Survival of mammoths (*Mammuthus* sp.) into the Late Pleistocene in Southwestern British Columbia (Vancouver Island), Canada

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Abstract
As part of a larger project identifying and directly radiocarbon dating Late Pleistocene megafaunal remains in British Columbia (B.C.), Canada we have confirmed the identity of many newly identified mammoth (Mammuthus sp.) specimens (n=32) from Vancouver Island in Southwestern B.C. We undertook radiocarbon dating on all specimens and were able to obtain dates (due to preservation) on 16 of these remains, including re-dating a previously dated mammoth using newer radiocarbon extraction methods. The mammoth dates span a wide range, from >47,500 to 18,000 radiocarbon years BP (uncalibrated). These later new dates support other lines of evidence for portions of Vancouver Island remaining unglaciated towards the end of Late Pleistocene.

Keywords
Vancouver Island, mammoth, Pleistocene, radiocarbon, ZooMS, refugia, glacial history

Introduction

Vancouver Island in Southwestern British Columbia was a natural coastal conduit for migrating animals at times of ice expansion and lower sea levels (Clague, 1976, Dyke and Prest 1987, Harington 1978). It is considered an important biogeographical area in Late Pleistocene studies regarding the viability of unglaciated landscapes to humans and their migrations southward along the Pacific coast from Beringia (Hebda and Haggarty 1997, Ward et al., 2003, Al-Suwaidi et al., 2006, Lesnek et al., 2018, Hebda et al., 2022).

Despite the island's central biogeographic position, a synthesis of the occurrence of mammoths on Vancouver Island, and British Columbia generally, has been overlooked possibly due to the perceived low likelihood of remains surviving in physically active glacial environments (McTaggart-Cowan 1941, Harington 1978). However, mammoth remains have been found on Vancouver Island and the adjacent Gulf Islands for more than a century, with the first recordings of them in the Royal B.C. Museum as early as 1895. Reports of mammoth remains have continued to the present (Kermode 1924, 1926, Sternburg 1930, 1963, McTaggart-Cowan 1941, Carl 1950, Harington, Tipper and Mott, 1974, Harington 1975, Keddie, 1995[1]) as well as isotope analyses on a few of the specimens (Metcalf et al. 2016).

When these remains are found, they are broadly ascribed to date within the geological strata in which they were found. However, the age of glacial strata on Vancouver Island can be challenging to establish because of the occurrence of several glacial episodes from several ice sources, complex topography, and varying sea levels (Clague 1976, Clague, 1980, Clague and James 2002, Jackson and Clague 2012). The use of relative dating of glacial drift deposits is further complicated by glacial reworking, fluvial transport and erosion (Clague and Ward, 2011) underscoring the importance of directly dating remains (Jass and Barrón-Ortiz 2017). Direct dating of mammoth fossils from known stratigraphic settings provides the opportunity to resolve relative dating issues and improve the interpretation of the area and extent of the latest ice advance into the region (Holland 1964).

We provide a comprehensive review of literature on the mammoth remains augmented by our extensive new sampling and radiocarbon dating program for this region and report many new radiocarbon dates. In particular we discuss the new radiocarbon evidence reported here for late-surviving mammoths, building upon the work first reported by Keddie (1979) who obtained the first young (ca. 17,000 BP) radiocarbon age on mammoth remains from this region.

Our study broadens the understanding of the western North American environment during the Late Pleistocene, adding to the compendium of mammoth research in the adjacent mainland of British Columbia and neighbouring provinces and territories of Yukon (Harington and Clulow 1973, Zazula et al., 2003, Metcalfe and Longstaffe 2012, Smith 2015), Alberta (Churcher 1972; Harington and Shackleton 1978, Burns, Baker and Mol 2003, Jass and Barrón-Ortiz 2017), and the states of Washington (Higley 1886, Hay 1923, Barton, 1999) and Oregon (Gilmour et al., 2015).

Region

Mammoths ranging in this shifting landscape are thought to have arrived on Vancouver Island from the Fraser Lowlands to the east, leaving in advance of encroaching glaciers and travelling along and across the Georgia Depression which created a connection to the mainland (Hicock. Hobson, Armstrong 1982) and was marked with braided streams and channels (Quadra Sand). Organic remains are often preserved in the Quadra Sands (Clague 1977), with the sands occurring intermittently along eastern Vancouver Island and Gulf Islands, and were laid down in a continuous time-transgressive body in the Georgia Depression. Glaciers advanced from the northern portion of today's Salish Sea from ~29,000 yr BP to ~17,000 BP in the south of Vancouver Island (Clague 1977, Clague and Ward 2011) creating depositional and preservation conditions similar to those on the Saanich Peninsula over a wide geographic region (Figure 1).

[1] Keddie, G. (1995) 'List of all Mammoth and Mastodon Fossils in the Collection of the Royal B.C. Museum as of October 14th, 1995. And List of Fossils once in the Collection that can not be located.' Manuscript in the RBCM Paleontology Division, pp. 1–16.

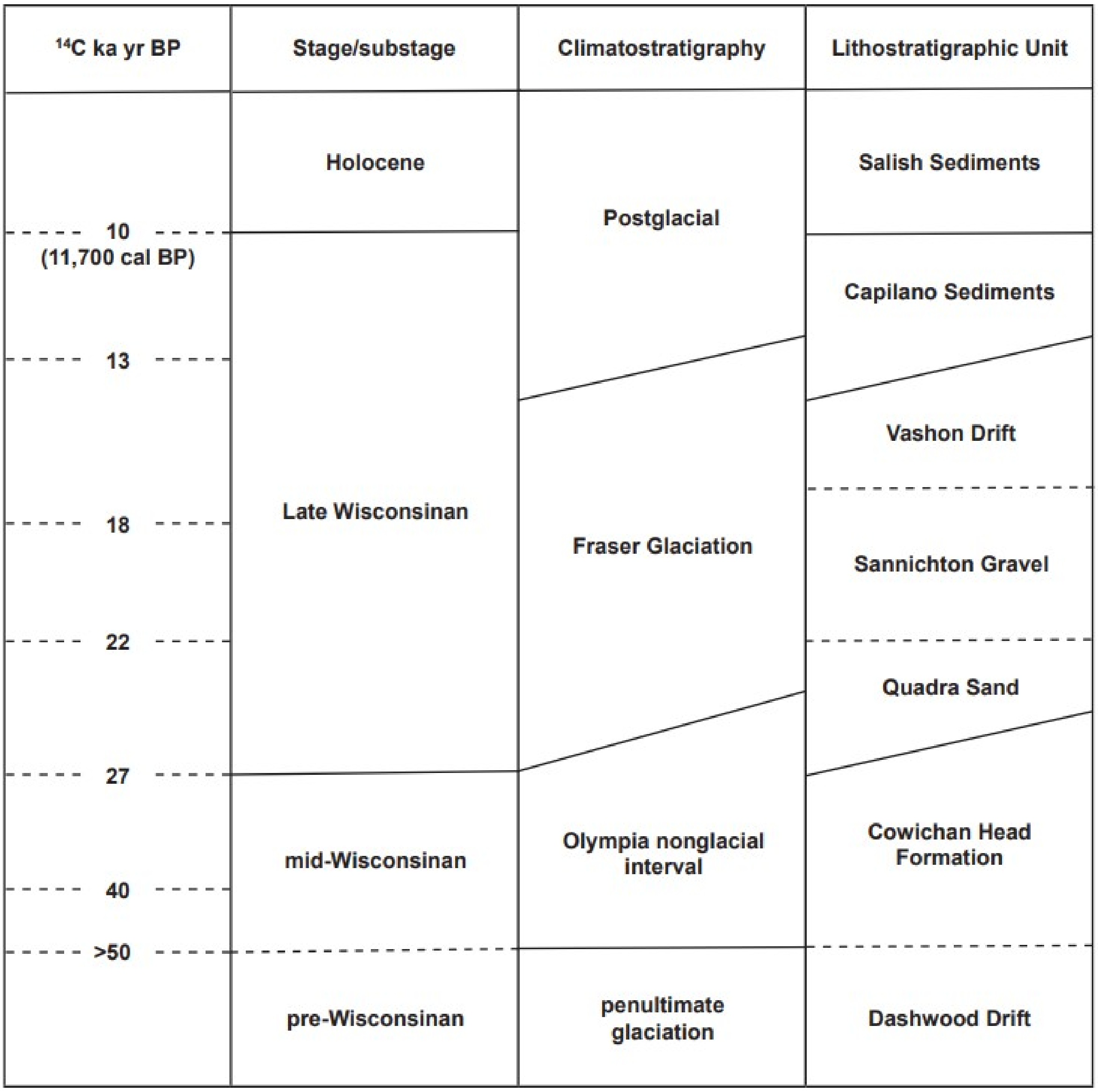

Figure 1. Southern Vancouver Island Quaternary sequences and deposits. Adapted from Bednarski (2015) and Blyth and Rutter (1992).

Cooling began towards the end of this Olympia nonglacial interval (Hebda, Lian and Hicock, 2016), with Halstead (1968) suggesting that localized ice advanced ~17,000 BP, and deposited outwash as Saanichton gravels. These gravels were widespread from east of Cobble Hill to most of the Saanich Peninsula (Miskelly 2012). By ~15,000 BP, Vashon Stade ice encroached in the area laying down till and glaciofluvial and glaciolacustrine sediments (Hicock and Armstrong, 1985) while eroding and reworking older Saanichton Gravels.

It is in these sand and gravel deposits that commercial gravel quarrying (Clapp 1912, Mate and Levson 2001, Keddie 2016a[2]) and coastal erosion, expose remains of extinct megafauna (Steffen and Harington 2010). Discoveries are concentrated in the Victoria area, where mammoth remains are known from extensive glacial drift deposits on the Saanich Peninsula (Keddie 1995). These occurrences may be the result of both rapid sediment accumulation in a

[2] Keddie, G. (2016a) ‘Muskox in British Columbia’. Victoria: Manuscript on file at the Royal BC Museum, pp. 1–8.

braided river stream environment that made it more likely for skeletal material to be buried, concentrated and preserved, as well as a high recent human population density leading to exposures of the mammoth remains from aggregate extraction.

Materials and methods

Localities

Mammoth remains sampled from Vancouver Island have been reported from the mid island at Courtenay, southward, with most clustered at the south end of the island (Figure 2). On the east side of Vancouver Island, a stream eroded molar (Harington 1975, Harington and Shackleton 1978) was recovered in the Browns River at Courtenay, delineating the northern extent of mammoths reported from Vancouver Island. This region is covered by unconsolidated Pleistocene deposits including, glacial, glacifluvial and glaciomarine sediments with pockets of Quadra Sand and Capilano Sediment forming aquifers (Cathyl-Bickford 2001). While the find location on the Browns River is nearest to Capilano aquifers, located between aquifer 952 to the northeast, and aquifer 951 to the southeast (Metherall 2019), it is not within a named aquifer, so would fall under the unconsolidated Pleistocene deposits. Underlying the location of discovery is the Late Cretaceous Trent River Formation comprised of Royston, Browns, and Puntledge members (Cathyl-Bickford 2001).

South of Courtenay, a molar was discovered in Port Alberni at the foot of "Copper Mountain" (Carl 1951, The Daily Colonist 1960, Keddie 1995). Now named Mount Hakin, China Creek flows east to south along its foot, where placer gold mining was active from 1862-1900 (Stevenson 1945). The tooth was recovered some twenty years after mining and may have been dislodged by this mining practice, from the ground moraine found in the area, suspected to be Vashon Drift (Fyles 1963). This area is significant because it has been proposed as a glacial refugium (Fender and Marshall 1994, Sendra and Wagnell 2019).

In the South Island region of Vancouver Island, most remains originated from commercial gravel quarries and share similar substrates from sites that lie near each other (Halstead 1968, Zubel 1980[3], Keddie 1995) (Figure 2 inset). Most notable are the gravel pits located between Elk Lake (Harington 1975, Pearson 1981) and Cordova Bay Beach. The gravel pits have changed names and boundaries over the years. The recently closed Trio Ready Mix, although across the street to the north, is an extension of the same deposits as the central Saanich Municipal gravel pit which was previously the McIntyre and Harding gravel pit. Nearby to the northwest, lies the oldest Butler Gravel pit in the region.

In contrast to the gravel quarries, is the sand pit at the base of Mount Tolmie, where fragments of a molar were found (Kermode 1924). The pit is interpreted to have formed from glacial ice contact against the slope of the mountain (Livingston 1963). The tooth may have been deposited in the same manner as a dropstone, as has been suggested for other mammoth remains in Finland (Ukkonen et al., 1999).

The best-known Vancouver Island site is Island View Beach Regional Park which includes the Cowichan Head Formation within the Vashon till-mantled drumlins in the area (Hicock, Hebda and Armstrong, 1982). These sediments span the Fraser glaciation and earlier times, and experience active coastal erosion. Readily visited by the public, remains of late Pleistocene animals are recovered regularly (Hebda and Cockburn 2014), although chance

[3] Zubel, M. (1980) 'Saanich Peninsula Water Supply - Groundwater Study', Memorandum, Ministry of the Environment. p. 10.

encounters will likely decrease with recent construction of a fence. An extension of the Quadra sands found on Island View Beach occurs nearby on James Island (Clague 1976).

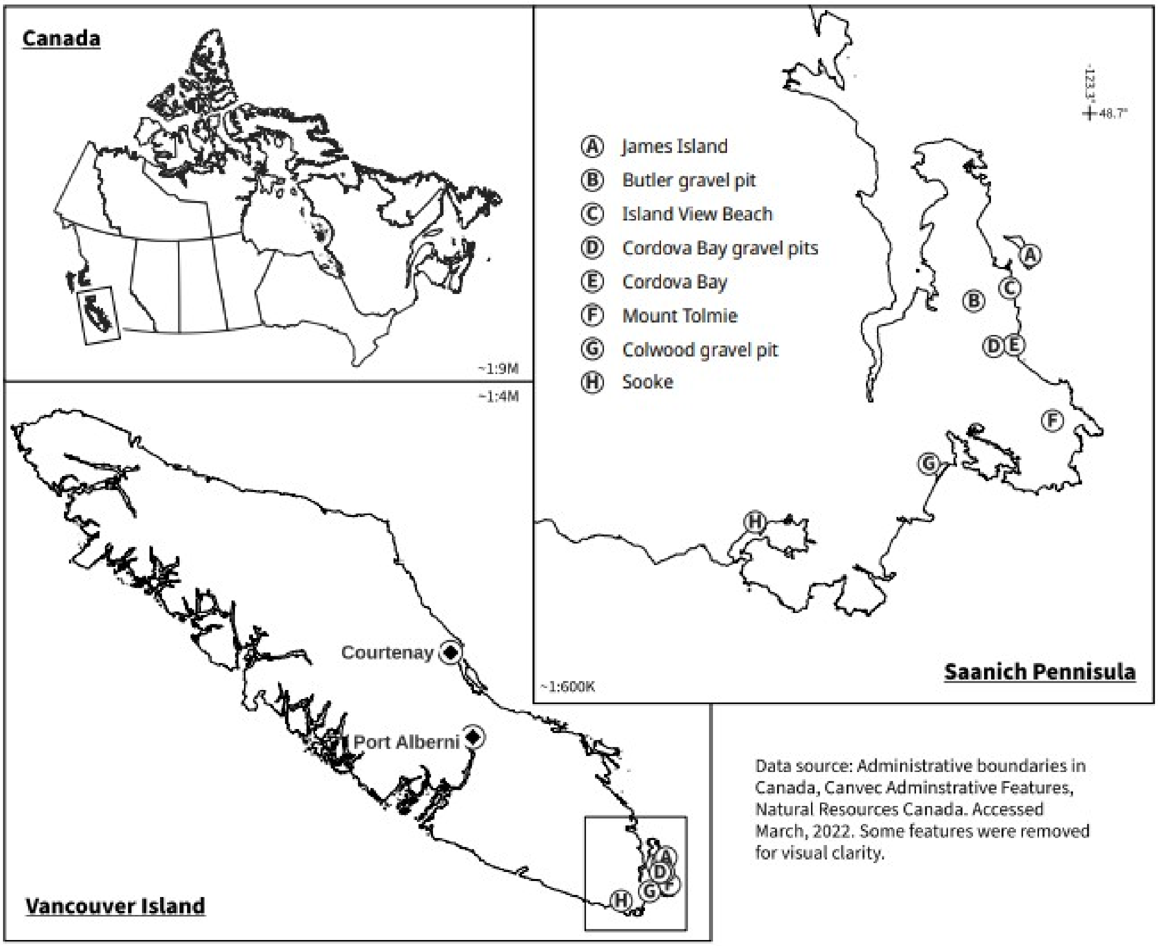

Figure 2. Locations of mammoth remains investigated in this study

Sampling

Specimens were sampled from the Courtenay and District Museum and Paleontology Centre (Courtenay, B.C.), and the Royal British Columbia Museum (Victoria, B.C.). To minimize destructive sampling, where possible pieces which had previously delaminated from the element were selected. Where fragments were not available, approximately 1.5 g of sample was removed by drill. Specimens are isolated elements, a trend that is found in the Albertan record (Jass and Barrón-Ortiz 2017). Typical museum donations include, in order of abundance, molars, tusks, with post cranial remains being much rarer as expected following taphonomic processes (Churcher and Wilson 1990).

All sampled mammoths are listed in Table 1, and this provides a record of material still available, as no specimens were destroyed for this analysis, and to illustrate negative results for completeness. In this list, species provide the identification of skeletal elements observed and recorded by earlier authors, follows Jass and Barrón-Ortiz (2017) conservative cf. attributions, and based on preliminary determinations from measurements made in this study.

Locality & Accession	S-SFU	Element	Taxon	Wear stage
Courtenay				
CDM 992.169.1, E4	2126	R $\geq M_4$	*Mammuthus* cf. *M. columbi*	≥C
Port Alberni				
RBCM.EH1994.003.0019	1663	molar	*Mammuthus* cf. *M. columbi*	n/a
James Island				
RBCM.EH1994.003.0004, No. 296	1658	max. molar	*Mammuthus* cf. *M. columbi*	n/a
RBCM.EH1994.003.0030, No. 377	1670	$\geq M^5$	*Mammuthus* cf. *M. columbi*	D1
Victoria				
Island View Beach				
RBCM.EH1994.003.0029, No. 299	1669	L $\geq M_4$	*Mammuthus* cf. *M. columbi*	B4
RBCM.EH1994.003.0034	1673	L M_6	*Mammuthus* cf. *M. primigenius*	≤D1
RBCM.EH2006.012.0009	1682	molar	*Mammuthus* cf. *M. columbi*	n/a
RBCM.EH2005.007.0001	1681	molar	*Mammuthus* cf. *M. columbi*	n/a
RBCM.EH2008.003.0001	1684	long bone	*Mammuthus* sp.	n/a
RBCM.EH2008.008.0002	1685	bone	cf. *Mammuthus* sp.	n/a
RBCM.EH2009.008.0001	1686	tusk	cf. *Mammuthus* sp.	n/a
RBCM.EH2009.009.0001	1687	≥M4	*Mammuthus* cf. *M. primigenius*	≤D1
Butler Bros gravel pit				
RBCM.EH1994.003.0013	1660	$\geq M_5$	*Mammuthus* cf. *M. columbi*	≥B2
RBCM.EH1994.003.0018	1662	long bone	*Mammuthus* sp.	n/a
RBCM.EH1994.003.0020	1664	L M^6	*Mammuthus* cf. *M. columbi*	B4
RBCM.EH1994.003.0036	1674	mandible	*Mammuthus sp.*	n/a
RBCM.EH1994.003.0044	1677	tusk	cf. *Mammuthus* sp.	n/a
Cordova Bay, McIntyre & Harding gravel pit				
RBCM.EH1994.003.0017	1661	$\geq M^5$	*Mammuthus* cf. *M. columbi*	≤D1
RBCM.EH1994.003.0026	1667	molar	*Mammuthus* cf. *M. columbi*	n/a
RBCM.EH1994.003.0027	1668	max molar	*Mammuthus* cf. *M. columbi*	n/a
RBCM.EH2006.012.0028	2308	flat bone	*Mammuthus* sp.	n/a
Cordova Bay, Central Saanich Municipal gravel pit				
RBCM.EH1994.003.0061, No. 713	1678	tusk	cf. *Mammuthus* sp.	n/a
RBCM.EH1994.003.0005, No. 714	1659	$\geq M^4$	*Mammuthus* cf. *M. columbi*	≤B3
RBCM.EH2016.012.0010	2251	tusk	*Mammuthus* sp.	n/a
Cordova Bay, Trio-Ready Mix gravel pit				
RBCM.EH1994.003.0024	1666	L $\geq M_2$	*Mammuthus* cf. *M. primigenius*	C
RBCM.EH1994.003.0039	1675	tusk	cf. *Mammuthus* sp.	n/a
RBCM.EH1994.003.0040	2125	humerus	*Mammuthus* sp.	n/a
RBCM.EH1994.003.0041	1676	tusk	cf. *Mammuthus* sp.	n/a
Cordova Bay Beach				
RBCM.EH1999.005.0001	1679	molar	*Mammuthus* sp.	n/a
RBCM.EH2003.002.0001	1680	$\geq M_4$	*Mammuthus* cf. *M. columbi*	D4
Mount Tolmie				
RBCM.EH2006.012.0034	1683	molar	*Mammuthus* sp.	n/a
Colwood gravel pit				
RBCM.EH1994.003.0012	252	max. molar	*Mammuthus* cf. *M. columbi*	n/a

Table 1. Mammoths from Vancouver Island sampled in this study. Molar numbering follows Laws (1966) and wear stage follows Louguet (2006). Molars sufficiently intact for order estimates are in super or subscript to indicate maxillary or mandibular placement. Symbol ≥ indicates minimum for molar order or wear. S-SFU 1675, 1676, 1686, 2125 were sampled

previously as BC-3, BC2, BC1, BC5 respectively in Metcalfe et al., (2016). Figures S1-S32 are in the supplementary material file.

Exclusions

Not all mammoth specimens known from Vancouver Island were sampled. Two molars from Cordova Bay (*Mammuthus* cf. *imperator*) (Harington, Tipper and Mott, 1974), likely *Mammuthus columbi* (Lister 2017) curated at the Canadian Museum of Nature (CMN 17707 and CMN 34960) were not examined. We did not attempt to sample a number of specimens in private collections (Keddie 1995). At the RBCM we did not sample specimens with unknown (n=15) or unclear (RBCM.EH94.003.022, RBCM No. 724) provenience. While some were not located (RBCM.EH1994.003.0025 RBCM No. 937, RBCM.EH1994.003.0038, RBCM.EH1994.003.0043 RBCM No. 484), one was mineralized (RBCM.EH2009.018.001 and another, tantalizing specimen (RBCM.EH2006.016.0001) recovered from Skutz Falls outside the range of reported localities, (suggested to be from a possible refugium) (Miskelly 2012) was in cold storage, and not accessible at time of sampling.

We could not include mastodons (*Mammut* sp.), in our study, due to sampling access. Mastodons are worth mentioning as two reported teeth exist on Vancouver Island (Harington, 1975, Keddie 2016b[4]), and they are often discussed alongside mammoths given their ordinal relationship and general postcranial similarities (Hodgson et al. 2008, Olsen 1972). These two teeth provide the only published evidence of mastodons in BC, fitting with their relative rarity in western North America (Jass, Burns and Milot, 2011, Zazula et al., 2014, Dooley et al., 2019). A mastodon (*Mammut americanum*) tooth (RBCM.EH1994.003.0023) near Mill Bay was thought to date at least 200,000 years ago (The Daily Colonist 1949). This was speculation, as it is more likely the mastodon would be at most ~80,000-40,000 yrs BP, as the lower tills in the Cowichan Valley are thought to be of Dashwood Drift age (Fyles 1963), and the tooth could likely be younger, given mastodon post-glacial presence on the Olympic Peninsula (Peterson et al. 1983). In Courtenay, a water-rolled mastodon (*Mammut americanum*) molar (E183) (Harington 1975), was found in the Tsolum River whose eastern banks consist of Quadra Sand (Metherall 2019) laid down during the Fraser Glaciation but before the Vashon Stade (Clague 1976). The basal date of Quadra Sand in Comox is 28,000 ± 740 yr BP (GSC-95) (Alley 1979). Minimally both occurrences likely date before the local LGM, consistent with extirpation before the LGM, as is seen in Alberta (Jass, Burns and Milot, 2011)

Identification

Knowing the species of mammoth present on Vancouver Island in different time periods is important for understanding mammoth biodiversity, migration, and distribution in northwest North America. Vancouver Island potentially lies withing the geographic range of both Columbian (*Mammuthus columbi*) and woolly mammoths (*Mammuthus primigenius)*, as it is close to regions with these species, with woolly mammoths in the south and north of mainland BC, and Columbian mammoths in western Washington. Also, given the island's location, relative to both of these species' distributions, molars may exhibit morphological variation (Widga et al., 2017) as a result of hybridization (Enk et al., 2016; Mitchell and Rawlence, 2021). Isolated molars are generally difficult to assign to species due to incompleteness and damage (Smith and Graham, 2017), and age-related factors such as

[4] Keddie, G. (2016b) 'Mastodon Remains in the Royal B.C. Museum Collection. Manuscript on file at the Royal BC Museum, pp. 1–10.

dental wear (Louguet, 2006). As a consequence, osteometric measurements may not permit species identification (Maglio 1973, Haynes 1991, Agenbroad 1994, Saunders et al., 2010)

Taxonomic designations for Vancouver Island mammoths have changed in the literature, with increasingly conservative attributions over time, (Sternberg 1930, McTaggart-Cowan 1941, Harington, Tipper and Mott, 1974; Harington, 1975; Harington and Shackleton, 1978). Now, most are recorded in the online RBCM catalogue as simply *Mammuthus* sp. It may be noted, however, that the original species attribution for these teeth may be more accurate, as they were based on teeth as they first appeared upon discovery, compared to their appearance today, because many have delaminated and degraded over time.

For these reasons, biomolecular analysis can be used for species determination (Heintzman et al., 2016; van der Valk et al., 2021). All dated samples (except S-SFU 2125 and S-SFU 2126) were sent for DNA analysis at the Centre for Palaeogenetics at Stockholm University, however none retained sufficient endogenous DNA for species attribution. Peptide mass fingerprinting of bone collagen (also known as ZooMS or 'zooarchaeology by mass spectrometry') is an alternative taxonomic identification method when DNA is not sufficiently preserved (Buckley et al., 2009, Welker et al., 2015). While collagen tends to preserve more readily in paleontological contexts, the taxonomic precision afforded by ZooMS is lower than genetic analysis, typically to the genus or family level (Buckley and Collins, 2011; Buckley, Larkin and Collins, 2011). We applied ZooMS in this study to confirm the taxonomic identifications for two postcranial elements in our dataset.

ZooMS

Differentiating between incomplete and damaged mammoth and mastodon elements can be difficult (Olsen 1972). For this reason, ZooMS was applied to three postcranial unidentified elements and one tusk to confirm the taxonomic attributions. These specimens included a long bone (RBCM.EH2008.003.0001, S-SFU 1684) from Island View Beach, a locality known to contain other Pleistocene vertebrate species (Steffen and Harington 2010). The original taxon designation of mammoth was trusted, given the rarity of mastodons, but the analysis was undertaken for biomolecular confirmation of species, as Victoria lies less than 100km from the Manis Mastodon site to the south in Washington State (Waters et al., 2011). An additional postcranial element was also analyzed, as it was originally accessioned as a cetacean scapula (RBCM.EH2016.012.0028, S-SFU 2308), though found in the Cordova Bay McIntyre & Harding Gravel Pit, a locality known to contain mammoth remains. A long bone (RBCM.EH1994.003.0018, S-SFU 1662) and a tusk (RBCM.EH2006.012.0010, S-SFU 2251) were also sampled.

Collagen extraction and purification took place at the Ancient DNA and Proteins (ADαPT) Facility at UBC followed the Buckley et al.,(2009) protocol, modified as in Rodrigues et al., (2018). Briefly, collagen was gelatinsed for 1 hour at 65°C in 100 µl of 50mM ammonium bicarbonate solution (NH4HCO3) pH 8.0; 50 µl of collagen was then digested with 0.4 µg of trypsin through overnight incubation at 37°C. The collagen was acidified and purified with 100 µL C18 resin ZipTip® pipette tips (EMD Millipore). The purified collagen was spotted in triplicate, along with calibration standards, and analyzed via matrix-assisted-laser desorption/ionisation time-of-flight mass spectrometry (MALDI-ToF-MS) on a Bruker ultraflex III MALDI TOF/TOF mass spectrometer with a Nd:YAG smart beam laser University of York, UK. Triplicate spectra were averaged and visually analyzed using mMass software (Strohalm et al., 2008) and taxonomic identifications were based on comparison with previously published diagnostic peaks (Buckley et al., 2009, Buckley and Collins, 2011, Buckley, Larkin and Collins, 2011).

Radiocarbon dating
Samples determined to contain sufficient collagen and a C/N value within the accepted range of 2.9-3.6 (DeNiro 1985), were sent to the Oxford Radiocarbon Accelerator Unit (ORAU). The dates in Table 2 were calibrated in Calib 8.2 using IntCal20 (Reimer et al., 2020). Collagen pre-screening was performed at the SFU Archaeology Isotope Laboratory, where collagen extraction followed methods outlined in Richards and Hedges (1999) with the inclusion of an ultrafiltration step (Brown et al., 1988). Isotope measurements of the bone collagen are on-going and will be reported elsewhere. Two samples reported below were dated prior to this study, and were not dated at ORAU. Bone (RBCM.EH1994.003.0040) was pretreated with 3N HCI, O.IN NaOH and distilled H_2O rinses, before being dated by beta-counting (GSC 2829) (Blake 1982). A molar (RBCM.EH1994.003.0012) sample sent to Beta Analytic for dating underwent their standard acid/alkali pretreatment that did not involve the use of ultrafiltration.

Results
Of the thirty-two mammoth remains sampled, sixteen were directly radiocarbon dated (Table 2). Poor preservation of sixteen of the remains meant radiocarbon dating was not possible, where collagen was not preserved, or poorly preserved (through measurements of the collagen C:N ratio). Poor collagen preservation was especially notable in tusk remains, and none were successfully dated. Best preserved are bone elements, with four out of six successfully radiocarbon dated. Molars had a 60% success rate, with twelve of the twenty radiocarbon dated. The teeth appear to be degrading rapidly in museum storage, with visible delamination on many and a loss of collagen noted over the span of only a few years (Beta-366537, S-SFU 252) on one molar (RBCM.EH1994.003.0012). Time elapsed since discovery and removal from protective matrix may also factor into collagen extraction success. For example, the earliest donations are of teeth from James Island which lack adequate collagen preservation. In other cases (RBCM.EH1994.003.017, RBCM.EH1994.018.001) it may be that they are semi-mineralized and are derived from much older deposits.

ZooMS analysis confirmed the identifications of mammoth for the analyzed samples, displaying diagnostic collagen peaks (α2 978=1145; α2 484=1453; α2 502=1579; α2 793=2115; α2 454=2808; α1 586= 2853; α2 757= 2999) indicative of elephantids, but ruling out mastodon.

Accession	S-SFU	Material	C/N	δ13C	^{14}C lab code	^{14}C yr BP	Calibrated age range (cal BP, ± 2 σ)	Median calibrated age (cal BP)
RBCM.EH1994.003.0019	1663	dentin	3.37	-21.44	OxA-39974	>47,500		
RBCM.EH1994.003.0013	1660	dentin	3.26	-21.41	OxA-40018	>46,900		
RBCM.EH1994.003.0034	1673	dentin	3.28	-20.84	OxA-39981	38,440 ± 960	43,873-43,535 (3.0%)	42,441
							43,500-41,274 (97.0%)	
RBCM.EH1999.005.0001	1679	dentin	3.24	-20.28	OxA-39983	28,440 ± 280	33,503-31,783 (100%)	32,603
RBCM.EH1994.003.0027	1668	dentin	3.40	-20.37	OxA-41642	27,520 ± 270	31,951-31,103 (100%)	31,481
RBCM.EH2008.008.0002	1685	bone	3.19	-21.65	OxA-39987	26,310 ± 220	31,006-30,127 (100%)	30,574
CDM 992.169.1, E4	2126	dentin	3.26	-21.09	OxA-41641	24,770 ± 180	29,294-28,618 (100%)	28,991
RBCM.EH1994.003.0020	1664	dentin	3.35	-20.58	OxA-39975	24,270 ± 190	28,869-27,881 (100%)	28,477
RBCM.EH1994.003.0036	1674	bone	3.21	-21.12	OxA-39982	22,620 ± 140	27,235-26,807 (68.5%)	26,968
							26,782-26,457 (31.5%)	
RBCM.EH2005.007.0001	1681	dentin	3.23	-20.46	OxA-39984	22,600 ± 140	27,218-26,802 (65.2%)	26,942
							26,794-26,459 (34.8%)	
RBCM.EH1994.003.0029, No. 299	1669	dentin	3.30	-19.99	OxA-39978	22,320 ± 130	27,059-26,310 (100%)	26,685
RBCM.EH2008.003.0001	1684	bone	3.19	-20.94	OxA-39986	22,280 ± 130	27,016-26,262 (97.5%)	26,648
							26,211-26,116 (2.5%)	
RBCM.EH1994.009.0001	1687	dentin	3.22	-20.40	OxA-39988	22,150 ± 130	26,897-26,600 (23.9%)	26,371
							26,544-25,987 (71.6%)	
RBCM.EH1994.003.0026	1667	dentin	3.52	-19.62	OxA-39977	19,680 ± 100	23,884-23,667 (48.2%)	23,606
							23,632-23,343 (51.8%)	
RBCM.EH1994.003.0024	1666	dentin	3.25	-20.14	OxA-39976	19,537 ± 99	23,795-23,227 (100%)	23,513
RBCM.EH1994.003.0012		tooth		-19.70	Beta-366537	18,080 ± 70	22,219-21,838 (100%)	22,035
RBCM.EH1994.003.0040	2125	bone	3.27	-20.80	OxA-41640	17,696 ± 76	21,085-21,790 (100%)	21,439
RBCM.EH1994.003.0040		bone		-21.80	GSC 2829	17,000 ± 240	21,108-19,887 (100%)	20,535

Table 2. Radiocarbon results. All OxA lab codes are new dates from this study, as these are paired with a S-SFU lab number from the SFU Archaeology Isotope Lab. For the new dates, the C/N was measured at SFU, and the δ^{13}C was measured and reported by OxA. The Beta date was submitted by Richard Hebda, and the GSC date was submitted by Grant Keddie (Keddie 1979). The percentages in parentheses indicate the relative area under probability distribution (Reimer et al. 2020).

Port Alberni

The Mount Hakin molar (RBCM.EH1994.003.0019, S-SFU-1663) has a non-finite date of >47,500 ka (Table 2). This date is older than the age of the previously identified Vashon Till in which the molar is thought to have been found. Fyles (1963) was cautious at presuming all tills in Port Alberni area were of Vashon age, owing to the uncertainty of disentangling till sources from converging glacial ice of different origins. He noted similarity in flow angle of the Port Alberni possible Vashon Till to the older Dashwood Drift. Assuming the tooth is not reworked form older deposit, it is likely of Dashwood Drift age, or older. This date indicates that mammoths lived on Vancouver Island long before the Fraser Glaciation and that there might be at least two tills of differing ages in the Port Alberni region.

East of Port Alberni, and south of Courtenay, are commercial gravel quarries of Qualicum Beach, where the Dashwood Drift tills underlie Quadra Sediments (Fyles 1963), and the remains of at least one mammoth are reported by the public, with more from the area likely residing in private collections (Graham Beard pers comm.). The stratigraphic position of these remains is unknown, but their remains here illustrate the occurrence of mammoths in the region.

Courtenay

The new date of 24,770 ± 180 ^{14}C yr BP on the Browns River molar (CDM 992.169.1, S-SFU 2126) places it firmly outside of the age of nearby Capilano sediment aquifers, and within the early to middle Fraser Glaciation (Hebda, Lian and Hicock 2016). Given its worn appearance and the unconsolidated glacial, glacifluvial and glaciomarine sediments which cover the immediate region (Cathyl-Bickford 2001), the tooth may have eroded from nearby Quadra Sands. The date is consistent with ages for pro-glacial lake sediments in the Point Homes bluffs in Comox, and for an upper layer of Quadra Sands in the Balmoral bluffs, where there are seeds, cones, and beaver chewed sticks.

Victoria

Notably, the oldest date from Island View Beach is 38,440 ± 960 ^{14}C yr BP, during the middle of the Olympia nonglacial interval. Climate at this time was sufficiently warm to be consistent with the expectations for Columbian mammoths being present on Vancouver Island (Harington 1975). The regional vegetation was wooded (Hebda, Lian and Hicock. 2016) another indication of conditions suitable for Columbian Mammoths. However, the lamellar frequency of this tooth (RBCM.EH1994.003.0034, S-SFU 1673) of 8 lophs/10 cm and an average enamel thickness of 1.67 mm, are in ranges appropriate for woolly mammoth. Further, these measurements are on an incomplete and damaged tooth, so the lamellar frequency could be a minimum.

Five of the six remains from Island View Beach reveal that most of the mammal remains from this exposure are from the latest part of the Olympia nonglacial interval and the early part of the Fraser Glaciation (~35,000-22,000 years ago) (Hebda, Lian and Hicock, 2016). They eroded out from a ~7m layer of fine silt and gravel that is constrained by Vashon Drift on top and underlying marine, glaciomarine, glaciolacustrine, and glacial fluvial Dashwood Drift sediments below (Clague and Luternauer 1983), with a basal layer inferred to date ~90,000 years ago (Hebda and Johns n.d.[5]).

Four remains cluster around 22,000 ^{14}C yr BP (from 22,600 ± 140 to 22,150 ± 130 BP), and their ages align closely to the date of a giant short-faced bear (*Arctodus simus*) from this locality at 22,750 ± 140 BP (UCIAMS-56480) (Steffen and Harington, 2010). These occur during the coldest and driest portion of the Fraser glaciation (Miskelly, 2012, Hebda, Lian and Hicock, 2016). Considering the abundance of remains, mammoths may have been widespread in the region at this time, just prior to their local extinction.

There is a clustering of dates on Vancouver Island around 22,000 yr BP. This trend is repeated in the Puget Lowland, where most mammoths date 22,000-20,000 14C yr BP, including two Columbian mammoth remains from nearby western Washington (Barton 1999). This 22,000 yr BP cutoff is also present in Alberta, however there, mammoths reappear at ~11,000 yr BP (Jass and Barrón-Ortiz 2017),

A Cordova Bay specimen from the McIntyre & Harding gravel pit (RBCM.EH1994.003.0027, S-SFU 1668) was assessed to derive from Saanichton gravel (Keddie 1995), and a date of 19,680 ± 100 BP (RBCM.EH1994.003.0026, S-SFU 1667) from the same site agrees with the inferred age of the strata in which RBCM.EH1994.003.0027, S-SFU 1668 was found. A similar date of 19,537 ± 99 BP (RBCM.EH1994.003.0024, S-SFU 1666) from the Trio-Ready Mix gravel pit would originate from the same Saanichton strata. No other undated remains have further stratigraphic information, so cannot be placed in relation to the dated remains.

The youngest mammoths on Vancouver Island are less than 19,000 radiocarbon years old. A mammoth tooth (RBCM.EH1994.003.0012) from the Royal Bay gravel quarry in the Colwood delta has a date of 18,080 ± 70 ^{14}C (Beta-366537). An additional date from an outer

[5] Hebda, R. Johns, M. n.d. Ice Age Fossils at Cowichan Head, Island View Beach, Saanich Peninsula, Vancouver Island. On file at the Royal BC Museum, pp 1-2.

fragment of this Colwood molar was attempted but had insufficient collagen preservation (S-SFU 252). The Colwood gravel mammoth date is significant stratigraphically because although the molar is rolled no Vashon Till overlies the gravels (Mate and Levson, 2001). A humerus (RBCM.EH1994.003.0040) from basal Saanichton gravel deposits in the Trio-Ready Mix Gravel Pit, 17,000 ± 240 BP (GSC 2829) (Keddie, 1979, Blake 1982,) was successfully redated (S-SFU 2125) with a very similar date of 17,696 ± 76 BP. A tusk (RBCM.EH1994.003.0039, S-SFU 1675) was found in the same layer and would presumably be of the same age. These late dates are in line with the proposed extirpation of mammoths in the Puget Lowland by 17,000-15,000 yr BP as Vashon Stade ice advanced to its southern limit (Barton 1999).

Conclusions

We have reported the analysis and direct radiocarbon dating of mammoths from the Late Pleistocene on Vancouver Island, Southwest British Columbia, Canada. The region is important for understanding glacial dynamics and limits at the end of the Pleistocene and we argue that the presence of mammoth remains indicates unglaciated periods and regions.

The dates and occurrences of fossils place mammoths on Vancouver Island prior to the onset of, and throughout most of the Fraser glaciation. The molar from Port Alberni indicates populations on Vancouver Island and mammoth inferred migration long before connection to the BC mainland and continental North America. It is likely that there were several mammoth populations and migrations onto the island.

We found a number of specimens older than the radiocarbon method can measure (i.e. >45,000 BP), a cluster around 35,000 BP, corresponding to the Olympia nonglacial interval, many remains from the coldest part of the Fraser Glaciation and surprisingly two dates at around 18,000 BP. One of these was not overlain by Vashon till. The relatively recent mammoth ages, their stratigraphic and geographic locations indicate that the region was widely habitable by large mammals and may have been supported and provided migration pathways for other mammal species during the late Pleistocene. Additional genetic investigations and radiocarbon dating may reveal the history of mammoths and its relationship to glacial history in this biogeographically critical region.

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Competing interests statement

The authors declare there are no competing interests.

Author contribution statement

L. Termes: Investigation, Writing - original draft, Writing – review & editing. G. Keddie: Conceptualization, Methodology, Resources, Writing – review & editing. R. Hebda:

Resources, Writing - original draft, Writing – review & editing. P. Trask: Resources, Writing – review & editing. Arbour: Resources, Writing – review & editing. C. Speller: Resources, Writing – review & editing. L. Paskulin: Resources, Validation. C. Ramsey: Resources. M. Richards: Conceptualization, Methodology, Funding acquisition, Supervision, Project administration, Writing - original draft, Writing – review & editing.

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Data availability statement
Data generated or analyzed during this study are available from the corresponding author upon reasonable request. All fossils analyzed in this study are permanently reposited at either the Courtenay and District Museum or the Royal BC Museum.

References

Agenbroad, L.D., (1994) Taxonomy of North American *Mammuthus* and biometrics of the Hot Springs mammoths. In: Agenbroad, L.D., Mead, J.I. (Eds.), *The Hot Springs Mammoth Site: A Decade of Field and Laboratory Research in Paleontology, Geology, and Paleoecology*. The Mammoth Site of Hot Springs, South Dakota, Inc., Hot Springs, pp. 158-207.

Al-Suwaidi, M. *et al.* (2006) 'Late Wisconsinan Port Eliza Cave deposits and their implications for human coastal migration, Vancouver Island, Canada', *Geoarchaeology*, 21(4), pp. 307–332. Available at: https://doi.org/10.1002/gea.20106.

Alley, N.F. (1979) 'Middle Wisconsin stratigraphy and climatic reconstruction, southern Vancouver Island, British Columbia', *Quaternary Research*, 11(2), pp. 213–237. Available at: https://doi.org/10.1016/0033-5894(79)90005-X.

Barton, B. (1999) 'Some Notable Finds of Columbian Mammoths from Washington State', *Washington Geology*, 27(2/3/4), pp. 23–27.

Bednarski, J.M. (2015). Surficial Geology and Pleistocene stratigraphy from Deep Bay to Nanoose Harbour, Vancouver Island, British Columbia. *Geological Survey of Canada*, Open File 7681.

Blake, W.J. (1982) Geological Survey of Canada radiocarbon dates XXII. *Geological Survey of Canada, Paper 82-7.*

Blyth, H.E and N.W. Rutter 1992 'Quaternary Geology of Southeastern Vancouver Island and Gulf Islands (92B/5, 6, 11, 12, 13 and 14)'. Pp: 407-414. *Geological Fieldwork 1992 A Summary of Field Activities and Current Research*, Paper 1993-1. Editors: B. Grant and J.M. Newell. Mineral Resources Division, Geological Survey Branch, Victoria, B.C.

Brown, T.A. *et al.* (1988) 'Improved Collagen Extraction by Modified Longin Method', *Radiocarbon*, 30(2), pp. 171–177. Available at: https://doi.org/10.1017/s0033822200044118.

Buckley, M. *et al.* (2009) 'Species identification by analysis of bone collagen using matrix-assisted laser desorption/ionisation time-of-flight mass spectrometry', *Rapid Communications in Mass Spectrometry*, 23(23), pp. 3843–3854. Available at: https://doi.org/10.1002/rcm.4316.

Buckley, M. and Collins, M.J. (2011) 'Collagen survival and its use for species identification in Holocene-lower Pleistocene bone fragments from British archaeological and paleontological sites', *Antiqua*, 1(1), p. 1. Available at: https://doi.org/10.4081/antiqua.2011.e1.

Buckley, M., Larkin, N. and Collins, M. (2011) 'Mammoth and Mastodon collagen sequences; survival and utility', *Geochimica et Cosmochimica Acta*, 75(7), pp. 2007–2016. Available at: https://doi.org/10.1016/j.gca.2011.01.022.

Burns, J.A., Baker, C.G. and Mol, D. (2003) ‘An extraordinary woolly mammoth molar from Alberta, Canada’, *Deinsea*, 9, pp. 77–85.
Carl, George Clifford (1950) *Provincial Museum of Natural History and Anthropology Report for the year 1949*. Don McDiarmid printer, Victoria, BC.
Carl, George Clifford (1951) *Provincial Museum of Natural History and Anthropology Report for the year 1950*. Don McDiarmid printer, Victoria, BC.
Cathyl-Bickford, C. (2001) ‘Lithostratigraphy of the Comox and Trent River Formations in the Comox Coalfield, Vancouver Island (92F/7, 10, 11, 14)’, *BC Ministry of Energy and Mines*, pp.363–370.
Cathyl-Bickford, C.G. (2001) *Lithostratigraphy of the Comox and Trent River Formations in the Comox Coalfield, Vancouver Island (92F/7, 10, 11, 14)*. British Columbia Geological Survey.
Churcher, C.S. (1972) ‘Imperial Mammoth and Mexican Half-Ass from near Bindloss, Alberta’, *Canadian Journal of Earth Sciences*, 1562(9), pp. 1562–1567. Available at: https://doi.org/10.1139/e72-138
Churcher, C. S. and Wilson. M. (1990). Quaternary mammals from the eastern Peace River District, Alberta. *Journal of Paleontology*, 53: 71-76
Clague, J. J. (1976) ‘Quadra Sand and Its Relation To the Late Wisconsin Glaciation of Southwest British Columbia.’, *Can J Earth Sci*, 13(6), pp. 803–815. Available at: https://doi.org/10.1139/e76-083.
Clague, J.J. (1977) ‘Quadra Sand: A study of the late Pleistocene geology and geomorphic history of coastal southwest British Columbia’, *Geological Survey of Canada Paper*, 77–17, pp. 1–24.
Clague, J. J. (1980) Late Quaternary geology and geochronology of British Columbia, Part 1: Radiocarbon dates. *Geological Survey of Canada*, Paper 80-13.
https://doi.org/10.4095/106640
Clague, J.J. and James, T.S. (2002) ‘History and isostatic effects of the last ice sheet in southern British Columbia’, *Quaternary Science Reviews*, 21(1–3), pp. 71–87. Available at: https://doi.org/10.1016/S0277-3791(01)00070-1.
Clague, J.J., and Luternauer, JL. (1983) *Late Quaternary Geology of Southwestern British Columbia.* Geological Association of Canada, Victoria Section, 1983.
Clague, J.J. and Ward, B. (2011) ‘Pleistocene Glaciation of British Columbia’, in *Developments in Quaternary Science*. 1st edn. Elsevier Inc., pp. 563–573. Available at: https://doi.org/10.1016/B978-0-444-53447-7.00044-1.
Clapp, Charles (1912) Southern Vancouver Island. *Canada Department of Mines*, Memoir No.13. Ottawa, Government Printing Bureau
DeNiro, M.J. (1985) ‘Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to paiaeodietary reconstruction’, *Nature*, 317, pp. 806–809. Available at: https://www.nature.com/articles/317806a0.
Dooley, AC, Jr., Scott, E. Jeremy Green, J., Springer, KB., Dooley, BS., Smith, GJ. (2019) *Mammut pacificus* sp. nov., a newly recognized species of mastodon from the Pleistocene of western North America. Peer J 7:e6614, https://doi.org/10.7717/peerj.6614
Dyke, A.S. and Prest, V.K. (1987) ‘Paleogeography of northern North America, 18,000-5,000 years ago’, *Geological Survey of Canada, ‘A’ Series Map*, 1705A(January 1987), pp. 3 sheets, scale 1:12,500,000. Available at: https://doi.org/10.4095/133927.
Enk, J. *et al.* (2016) ‘Mammuthus Population Dynamics in Late Pleistocene North America: Divergence, Phylogeography, and Introgression’, *Frontiers in Ecology and Evolution*, 4, pp. 1–13. Available at: https://doi.org/10.3389/fevo.2016.00042.
Fender, W.M. and Marshall, V.G. (1994) ‘North American earthworms native to Vancouver Island and the Olympic Peninsula’, *Canadian Journal of Zoology*, 72, pp. 1325–1339.

Fyles, J.G. (1963) *Surficial Geology of Horne Lake and Parksville Map-Areas, Vancouver Island, British Columbia*. Memoir 318. Department of Mines and Technical Surveys Canada.
Gilmour, D.M. *et al.* (2015) 'Chronology and ecology of late Pleistocene megafauna in the northern Willamette Valley, Oregon', *Quaternary Research (United States)*, 83(1), pp. 127–136.
Halstead, E.C. (1968) 'The Cowichan Ice tongue, Vancouver Island', *Canadian Journal of Earth Sciences*, 5(6), pp. 1409–1415. Available at: https://doi.org/10.1139/e68-140.
Harington, C.R. (1975) 'Pleistocene Muskoxen (*Symbos*) from Alberta and British Columbia', *Canadian Journal of Earth Sciences*, 12(6), pp. 903–919. Available at: https://doi.org/10.1139/e75-083.
Harington, C.R. and Clulow, F. V. (1973) 'Pleistocene mammals from Gold Run Creek, Yukon Territory', *Canadian Journal of Earth Sciences*, 10(5), pp. 697–759. Available at: https://doi.org/10.1139/e73-069.
Harington, C. R. (1978) Quaternary Vertebrate Faunas of Canada and Alaska and Their Suggested Chronological Sequences. *Syllogeus*, No. 15. National Museums of Canada.
Harington, C.R. and Shackleton, D.M. (1978) 'A tooth of Mammuthus primigenius from Chestermere Lake near Calgary, Alberta, and the distribution of mammoths in southwestern Canada', *Canadian Journal of Earth Sciences*, 15(8), pp. 1272–1283. Available at: https://doi.org/10.1139/e78-134.
Harington, C.R., Tipper, H.W. and Mott, R.J. (1974) 'Mammoth from Babine Lake, British Columbia', *Canadian Journal of Earth Sciences*, 11, pp. 285–303. Available at: https://doi.org/10.1139/e74-025
Hay OP. (1923) *The Pleistocene of North America and Its Vertebrated Animals Form the States East of the Mississippi River and Form the Canadian Provinces East of Longitude 95* . Washington, D.C.: Carnegie Institution of Washington
Haynes, G. (1991) Mammoths, Mastodonts and Elephants: Biology, Behavior, and the Fossil Record. Cambridge University Press.
Hebda, C.F.G. *et al.* (2022) 'Late Pleistocene palaeoenvironments and a possible glacial refugium on northern Vancouver Island, Canada: Evidence for the viability of early human settlement on the northwest coast of North America', *Quaternary Science Reviews*, 279, p. 107388. Available at: https://doi.org/10.1016/j.quascirev.2022.107388.
Hebda, R.J., and Cockburn, T. (2014). Field Trip Guide Cowichan Head Pleistocene Deposits and Fossils. *Tenth British Columbia Paleontology Symposium*, Victoria, May 9-12, 2014, 18 pp.
Hebda, R.J., and Haggarty, JC. . (1997). Brooks Peninsula: an Ice Age refugium on Vancouver Island Ministry of Environment, Lands and Parks and BC Parks, Victoria, B.C. Occasional Paper .
Hebda, R.J., Lian, O.B. and Hicock, S.R. (2016) 'Olympia interstadial: Vegetation, landscape history, and paleoclimatic implications of a mid-wisconsinan (MIS3) nonglacial sequence from southwest british columbia, canada', *Canadian Journal of Earth Sciences*, 53(3), pp. 304–320. Available at : https://doi.org/10.1139/cjes-2015-0122.
Heintzman, P.D. *et al.* (2016) 'Bison phylogeography constrains dispersal and viability of the Ice Free Corridor in western Canada', *Proceedings of the National Academy of Sciences*, 113(29), pp. 8057–8063. Available at: https://doi.org/10.1073/pnas.1601077113.
Hicock, S.R. and Armstrong, J.E. (1985) 'Vashon Drift: definition of the formation in the Georgia Depression, southwest British Columbia.', *Canadian Journal of Earth Sciences*, 22(5), pp. 748–757. Available at: https://doi.org/10.1139/e85-079.
Hicock, S.R., Hebda, R.J. and Armstrong, J.E. (1982) 'Lag of the Fraser glacial maximum in the Pacific Northwest: pollen and macrofossil evidence from western Fraser Lowland, British Columbia', *Canadian Journal of Earth Sciences*, 19(12), pp. 2288–2296. Available at:

https://doi.org/10.1139/e82-201.
Hicock, S.R., Hobson, K. and Armstrong, J.E. (1982) 'Late Pleistocene proboscideans and early Fraser glacial sedimentation in eastern Fraser Lowland, British Columbia', *Canadian Journal of Earth Sciences*, 19, pp. 899–906. Available at: https://doi.org/10.1139/e82-075.
Higley, W.K. (1886) A Paper on *Mammuthus Primigenius*. *Bulletin of the Chicago Academy of Science*, Vol 1(10):123-127, Chicago.
Hodgson, J. A., W. D. Allmon, J. M. Sherpa, and P. L. Nester. 2008. Geology and taphonomy of the North Java mastodon site, Wyoming County, New York. Pp 385-415, in: *Mastodon Paleobiology, Taphonomy, and Paleoenvironment in the Late Pleistocene of New York State:* Studies on the Hyde Park, Chemung, and North Java Sites, W. D. Allmon & P. L. Nester (eds), Palaeontographica Americana 61
Holland, S. (1964) Landforms of British Columbia, A Physiographic outline. British Columbia *Department of Mines and Petroleum Resources.* Bulletin No 48. A. Sutton Printer, BC
Jackson, L.E. and Clague, J.J. (2012) 'The Cordilleran Ice Sheet: One Hundred and Fifty Years of Exploration and Discovery L'Inlandsis de la Cordillère : cent cinquante ans d'exploration et de découvertes Die Kordilleren-Eisdecke: 150 Jahre Erforschung und Entdeckung', *Géographie physique et Quaternaire*, 45(3), p. 269. Available at: https://doi.org/10.7202/032874ar.
Jass, C.N. and Barrón-Ortiz, C.I. (2017) 'A review of Quaternary proboscideans from Alberta, Canada', *Quaternary International*, 443, pp. 88–104. Available at: https://doi.org/10.1016/j.quaint.2016.10.028.
Jass, C.N., Burns, J.A. and Milot, P.J. (2011) 'Description of fossil muskoxen and relative abundance of pleistocene megafauna in central Alberta', *Canadian Journal of Earth Sciences*, 48(5), pp. 793–800. Available at: https://doi.org/10.1139/e10-096.
Keddie, G. (1979) 'The Late Ice Age of Southern Vancouver Island', *The Midden Archaeological Society of British Columbia Publication*, 11(4), pp. 16–22.
Kermode, F. (1924) *Report of the Provincial Museum of Natural History for the year 1923*.
Kermode, F. (1926) *Report of the Provincial Museum of Natural History for the year 1925*. Victoria: Charles F. Banfield. Available at: http://www.biodiversitylibrary.org/item/123717.
Laws, R. M. (1966) Age criteria for the African elephant *Loxodonta a. africana*. *East African Wildlife Journal* 4:1-37.
Lesnek, A.J. *et al.* (2018) 'Deglaciation of the Pacific coastal corridor directly preceded the human colonization of the Americas', *Science Advances*, 4(5), p. eaar5040. Available at: https://doi.org/10.1126/sciadv.aar5040.
Lister, AM, Sher AV. (2015) Evolution and dispersal of mammoths across the Northern Hemisphere. *Science* 350:805-809. DOI:10.1126/science.aac5660.
Lister, A.M. (2017) 'On the type material and evolution of North American mammoths', *Quaternary International*, 443, pp. 14–31. Available at: https://doi.org/10.1016/j.quaint.2017.02.027.
Livingston, E. (1963) 'Surficial Geology Saanich, Additional Notes October, 1961', *Ministry of Environment*, pp. 1–4. Available at: https://doi.org/10.1109/PROC.1970.7880.
Louguet, S. (2006) Determining the age of death of proboscids and. rhinocerotids from dental attrition, Recent advances in ageing and sexing animal bones *Proceedings of the 9th Conference of the International Council for Archaeozoology, Durham, 2002*. Edited by D. Ruscillo.
Maglio, V.J. (1973) *Origin and Evolution of the Elephantidae*, *Transactions of the American Philosophical Society*. Available at: https://doi.org/10.1080/14786443908649806.
Mate, D. and Levson, V. (2001) 'Geology and Aggregate Production of the Colwood Delta', in *37th Annual Forum on Industrial Minerals Proceedings, Industrial Minerals with*

emphasis on Western North America. British Columbia Ministry of Energy and Mines, Geological Survey Branch, Victoria., pp. 107–112.
McTaggart-Cowan, Ian (1941) Fossil and Subfossil Mammals from the Quaternary of British Columbia. *Transactions of the Royal Society of Canada*, 3rd Series. 35 (Sect. 4):39-50.
Metcalfe, J.Z. *et al.* (2016) ‘Taxonomy, location of origin and health status of proboscideans from Western Canada investigated using stable isotope analysis’, *Journal of Quaternary Science*, 31(2), pp. 126–142. Available at: https://doi.org/10.1002/jqs.2849.
Metcalfe, J.Z. and Longstaffe, F.J. (2012) ‘Mammoth tooth enamel growth rates inferred from stable isotope analysis and histology’, *Quaternary Research*, 77(3), pp. 424–432. Available at: https://doi.org/10.1016/j.yqres.2012.02.002.
Metherall, C. (2019) *Tsolum River Agricultural Watershed Plan: Phase 1*. Prepared for Comox Valley Regional District.
Miskelly, K. (2012) *Vegetation and climate history of the Fraser Glaciation on southeastern Vancouver Island, British Columbia, Canada*. University of Victoria. Available at: https://dspace.library.uvic.ca/handle/1828/4343?show=full.
Mitchell, K.J. and Rawlence, N.J. (2021) ‘Examining Natural History through the Lens of Palaeogenomics’, *Trends in Ecology and Evolution*, 36(3), pp. 258–267. Available at: https://doi.org/10.1016/j.tree.2020.10.005.
Olsen, S. J. (1972) Osteology for the archaeologist: the American mastodon and the woolly mammoth. *Papers of the Peabody Museum of Archaeology and Ethnology,* Harvard University, Cambridge, 56(3): 1-47.
Pearson, A.(1981) *Sea-Lake: Recollections and History of Cordova Bay and Elk Lake*. Sea-Lake Editions, Victoria, B.C.
Petersen, K. L., Mehringer, P. J., & Gustafson, C. E. (1983) Late-glacial vegetation and climate at the Manis Mastodon site, Olympic Peninsula, Washington. Quaternary Research, 20(2), 215–231. https://doi.org/10.1016/0033-5894(83)90078-9.
Reimer, P.J. *et al.* (2020) ‘The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0-55 cal kBP)’, *Radiocarbon*, 62(4), pp. 725–757. Available at: https://doi.org/10.1017/RDC.2020.41.
Richards, M.P. and Hedges, R.E.M. (1999) ‘Stable isotope evidence for similarities in the types of marine foods used by late Mesolithic humans at sites along the Atlantic coast of Europe’, *Journal of Archaeological Science*, 26(6), pp. 717–722. Available at: https://doi.org/10.1006/jasc.1998.0387.
Rodrigues, A.S.L. *et al.* (2018) ‘Forgotten Mediterranean calving grounds of grey and North Atlantic right whales: evidence from Roman archaeological records’, in *Proceedings of the Royal Society B: Biological Sciences*. Available at: https://doi.org/10.1098/rspb.2018.0961.
Saunders, J.J. *et al.* (2010) ‘Paradigms and proboscideans in the southern Great Lakes region, USA’, *Quaternary International*, 217(1–2), pp. 175–187. Available at: https://doi.org/10.1016/j.quaint.2009.07.031
Sendra, A. and Wagnell, C. (2019) ‘The cave-dwelling dipluran (Diplura, Campodeidae) on the edge of the Last Glacial Maximum in Vancouver Island caves, North America (Canada)’, *Subterranean Biology*, 29, pp. 59–77. Available at: https://doi.org/10.3897/subtbiol.29.31467.
Smith, G.J. (2015) *Taxonomic and Ecologic Implications of Mammoth Molar Morphology as Measured via Computed Tomography*, *The Pennsylvania State University*. Available at: https://etda.libraries.psu.edu/files/final_submissions/11085.
Smith, G.J. and Graham, R.W. (2017) ‘The effects of dental wear on impairing mammoth taxonomy: A reappraisal of the Newton mammoth, Bradford County, northeastern Pennsylvania’, *Quaternary International*, 443, pp. 40–51. Available at: https://doi.org/10.1016/j.quaint.2017.01.030.
Steffen, M.L. and Harington, C.R. (2010) ‘Giant short-faced bear (Arctodus simus) from late

Wisconsinan deposits at Cowichan Head, Vancouver Island, British Columbia’, *Canadian Journal of Earth Sciences*, 47(8), pp. 1029–1036. Available at: https://doi.org/10.1139/E10-018.

Sternberg, C.M. (1930) New Records of Mastodons and Mammoths in Canada. *The Canadian Field Naturalist*. Vol 44 (3):59-65.

Sternberg, C.M. (1963) Additional Records of Mastodons and Mammoths in Canada. National Museum of Canada. *Natural History Papers,* (19):1-1. National Museum of Canada, Queen's Printer, Ottawa.

Stevenson, J. (1945) *Geology and Ore Deposits of the China Creek Area, Vancouver Island, British Columbia*, *British Columbia Department of Mines Bulletin 20*.

Strohalm, M. *et al.* (2008) ‘mMass data miner: An open source alternative for mass spectrometric data analysis’, *Rapid Communications in Mass Spectrometry*, pp. 905–908. Available at: https://doi.org/10.1002/rcm.3444.

The Daily Colonist (1949) *Ancient Mammal’s Tooth Discovery of Island Man*. Friday February 25, pg. 10.

The Daily Colonist (1960) *Prehistoric Mammoths Left Evidence on Island.* Sunday December 11, pg 17.

Ukkonen, P. *et al.* (1999) ‘New radiocarbon dates from Finnish mammoths indicating large ice-free areas in Fennoscandia during the Middle Weichselian’, *Journal of Quaternary Science*, 14(7), pp. 711–714. Available at: https://doi.org/10.1002/(SICI)1099-1417(199912)14:7<711::AID-JQS506>3.0.CO;2-E.

van der Valk, T. *et al.* (2021) ‘Million-year-old DNA sheds light on the genomic history of mammoths’, *Nature*, 591(7849), pp. 265–269. Available at: https://doi.org/10.1038/s41586-021-03224-9.

Ward, B.C. *et al.* (2003) ‘Port Eliza cave: North American West Coast interstadial environment and implications for human migrations’, *Quaternary Science Reviews*, 22(14), pp. 1383–1388. Available at: https://doi.org/10.1016/S0277-3791(03)00092-1.

Waters, M.R. *et al.* (2011) ‘Pre-Clovis mastodon hunting 13,800 years ago at the Manis site, Washington’, *Science*, 334(6054), pp. 351–353. Available at: https://doi.org/10.1126/science.1207663.

Welker, F. *et al.* (2015) ‘Ancient proteins resolve the evolutionary history of Darwin’s South American ungulates’, *Nature*, 522(7554), pp. 81–84. Available at: https://doi.org/10.1038/nature14249.

Widga, C. *et al.* (2017) ‘Late Pleistocene proboscidean population dynamics in the North American Midcontinent’, *Boreas*, 46(4), pp. 772–782. Available at: https://doi.org/10.1111/bor.12235.

Zazula, G.D. *et al.* (2003) ‘Plants, bugs, and a giant mammoth tusk: Paleoecology of Last Chance Creek, Yukon Territory’, *Yukon Exploration and Geology 2002*, pp. 251–258.

Zazula, G.D. *et al.* (2014) ‘American mastodon extirpation in the Arctic and Subarctic predates human colonization and terminal Pleistocene climate change’, *Proceedings of the National Academy of Sciences*, 111(52), pp. 18460–18465. Available at: https://doi.org/10.1073/pnas.1416072111.