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Supplementary Information for

11,500 Years of Human-Clam Relationships Provide Long-term Context for Intertidal Management in the Salish Sea, British Columbia

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Supplementary text
Figs. S1 to S2
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Caption for Dataset S1

Other supplementary materials for this manuscript include the following:

Dataset S1 Master data spreadsheet

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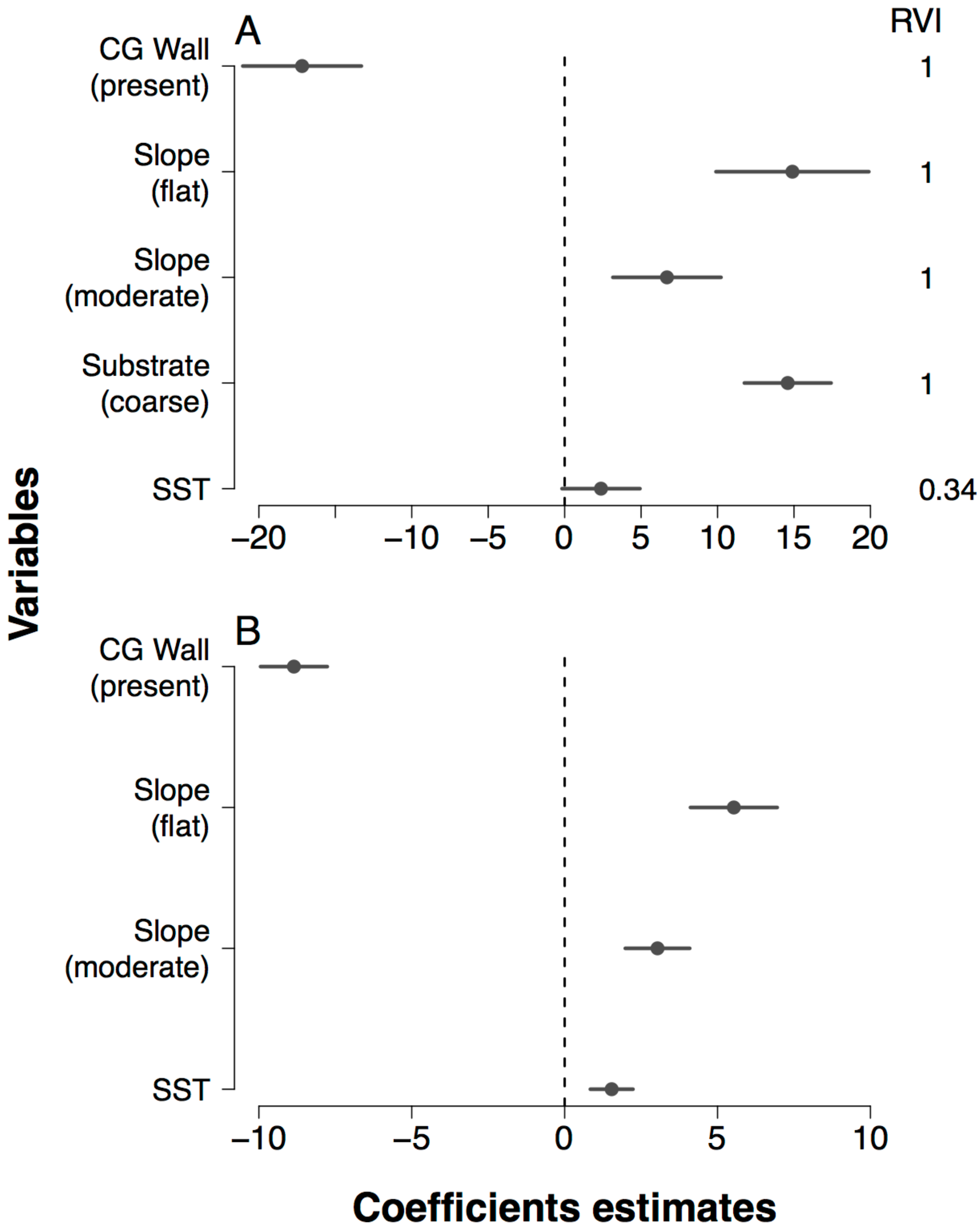

Fig. S1. Model average coefficient estimates and standard error with RVI for a. Size at Death b. Age at Death. Note the absence of RVI in B as there was one clear top model so no model averaging was done. CG Wall indicates that a clam garden wall is present, SST indicates sea surface temperature.

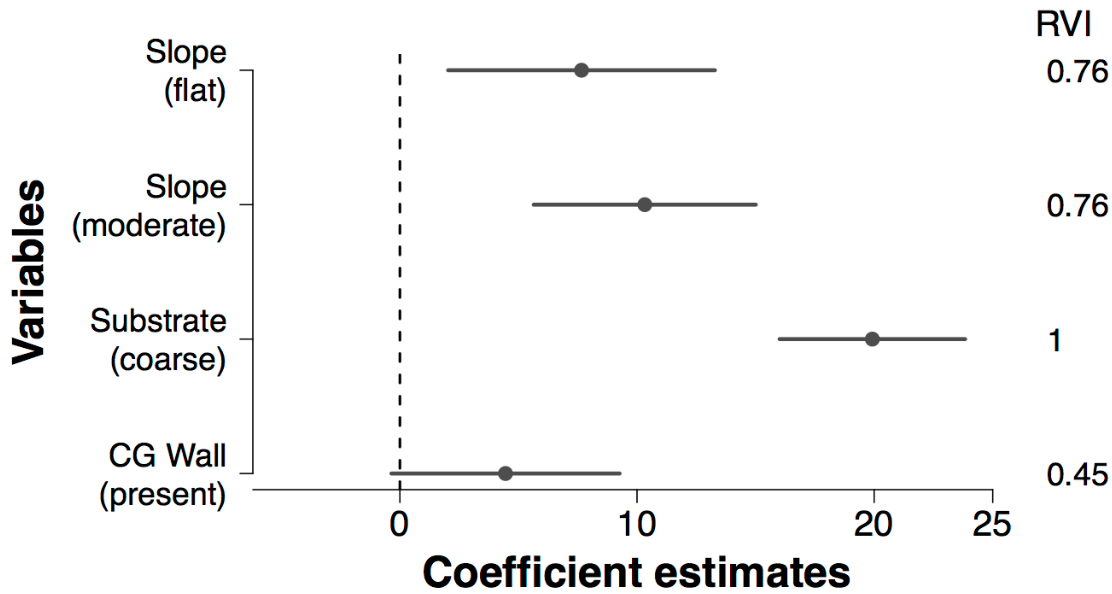

Fig. S2. Model average coefficient estimates and standard error with RVI for L_∞ values. Model forced through zero. CG Wall indicates that a clam garden wall is present.

Table S1. Predicted effects of environmental and cultural parameters on butter clam growth

Attribute	Predicted Effect on Growth	How Evaluated	Rationale and Mechanisms Affecting Clam Growth
Environmental			
Substrate (coarse, fine)	Increased growth with coarse sediments (gravel-sand, and shell-hash-sand)	Field observations	Predominance of fine clay and silt substrate decreases survival [1], likely due to anoxic conditions. Coarse sand, shell, gravel and esp. shell-hash improve growth and survival [2-5]; medium grain size sediment is beneficial to metabolism [6].
Beach Slope (Steep, Moderate, Flat)	Increased growth with flatter slopes	Field observations	Shallow slopes = lower energy environments, yet higher than muddy beaches, creating clear and shallow water column, heightened phytoplankton production, and longer duration of submerged siphoning of phytoplankton by clams.
Sea Surface Temperature (SST) (°C)	Decreased growth with extreme high or low temperatures	Published literature (Kienast and McKay 2001)	Warm waters increase metabolism and phytoplankton production. Stable warm water temperatures between 8.98 - 11.85°C enhance *S. gigantea* growth [7-10]. Extreme cold temperatures/freeze events can cause mass mortalities [11].
Cultural			
Human Interaction (High, Moderate, Low) *	Increased growth in beaches with more interaction, but moderate harvests †	Proximity to archaeological settlement	Many human actions can increase productivity, including harvesting and especially with harvest restrictions on clam numbers and sizes (by decreasing compensatory density dependence), tilling, removal of non-human predators, altering substrate, and rock removal [12-15]. Harvesting/tilling inhibits build-up of anoxic sediments, increasing the oxygen required for metabolism. Removal of stressors such as predators and rocks increases clam survival and inhabitable areas.
Clam Garden (Present, Absent) and associated management	Increased growth with clam gardens	Field observations	Many of the above attributes, including shell hash and coarse sediment accumulation and intentional addition, reduced beach slope, and increased management of clam habitat, such as thinning (decreasing density dependent competition) will increase growth.

* Excluded from our models because of high co-linearity with other attributes.

† Some human interactions will not enhance growth rates (e.g., over harvest, trampling, displacing sediment, leaving open holes).

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Table S2. Significance results of comparisons of butter clam size at death, age at death, L-inf, and size at age 1 through 5 between time periods.

	Figure No.	Comparisons of time periods (years ago)	estimate	SE	df	t.ratio	p.value
Size at Death	2a	11,500-11,000 - 10,900-9,500	-13.68972	4.161268	117	-3.289795	2.19E-02
		11,500-11,000 - 4,200-2,900	-29.39824	4.949429	117	-5.939724	6.23E-07
		10,900-9,500 - 4,200-2,900	-15.70853	4.031261	117	-3.896678	3.02E-03
		4,200-2,900 - 2,800-2,300	24.02914	4.290767	117	5.600198	2.97E-06
		4,200-2,900 - 500-200	20.23405	4.290767	117	4.715719	1.34E-04
		4,200-2,900 - 250-100	15.92067	4.840637	117	3.288961	2.19E-02
		4,200-2,900 - Live-Collected	24.55096	4.528002	117	5.422029	6.60E-06
Age at Death	2b	11,500-11,000 - 4,200-2,900	-5.371212	1.488335	117	-3.608874	8.04E-03
		11,500-11,000 - 2,800-2,300	5.021645	1.327066	117	3.784019	4.47E-03
		10,900-9,500 - 2,800-2,300	6.895545	1.007708	117	6.842799	7.91E-09
		10,900-9,500 - 500-200	5.609831	1.007708	117	5.56692	3.45E-06
		10,900-9,500 - Live-Collected	3.544355	1.097569	117	3.229278	2.62E-02
		4,200-2,900 - 2,800-2,300	10.392857	1.290269	117	8.054797	1.58E-11
		4,200-2,900 - 500-200	9.107143	1.290269	117	7.058327	2.69E-09
		4,200-2,900 - 250-100	6.916667	1.45562	117	4.751698	1.16E-04
		4,200-2,900 - Live-Collected	7.041667	1.361608	117	5.171582	1.98E-05
Linf	3b	11,500-11,000 - 4,200-2,900	-31.06599	7.625922	117	-4.073736	1.60E-03
		11,500-11,000 - 2,800-2,300	-29.62072	6.799617	117	-4.356234	1.60E-03
		11,500-11,000 - 500-200	-26.97115	6.799617	117	-3.966569	1.60E-03
		2,800-2,300 - Live-Collected	19.02852	6.062429	117	3.138761	1.60E-03
Age 1	4b	500-200 - 250-100	-5.341667	1.224828	116	-4.361156	5.49E-04
		4,200-2,900 - 250-100	-6.133333	1.381793	116	-4.438679	4.07E-04
		250-100 - Live-Collected	4.829167	1.292549	116	3.736159	5.28E-03
		2,800-2,300 - 250-100	-4.632143	1.224828	116	-3.781871	4.52E-03
		11,500-11,000 - 250-100	-5.787121	1.412848	116	-4.096068	1.48E-03
		10,900-9,500 - 250-100	-5.031667	1.156091	116	-4.352312	5.68E-04

Age 2	**4b**	11,500-11,000 - 250-100	-8.082576	1.938773	116	-4.168914	1.14E-03
		10,900-9,500 - 250-100	-6.071667	1.586439	116	-3.82723	3.86E-03
		4,200-2,900 - 250-100	-5.966667	1.896157	116	-3.146715	3.33E-02
		500-200 - 250-100	-5.725	1.680764	116	-3.40619	1.54E-02
Age 3	**4b**	11,500-11,000 - 2,800-2,300	-7.042424	2.309409	117	-3.049448	4.37E-02
		11,500-11,000 - 250-100	-9.809091	2.590054	117	-3.787214	4.42E-03
Age 4	**4b**	11,500-11,000 - 4,200-2,900	-9.804545	3.043965	115	-3.220978	2.69E-02
		11,500-11,000 - 2,800-2,300	-10.074545	2.737362	115	-3.680385	6.38E-03
		11,500-11,000 - 500-200	-8.668831	2.714137	115	-3.193955	2.91E-02
		11,500-11,000 - 250-100	-11.254545	3.043965	115	-3.69733	6.03E-03
Age 5	**4b**	11,500-11,000 - 4,200-2,900	-14.65076	3.328128	108	-4.402102	4.94E-04
		11,500-11,000 - 2,800-2,300	-13.3202	3.051332	108	-4.365373	5.68E-04
		11,500-11,000 - 500-200	-10.61435	3.02072	108	-3.513849	1.12E-02
		11,500-11,000 - 250-100	-13.09091	3.399708	108	-3.850598	3.67E-03

Table S3. Environmental and cultural attributes of study sites within each temporal category and predictions about growing conditions by temporal category.

Temporal Category in Yrs Ago (Total N of shells)*	Sites (N of shells)	Context†	SST (°C) ‡	Beach Slope	Substrate	Human Interaction§	Predictions¶
11,500-11,000 (11)	EbSh-36 (4)	PB	5-7	Steep	Fine	Low	Poor
	EbSh-5 (7)	PB	5-7	Moderate	Fine	Low	
10,900-9,500 (31)	EbSh-36 (25)	PB	10-13	Steep	Coarse	Low	Good/improving
	EbSh-5 (6)	PB	10-13	Moderate	Fine	Low	
4,200-2,900 (12)	EbSh-77 (12)	PB	9-11	Moderate	Coarse	Medium	Excellent
2,800-2,300* (21)	EbSh-14 (21)	M/CG#	9-11	Moderate	Coarse	High	Excellent
500-200* (21)	EbSh-13 (21)	M/CG	10	Flat	Coarse	High	Excellent
Early Historic (12)	EbSh-13 (5)	PB/CG	10	Flat	Coarse	Medium	Good/degrading
	EbSh-5 (7)	PB/CG	10	Flat	Coarse	Medium	
Living* (16)	EbSh-13 (16)	MB/CG	10	Flat	Fine	Low	Poor

*Shellfish harvested in the past and deposited in middens or harvested by the research team (Living). Since shells from middens were selected from the beach by ancient harvesters, they will tend to be biased towards larger specimens at any given age than the shells from non-midden samples. In the case of the Live-collected specimens, there are no such size biases since all encountered specimens were collected. However, because these specimens were harvested, they did not reach maximum age or size.
†PB = paleo-beach, M = midden, CG = clam garden beach; MB= modern beach (i.e., active intertidal zone).
‡ SST = sea surface temperature, taken from Kienast and McKay 2001
§ Human interaction is inferred from number, size, and proximity of ancient settlements to the harvested beach. We assume that the closer a large shell midden, the greater the occurrence of tilling and harvesting in the intertidal.
¶ Predictions based on the assumptions that poor conditions are those where abiotic factors (grain size, water temperature, slope) are outside the preferred range for butter clams, and where there has been no human management. These conditions characterize the temporal category 11.5 to 11 ka (see Table S1).
# We cannot determine independently the age of the clam garden at this site because the garden wall has been largely destroyed by industrial activity. However, based on the fact that clam gardens were being built in the area at this time, and the association of a large settlement with this location, we reason that the beach supported a clam garden during this period.

Table S4. Relative variable importance of parameters included in model averages of Size (mm) of clams ages 1 to 5.

	CG Wall	Substrate	Slope	SST
Age 1	0.72	0.64	1	0.43
Age 2	0.55	1	0.87	0.29
Age 3	0.63	1		
Age 4	0.6	1		
Age 5	0.51	1		

CG Wall indicates that a clam garden wall is present, SST indicates sea surface temperature.

Table S5. Top models evaluated to within 2 ΔAICc units for each response variable, size at ages 1-5, Linf, and size and age at death.

Response Variable	Model	K	logLik	AICc	ΔAICc	weight	adj-r2
Size at Age 1	CG.Wall	3	-331.91	670.02	0	0.27	0.03
	Substrate	4	-331.24	670.81	0.79	0.18	0.04
	CG.Wall + Substrate	5	-330.29	671.09	1.07	0.16	0.06
Size at Age 2	CG.Wall + Substrate	5	-363.04	736.6	0	0.46	0.11
	CG.Wall + Substrate + z.SST	6	-362.24	737.2	0.61	0.34	0.12
Size at Age 3	CG.Wall + Substrate	5	-395.99	802.49	0	0.55	0.17
	CG.Wall + Substrate + z.SST	6	-395.35	803.42	0.93	0.34	0.17
Size at Age 4	CG.Wall + Substrate	5	-363.04	736.6	0	0.46	0.11
	CG.Wall + Substrate + z.SST	6	-362.24	737.2	0.61	0.34	0.12
	Substrate	4	-366.06	740.46	3.86	0.07	0.06
Size at Age 5	CG.Wall + Substrate	5	-392.37	795.28	0	0.49	0.29
	CG.Wall + Substrate + z.SST	6	-391.27	795.33	0.04	0.48	0.3
Size at Death	Substrate	4	-481.8	971.93	0	0.42	0.27
	CG.Wall + Substrate	5	-481.18	972.88	0.95	0.26	0.27
	Substrate + z.SST	5	-481.64	973.8	1.87	0.16	0.27
	CG.Wall + Substrate + z.SST	6	-480.57	973.85	1.93	0.16	0.28
Age at Death	CG.Wall + Substrate	5	-339.33	689.17	0	0.38	0.37
	CG.Wall	3	-342.16	690.52	1.35	0.19	0.34
	CG.Wall + z.SST	4	-341.33	690.99	1.82	0.15	0.35
	CG.Wall + Substrate + z.SST	6	-339.18	691.08	1.91	0.14	0.37
Linf	CG.Wall + Substrate	5	-534.31	1079.14	0	0.41	0.2
	Substrate	4	-535.72	1079.78	0.64	0.3	0.18
	CG.Wall + Substrate + z.SST	6	-534	1080.71	1.57	0.19	0.21

CG Wall indicates that a clam garden wall is present, z.SST indicates standardized sea surface temperature.

Additional data (separate file)

Dataset S1. Master data spreadsheet.