 individuals are preferred when performing regression, acceptable models of this type have been produced in the past with as few as 12 reference specimens (Orchard, 2001, pp. 69, 71; Reitz et al., 1987, Table 3). One sablefish was collected from St. John Baptist Bay by Dana Hanselman (Alaska Fisheries Science Center, National Oceanic and Atmospheric Administration), and an additional 10 unprovenienced individuals were provided by Dan Kamikawa (Northwest Fisheries Science Center, NOAA). FL in the reference sample ranged from 32 cm to 60 cm ($\bar{x} = 44$ cm) (Table 2). Prior to collecting our vertebral measurements, Butler prepared two sablefish skeletons (PSU 13-2-1 and PSU 13-2-2) by warm-water maceration, and Nims extracted abdominal vertebrae from the remaining sablefish after baking them under several layers of aluminum foil at 175 °C for 30 min.

Nims used Mitutoyo CD-6″CX digital calipers to record the maximum height of each vertebral centrum (Fig. 2; Table 2; Supplementary Table 1). Measurements for the atlas were collected three times and then averaged. Measurements for abdominal vertebrae were collected once, and then averaged across all abdominal vertebrae from each individual. All outlier heights were re-measured to check for measurement error. Comparing the heights of abdominal vertebrae across the vertebral column shows that variability is very low across all individuals (Fig. 3; Table 2). Based on these observations, we are confident that average abdominal centrum height provides an accurate measure for regression analysis.

Using R version 3.4.2, we created linear regression models comparing FL to the atlas centrum height and average abdominal centrum height (Table 3; Fig. 4). For comparison, Nims also calculated models comparing FL to measures of centrum width and length. All six models show statistically significant ($p < 0.05$) and practically significant (high R^2 values) relationships between FL and centrum dimensions, but as regression models based on centrum height provided the best fit (Table 3) we only used these when estimating the FL of Čḯxʷicən sablefish specimens.

One limitation of these models is that our reference set of modern sablefish only represents a fraction of the juvenile size-classes that are of interest; our smallest reference fish has a FL of 32 cm, but sablefish measure around 20 cm when they end their shoreward migration. If there is a change in the allometric relationship between vertebra size and body-size between lengths of about 20 cm and 32 cm, our regression models would make inaccurate FL predictions for smaller juveniles, potentially leading to incorrect assessments of habitat use. Fortunately, there is no reason to expect that this relationship would change over the juvenile life-stage, and our reference set shows no evidence that the relationship changes between the adult and juvenile life-stages. Therefore, we confidently assume that our model can accurately predict FL from sablefish smaller than 32 cm, though in the future we hope to expand the sample size of our reference set to include smaller juveniles, especially those smaller than 20 cm FL.

3.2. Čḯxʷicən materials

The Čḯxʷicən faunal collection comes from a large excavation project carried out by Larson Anthropological Archaeological Services (LAAS) and LEKT members in 2004 (Reetz et al., 2006). All excavated matrix was collected in 10 L buckets and wet-screened through nested 1″ (25.6 mm), 1/2″ (12.8 mm), and 1/4″ (6.4 mm) mesh. At least one 10 L bucket from each micro-stratum identified in the field was also screened through 1/8″ (3.2 mm) mesh and designated a 'complete' ("C") bucket. The fishbone collection used in this study was analyzed during a large-scale zooarchaeological and geoarchaeological analysis initiated by Butler, Kristine Bovy (University of Rhode Island), Sarah Campbell (Western Washington University[WWU]), Mike Etnier (WWU), and Sarah Sterling (Portland State University) that focused on animal remains recovered from two plankhouse structures, and extramural activity and midden areas at Čḯxʷicən (for a full history of the Čḯxʷicən mitigation project, see Butler et al., 2018a, *this issue*; and for overall faunal analysis and sampling, see Butler et al., 2018b, *this issue*).

Butler directed analysis of the fishbone assemblage at PSU from 2012 to 2015 following QC/QA protocols that are consistent with Driver's (2011) recommendations. PSU master's students Kathryn Mohlenhoff, Anthony Hofkamp, Shoshana Rosenberg, and Nims identified fish remains from "C" buckets (and other sample types), and Butler verified and often adjusted all initial identifications under magnification. For a full account of fishbone identification methods and protocols, see Butler et al. (2018c). To evaluate the reproducibility of the Čḯxʷicən fishbone identifications, Nims and Butler (2017) conducted a blind reanalysis of 14 "C" buckets (140 L) from three stages of the project and found that our results are highly reproducible.

The analyzed fishbone from Čḯxʷicən represents seven chronological zones (CZs) of activity spanning the last 2150 years (Fig. 5; Campbell et al., 2018, *this issue*). In this study, we compare patterns of sablefish representation between CZ's (Table 4) – and to general patterns in regional environmental history (Fig. 5) – to explore whether the climate shifts and tectonic events discussed by Hutchinson et al. (2018, *this issue*) affected catches of sablefish. Here, we assume that local atmospheric and marine temperatures are correlated, and this assumption
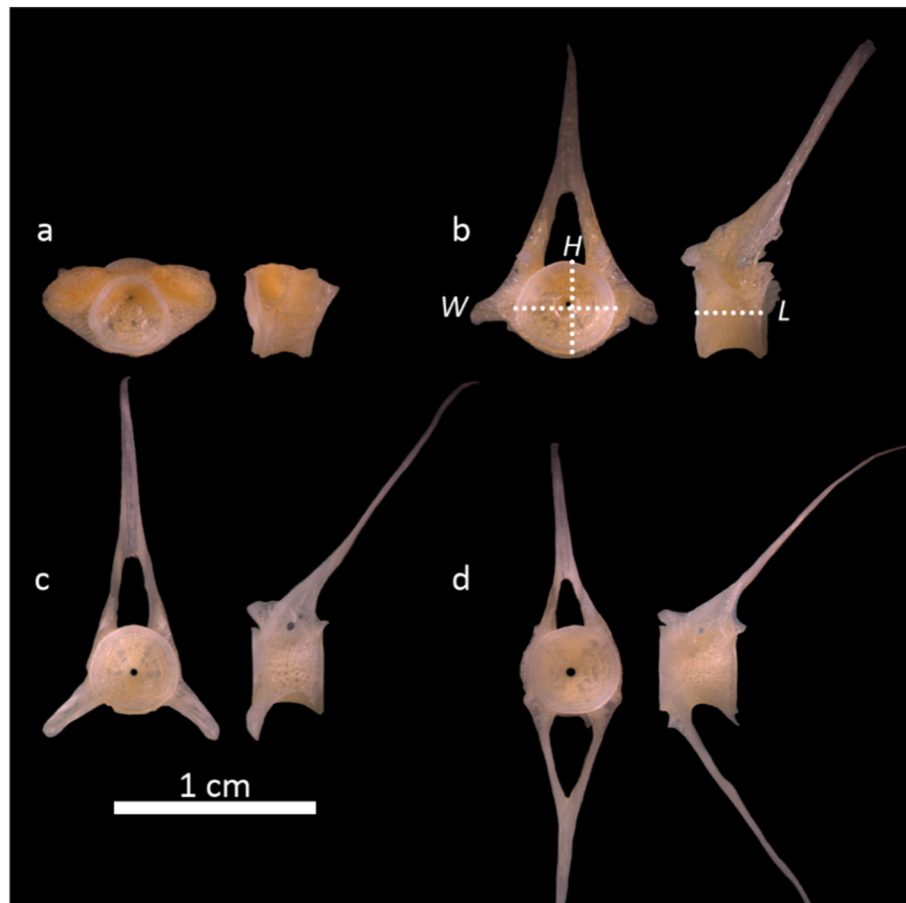
Fig. 2. Rostral and lateral aspects of sablefish vertebrae and the dimensions used in our body-size regression models: H = height, W = width, L = length. We present separate regression models for the atlas (a) and abdominal vertebrae (b, c). No models were developed for caudal vertebrae (d).

is supported by long-term reconstructions of oceanic sea surface temperatures (SST) at global and ocean-basin scales (McGregor et al., 2015). McGregor et al.'s synthesis of SST records for the past 2000 years shows a cooling trend in Pacific Ocean waters from 1850 to 1450 BP, followed by a warming period with peak temperatures around 850 BP, and another cooling phase that lasted from 650 to 50 BP. As these trends closely match local reconstructions for atmospheric trends, we use changes in atmospheric temperatures as a proxy for marine SST.

We also contrast patterns of sablefish representation in two households to explore whether sablefish abundances reflect social differences. Excavations at Číxʷicən revealed remains from two separate plankhouses in Area A1 and Area A4 of the site (Fig. 6). The house in Area A4 was first established during CZ 4 (Fig. 5), and two distinct floor

deposits (Floor 1 and Floor 2) date to this period of occupation. Subsequent floor levels from this house date to CZ 5 (Floor 3) and CZ 6 (Floor 4) (Campbell et al., 2018, *this issue*). The house in Area A1 was first established during CZ 5, after the Area A4 household formed (Fig. 5), and it also contains floor deposits that date to CZ 5 (Floor 1) and CZ 6 (Floor 2). Given the contemporaneous occupations, we compare sablefish use between the two households for CZ 5 and CZ 6 (Table 5).

Nims measured the centrum height of all sablefish atlases and abdominal vertebrae in the Číxʷicən fishbone collection with at least one intact centrum face. All vertebrae were recorded three times, and then averaged (Supplementary Table 2). If there was noticeable disagreement between the three measurements for any specimen, Nims

Table 2

Fork length and vertebral height measurements of sablefish used in linear regression model.

| Accession number	FL (cm)	Atlas height (mm)	Abdominal vertebrae					
			Number measured	Average height (mm)	Min.	Max.	Std. Dev. (mm)	CV (%)
PSU 13-2-1	34.8	4.34	26	4.25	4.14	4.46	0.09	2.1
PSU 13-2-2	37.4	4.71	26	4.67	4.50	4.88	0.10	2.1
PSU 15-1-1	37.0	4.86	27	4.63	4.42	4.84	0.13	2.8
PSU 15-1-2	56.0	7.10	27	6.65	6.32	6.93	0.17	2.6
PSU 15-1-3	45.3	5.87	28	5.69	5.56	5.81	0.08	1.4
PSU 15-1-4	60.0	8.70	23	8.02	7.83	8.46	0.18	2.2
PSU 15-1-5	45.0	6.02	25	6.12	5.96	6.38	0.09	1.5
PSU 15-1-6	41.3	5.40	25	5.23	5.07	5.37	0.08	1.5
PSU 15-1-7	32.0	3.97	25	3.92	3.76	4.05	0.06	1.5
PSU 15-1-8	34.5	4.66	28	4.53	4.36	4.81	0.12	2.6
PSU 15-1-9	35.5	4.57	26	4.50	4.33	4.68	0.09	2.0
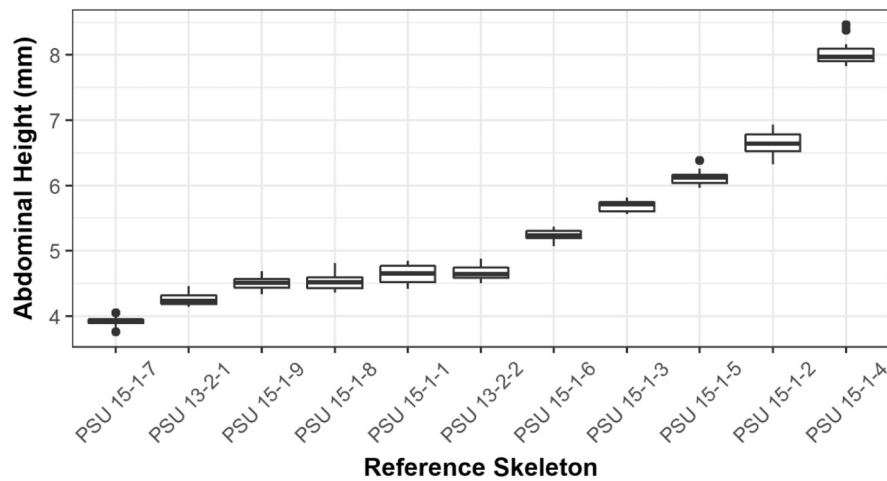
Fig. 3. Heights of abdominal vertebral centra from modern sablefish reference specimens.

Table 3

Summary of linear regression models calculated for sablefish body-size estimation. Models shown in bold provide the best fit based on R^2 values. ("Abd." = abdominal).

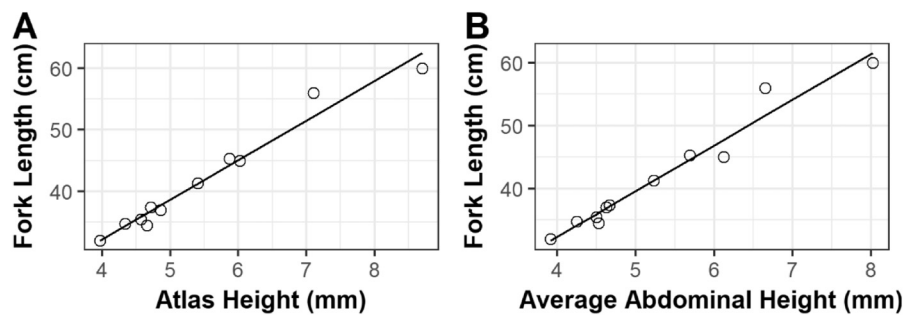| Dependent variable	Independent variable	Coefficient	Intercept	df	F	p	R^2
Fork length	**Atlas height**	**64.408**	**64.603**	**1, 9**	**269.5**	**< 0.001**	**0.967**
	Atlas width	54.534	81.854	1, 9	114.6	< 0.001	0.927
	Atlas length	80.749	92.919	1, 9	106.3	< 0.001	0.921
	Abd. vertebra height	**72.819**	**31.746**	**1, 9**	**216.3**	**< 0.001**	**0.960**
	Abd. vertebra width	63.393	71.022	1, 9	138.7	< 0.001	0.939
	Abd. vertebra length	71.472	101.316	1, 9	72.66	< 0.001	0.889

Fig. 4. Linear regression models for sablefish fork length and (A) height of atlas vertebral centrum, and (B) average height of abdominal centrum.
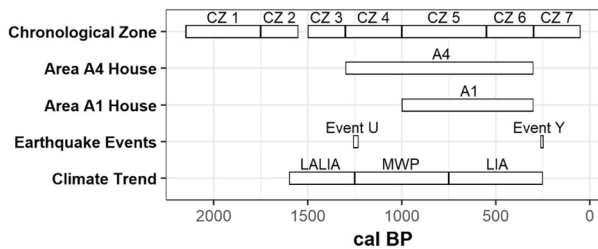

Fig. 5. Chronology of the Číxʷicən fishbone assemblages, household occupation, and major environmental events (Hutchinson et al., 2018, *this issue*). LAIA = Late Antique Little Ice Age; MWP = Medieval Warm Period; LIA = Little Ice Age.

Table 4

Sample size for all fish specimens in NISP and volume of "C" buckets analyzed (L) for each CZ at Číxʷicən.

CZ	Sample size (NISP)	Volume (L)
CZ 7	841	130
CZ 6	29,140	1280
CZ 5	8815	1010
CZ 4	3326	590
CZ 3	1040	670
CZ 2	227	370
CZ 1	274	280
Total	43,663	4330

discarded the values and repeated the measurement. We calculated FL estimates from the average of the three trials using the linear model appropriate for the given element with R version 3.4.2.

4. Results

4.1. Sablefish size-frequency distributions

The FL estimates for all measurable sablefish vertebrae from Číxʷicən fall into the demersal stage of juvenile sablefish life history between 20 cm and 40 cm FL (Fig. 7; Table 1). A total of 41 atlas
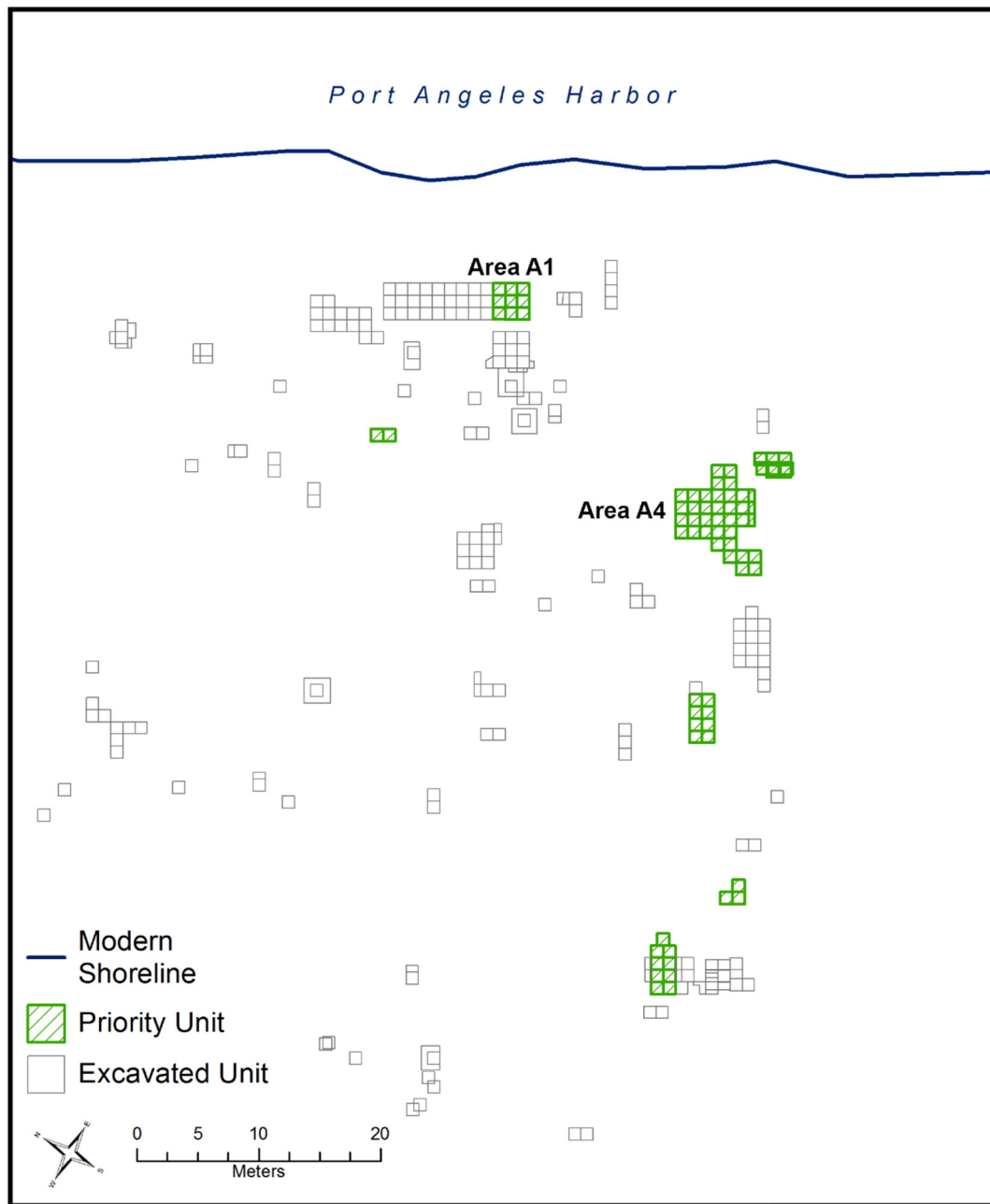
Fig. 6. Plan map of Čḯxʷicən excavations showing priority units (green) that were targeted for faunal analysis. Areas A1 and A4 contain remains of plankhouses representing separate households (drawn by Kristina Dick). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 5
Sample size for all fish specimens in NISP and volume analyzed (L) for the floor deposits in Area A1 and Area A4.

Area	CZ	Floor	Sample size (NISP)	Volume (L)
A4	CZ 6	Floor 4	6862	280
	CZ 5	Floor 3	2057	360
A1	CZ 6	Floor 2	786	140
	CZ 5	Floor 1	2858	240
Total			12,563	1010

specimens and 1074 abdominal vertebrae were intact enough to measure, with a remaining 2023 vertebral specimens that were either fragmented, crushed, or identified as caudal vertebrae.

As individual sablefish have approximately 26 abdominal vertebrae

each (Supplementary Table 1), we compared the FL estimates calculated from the atlas to those of the abdominal vertebrae to check whether the abdominal vertebrae size-distributions are biased by differential survivorship of vertebrae from different size-classes. We used Welch's unequal variances t-test to compare the mean FL estimates from atlases (mean FL = 28.1 ± 1.9 cm) and abdominal vertebrae (mean FL = 27.7 ± 2.7 cm); Welch's t-test is more robust than Student's t-test of independent samples when samples have unequal variances or sample sizes. The test results show there is no statistical difference between the two vertebral type samples ($t = 1.13$, df = 46.51, $p = 0.264$), and the difference of 0.4 cm in mean FL has no practical significance (Cohen's d = 0.129; see Wolverton et al., 2016 for more on practical significance).

Combining atlas and abdominal vertebra FL estimates into a single size-frequency distribution shows a strongly unimodal distribution in
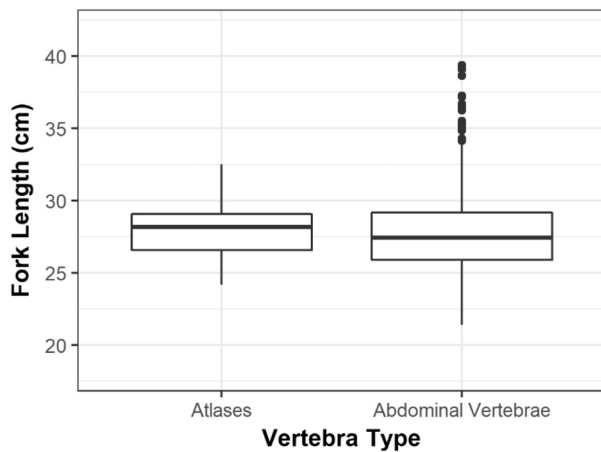
Fig. 7. Distribution of sablefish fork length estimates based on atlases and abdominal vertebrae. Mean fork length estimates for the two vertebrae types are statistically indistinguishable (NISP$_{atlas}$ = 41; NISP$_{abdominal}$ = 1074).

Table 6
Summary of fork length (FL) estimates for Čʼíxʷicən sablefish by chronozone (CZ).

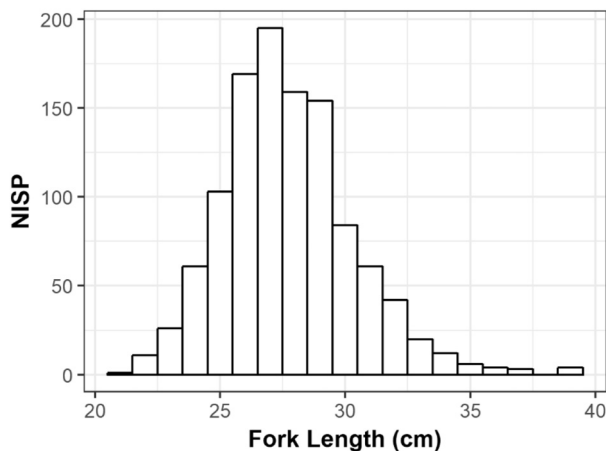| CZ	Sample size (NISP)	Mean FL (cm)	Standard deviation
CZ 7	29	27.8	2.9
CZ 6	532	27.4	2.6
CZ 5	282	28.0	2.6
CZ 4	186	28.2	2.6
CZ 3	49	28.2	2.2
CZ 2	5	27.5	1.6
NPA[a]	32	27.2	2.5
Total	1115	27.7	2.6

[a] Not assigned to CZ.

Fig. 8. Size-frequency distribution of fork length estimates from all measured sablefish vertebrae at Čʼíxʷicən (NISP = 1115).

the sablefish catch at Čʼíxʷicən (Table 6; Fig. 8). The mean FL of 27.7 ± 2.6 cm suggests sablefish were captured in the period between fall, when juveniles first arrive inshore, and their second summer, when southeast Alaskan sablefish approach average lengths of 30 cm (Rutecki and Varosi, 1997a). The same pattern is evident across all CZ's that have a minimum sample size of 29 NISP, which show < 1 cm of variation in mean FL for all sablefish captured across 1500 years of Čʼíxʷicən's occupation (Fig. 9; Table 6).
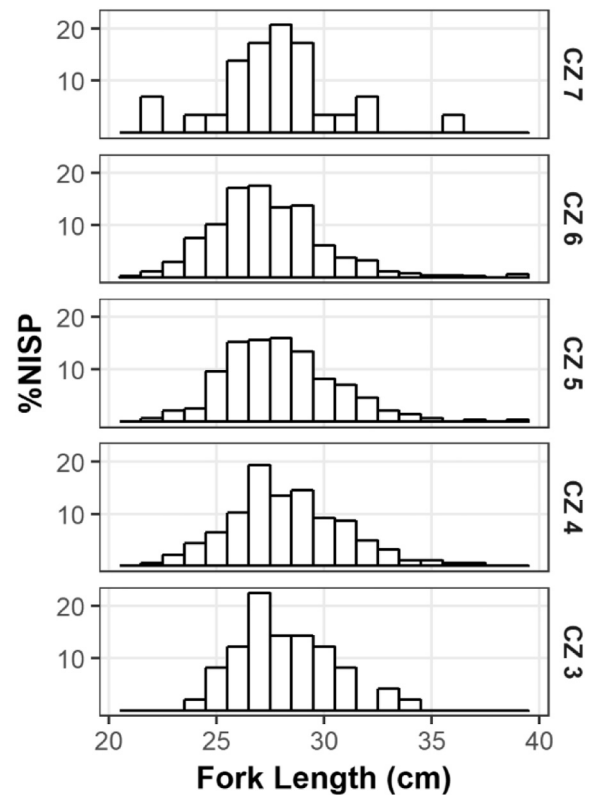

Fig. 9. Percent size-frequency distributions of sablefish from 5 chronological zones (CZ's) of Čʼíxʷicən. No measurable vertebrae were identified in CZ 1. CZ 2 is excluded due to very small sample-size (NISP = 5). (Sample sizes: CZ 7 = 29 NISP; CZ 6 = 532 NISP; CZ 5 = 282 NISP; CZ 4 = 186 NISP; CZ 3 = 49 NISP).

4.2. Spatio-temporal variation in sablefish abundance

Sablefish relative abundance varies moderately throughout the occupation of Čʼíxʷicən (Fig. 10). Sablefish is ranked as the sixth most common fish taxon in CZ 1, and then falls to seventh most common in CZ 2, though its proportional representation does not change. From CZ 3, sablefish rank-order increases to the third most common fish and then alternates between second and third most abundant in the remaining four CZ's. While herring (*Clupea pallasii*) clearly dominate the Čʼíxʷicən fishbone record, these distributions show that juvenile sablefish – along with flatfishes (Pleuronectiformes), salmons (*Oncorhynchus* sp.), staghorn sculpin (*Leptocottus armatus*), and dogfish shark (*Squalus suckleyi*) – were a key and reliable fish species for 2150 years (Fig. 10).

Comparing this pattern with regional histories of climate trends and earthquake events (Fig. 5) shows these processes had little to no long-term effect on sablefish catches at Čʼíxʷicən. Current research on sablefish population dynamics has revealed complex relationships between year-class strength and environmental factors (Echave et al., 2012; McFarlane et al., 1997; Shotwell et al., 2014; Sogard, 2011). On one hand, growth rates in larval and early juvenile-stage sablefish increase with sea surface temperature (SST), enhancing year-class strength (McFarlane et al., 1997; Sogard, 2011). However, Shotwell et al. (2014) concluded that increases in primary productivity associated with cooler SSTs are a more important control on sablefish recruitment. Therefore, we assume that cooler periods would enhance sablefish year-class strength and encounter rates. Using atmospheric trends as a proxy for SST (see above), sablefish abundance might be expected to increase at Čʼíxʷicən during the Late Antique Little Ice Age (~1600–1250 cal BP in this region [after Hutchinson et al., 2018, *this issue*]) and the Little Ice Age (~750–250 cal BP) (Fig. 5). These cool periods overlap with every CZ at Čʼíxʷicən except CZ 1, making it difficult to compare changes in these assemblages to changes in climate
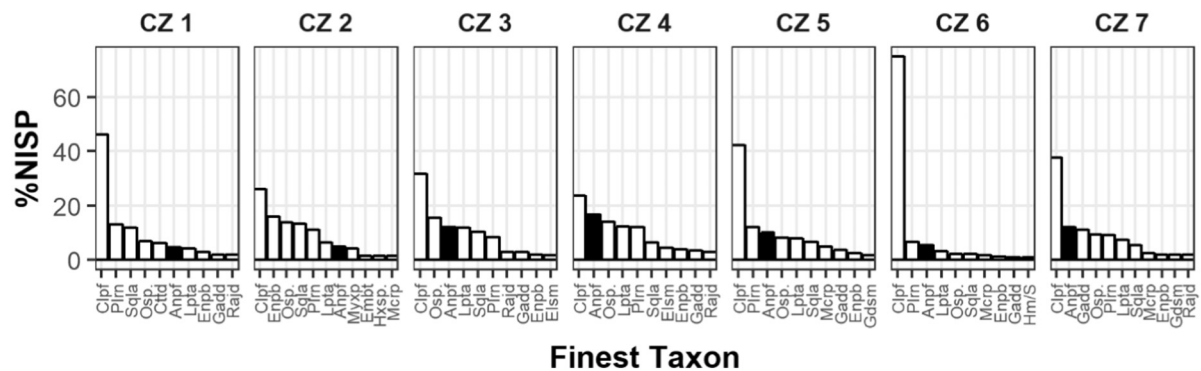
Fig. 10. Relative abundance (%NISP) of the 10 most abundant fishes in each chronozone (CZ) from Čḯxʷicən. Black bars highlight sablefish frequencies. "Anpf" = *Anoplopoma fimbria*; "Clpf" = Clupeiformes; "Cttd" = Cottid; "Elsm" = Elasmobranchii; "Embt" = Embiotocidae; "Enpb" = *Enophrys bison*; "Gadd" = Gadidae; "Gdsm" = *Gadus macrocephalus*; "Hm/S" = *Hemilepidotus/Scorpaenichthys*; "Hxsp." = *Hexagrammos* sp.; "Lpta" = *Leptocottus armatus*; "Mcrp" = *Microgadus proximus*; "Myxp" = *Myoxocephalus polyacanthocephalus*; "Osp." = *Oncorhynchus* sp.; "Plrn" = Pleuronectiformes; "Rajd" = Rajidae; "Sqla" = *Squalus suckleyi* (formerly *Squalus acanthias*).

regime. However, the absence of any noticeable change during CZ 4 and CZ 5, which overlap more with the Medieval Warm Period (~1250–750 cal BP) than either cool period, suggests changes in climate did not appreciably affect human capture rates of juvenile sablefish.

Meanwhile, there is no a priori reason to suspect that sablefish populations would be affected by earthquake or tsunami events for more than a season. As adults reside and spawn offshore, any short-term disruptions to inshore environments could only affect a single year-class of juveniles. Tectonic events could affect sablefish catch sizes indirectly if the fishing gear or watercraft necessary for fishing in waters 20 m to 60 m deep were lost or destroyed in a tsunami, but this would only have a long-term effect in the event that people did not replace their equipment and stopped fishing from boats. While there is clear evidence of variation in occupation intensity at Čḯxʷicən following earthquake event "U" (Hutchinson et al., 2018, *this issue*), the consistency in sablefish representation over this period shows that village inhabitants were able to procure juvenile sablefish at the same rates as before (Fig. 10).

Despite the overall consistency in sablefish relative abundance from CZ 4 to CZ 7 when the aggregated assemblage is considered (Fig. 10), there are differences in sablefish representation over the occupation of the two houses associated with Areas A1 and A4 of Čḯxʷicən (Fig. 11), suggesting social factors mediated fish use. Butler et al. (2018b, *this issue*) have examined all animal classes to explore whether households were *autonomous* or *communal* in resource use. They predict households that operate more communally – sharing gear or access to harvest areas or captured fish – would generate faunal deposits that are more similar relative to households that operate autonomously. In CZ 5, Butler et al. (2018b, *this issue*) found that fish use was relatively consistent between households, suggesting a communal social structure. In CZ 6, the pattern changes, with stark differences in fish representation between houses, suggesting a more autonomous social structure.

The sablefish record between households and CZs is consistent with this broader pattern in fish representation. In the earlier CZ 5, sablefish remains are modestly represented in both houses (Fig. 11). In CZ 6, sablefish representation differs greatly between households: sablefish is ranked second after herring in the Area A4 house, but it is ranked 10th in the Area A1 house. Butler et al. (2018b, this issue) analysis found that the two households also vary greatly during CZ 6 in representation of herring (A4: high; A1: low), staghorn sculpin (A4: low; A1: high), and salmon (A4: high; A1: low). Overall, the record shows that the households operated much more independently in the later time period. Given the ethnographic link of sablefish to prestige and gifting, higher abundances at Area A4 indicate occupants of this household may have had privileged access rights to sablefish or ownership of fishing grounds

where young-of-the-year congregated. While the specific social factors involved remain uncertain, the contemporaneity and shared locality of the two households demonstrates these patterns are not linked to environmental drivers.

5. Discussion and conclusions

Our reconstructed sablefish body-size distributions reveal that Čḯxʷicən's inhabitants fished exclusively for inshore demersal juveniles that today inhabit bays and inlets at depths of 20 m to 60 m (Fig. 8; Table 1). There is a clear unimodal distribution in sablefish FL estimates that suggest they were largely captured between late fall and spring. These juveniles are one of the most abundant fishes among a group of fish taxa that are consistently well-represented in each Čḯxʷicən fish-bone assemblage, and they provided a reliable resource through long-term climate shifts and short-term socio-environmental disruptions caused by tectonic events (Fig. 10).

These patterns provide an intriguing contrast with available ethnohistoric information about traditional sablefish use, which largely relate to mature sablefish. Swan's (1887) observations specifically highlighted the importance of adult sablefish in the Salish Sea and cited their depth as a limiting factor in sablefish consumption. Discussions of sablefish at Haida Gwaii also imply that sablefish were primarily captured as adults with long-line trawls measuring up to 350 m in length (Hobler, 1978; Swan, 1887). However, Arima and Dewhirst's (1990) account of fishing for sablefish with lures from canoes may indicate that sablefish were being captured as juveniles from western Vancouver Island as lures would only be effective for attracting demersal fishes in relatively shallow waters, which would not be inhabited by adults. Considering the ethnohistoric and the archaeological evidence together, it is clear that Native American/First Nations peoples in northwestern North America took sablefish using a variety of methods that intersected with a number of stages in sablefish life history. Importantly, our work highlights problems with over-reliance on ethnographic records in interpreting archaeological assemblages (for other examples, see Moss, 1993; Orchard and Wigen, 2016).

Regarding the social significance of sablefish, the evidence from Čḯxʷicən is consistent with Swan's (1887) assertion that sablefish were a prized resource. Though the Čḯxʷicən catch is entirely composed of juveniles, and Swan (1887) argued that only mature sablefish were highly regarded by peoples living on the shores of the Strait of Juan de Fuca, sablefish are well represented throughout the site's occupation (Fig. 10). We also observed marked differences in sablefish abundance that suggest household members associated with the Area A4 household may have had privileged access to sablefish. Differential access could arise directly through ownership of fishing grounds that sablefish
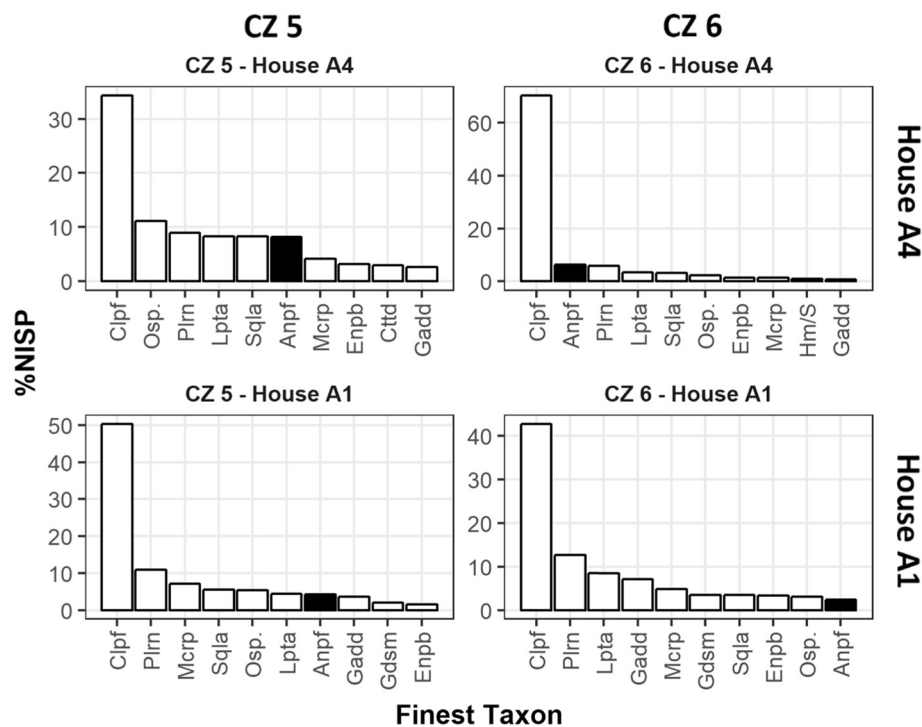
Fig. 11. Relative abundance (%NISP) of the 10 most abundant fishes from floor levels in two houses by chronological zone (CZ) showing marked differences in sablefish catches (black bars). See Fig. 10 for a key to taxon abbreviations.

particularly favor, or indirectly through greater access to watercraft, necessary fishing gear, labor, or other resources. Alternatively, if Swan's (1887) observation that sablefish were a chiefly luxury held true at Čḯxʷicən, the higher frequencies of sablefish in Area A4 may reflect higher rates of gifting and/or tribute to the house's inhabitants.

While we are not in a position to answer our original question about why sablefish are so scarce in northwest North American archaeology, the insights from Čḯxʷicən provide much needed context that can help guide future research on this topic. Importantly, the consistency in sablefish abundance at Čḯxʷicən indicates the species can be productively and sustainably harvested at local scales for millennia, despite major shifts in climate and tectonic disruption. This suggests the absence of sablefish is probably not related to environmental perturbations, as sablefish and their juveniles are apparently able to tolerate a wide range of marine conditions. But if juvenile populations were as variable in the past as they are today, environmental factors could still play a role in determining the archaeological distributions of sablefish remains through their controls on year-class-strength and influencing where sablefish congregate. Unfortunately, these relationships remain poorly understood.

Our research also confirms our assumption that, at least in some contexts, sablefish were considered an attractive resource and some people may have had privileged access to the species. This could lead to high degrees of intra-site variation in sablefish deposition, affecting our ability to recognize sablefish archaeologically at sites where time and budget constraints prevent the implementation of an intensive sampling-strategy. However, sablefish at Čḯxʷicən are widely distributed throughout the site, and the number of sablefish remains identified from Area A1 alone greatly outnumber the total number of sablefish remains recorded at all other northwestern North American archaeological sites despite the marked differences in relative abundance that we documented between the two houses. We doubt that intra-site variation in sablefish frequencies could be so extreme that sablefish would only be recovered from a single context, and it seems unlikely that intra-site variability in sablefish distribution accounts for the rarity of sablefish in most archaeological sites.

Finally, though the archaeological record presents an uninterrupted history of sablefish procurement by the inhabitants of Čḯxʷicən, juvenile sablefish are not known to congregate in or around Čḯxʷicən today. Most juvenile sablefish studies have focused their efforts on regions north of Vancouver Island (Kennedy and Smith, 1972; Mason et al., 1983; McFarlane and Beamish, 1983; Rutecki and Varosi, 1997a). It is not clear when juvenile sablefish stopped congregating in the vicinity of Čḯxʷicən, or why they are no longer abundant, but future work on these questions could help resolve the factors that lead juveniles to their preferred nurseries. Combining such information with reconstructions of coastal environmental conditions could help predict where sablefish would or would not have congregated in the past, allowing us to test hypotheses about whether the archaeological scarcity of sablefish is related to the distribution of sablefish populations in the past.

Like other focused studies of individual fish taxa (e.g. herring - McKechnie et al., 2014; halibut - Orchard and Wigen, 2016; lampreys - Smith and Butler, 2008), we found that paying close attending to particular species like sablefish can deepen our understanding of, and our appreciation for, the people who skillfully managed these food webs in the past.

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loaned comparative fish skeletons and/or assisted with identifications. Dan Kamikawa (NOAA) and Dana Hanselman (Alaska Fisheries Science Center, NOAA), collected the sablefish used in the study; Jessica Miller (Oregon State University) and Ed Backus (Collaborative Fisheries Associates) delivered them to Butler. Former PSU students Tony Hofkamp, Kathryn Mohlenhoff, Emily Rocha, Shoshanna Rosenberg, and Laura Syvertson assisted in the lab. Bruce Floyd (University of Auckland) provided invaluable statistical advice. Kris Bovy and two anonymous reviewers provided valuable comments on an earlier version of this manuscript. We alone are responsible for any errors. Work was funded by the National Science Foundation [grant numbers 1219468, 1353610, and 1663789].

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