AGRICULTURE

Engineered feature used to enhance gardening at a 3800-year-old site on the Pacific Northwest Coast

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Humans use a variety of deliberate means to modify biologically rich environs in pursuit of resource stability and predictability. Empirical evidence suggests that ancient hunter-gatherer populations engineered ecological niches to enhance the productivity and availability of economically significant resources. An archaeological excavation of a 3800-year-old wetland garden in British Columbia, Canada, provides the first direct evidence of an engineered feature designed to facilitate wild plant food production among mid-to-late Holocene era complex fisher-hunter-gatherers of the Northwest Coast. This finding provides an example of environmental, economic, and sociopolitical coevolutionary relationships that are triggered when humans manipulate niche environs.

INTRODUCTION

A rapidly expanding body of archaeological evidence suggests that ancient humans used various deliberate means to enhance the productivity and predictability of economically important species in habitats rich in biotic resources (*1*). Deliberate engineering of ecological niches promotes coevolutionary interactions among humans, plants, and animals that have profound ecological effects (*2*). These include impacts to resource availability, hydrological regimes, and, in some cases, alterations to selection pressures that facilitate genetic responses (*3*–*5*). Although these impacts are both driven by and often lead to greater sociopolitical complexity of human communities, they do not inevitably lead to domestication of target resources (*6*–*10*). Archaeological examples of nondomestic plant management include the intensification of geophyte harvesting among the Island Chumash (*11*) and the silviculture of nut- and fruit-bearing woody plants in the Eastern Woodlands (*12*) of North America. Ancient examples of aquaculture include construction of fish (*13*) and eel traps in Australia (*14*) and clam gardens on the Pacific Northwest of North America (*15*, *16*). Many examples of plant management strategies from the Pacific Northwest, such as prescribed burning to increase yield and maintain open spaces (*17*, *18*) and selective harvest and tending of geophytes including wapato (*19*–*21*), are limited to the very late Holocene and historic era.

Here, we report the first direct archaeological evidence of in situ nondomesticated plant cultivation, production, and management by mid-to-late Holocene peoples of the Northwest Coast at an exceptionally well-preserved wetland garden near Vancouver, British Columbia, Canada (Fig. 1). This is a particularly strong example because it does not rely only on proxy evidence for plant management. These findings demonstrate management of an economically important plant food species. We argue that ancient inhabitants deliberately engineered an existing ecological niche and established a coevolutionary relationship with wapato by creating an economic niche around its production.

SITE SETTING

Archaeological site DhRp-52 was discovered during inspection of a road right-of-way across a once ecologically rich, tidally influenced freshwater wetland. The wetland is situated in Katzie First Nation territory. Ethnographic sources detail Katzie's ancestral, spiritual, and economic ties to the wetland and control over access to its abundant resources (*22*–*24*).

DhRp-52 is situated along the edge of a sandy, ridged platform that provided a dry, stable landform suitable for human habitation after sea-level regression circa 6000 calendar years before the present (cal B.P.) (*25*). Site deposits include a low-lying wet site, where organic materials and artifacts were preserved in an anaerobic environment, and, on an adjacent raised landform, a contemporaneous dry site with deeply stratified, intact cultural deposits. Analysis of stratigraphic patterns and 106 ^{14}C dates derived from both wet- and dry-site areas indicates Early (5700–5300 cal B.P.), Middle (5300–4250 cal B.P.), and Late Components (4100–3200 cal B.P.) (table S1 and fig. S1). The wet site is composed of three distinct areas of activity: the midden zone, the bank transition zone, and the garden area, which occupies the lowest portion of the wet site (Fig. 2). Gardening is most intensive during the Late Component occupations. The dry site contains two large Middle Component rectangular habitation structures and a Late Component ovoid house pit feature with a central hearth. Use of a large pit feature, the excavated portion of which (242 m^3) contained over 12 metric tons of fire-altered rock (FAR), was most intensive during the Middle and Late Component occupations. Decorative items, including labrets, ear spools, and an assemblage of over 90,000 stone beads are almost exclusively associated with Late Component occupations. Beads are considered indicators of material wealth accumulation and wealth-based inequality among ancestral peoples of the Pacific Northwest region (*26*).

RESULTS

Submerged rock pavement and wapato (*Sagittaria latifolia*)

Wet-site excavations unearthed 42 m^2 of a unique rock pavement feature composed of tightly packed FAR interspersed with smooth cobbles, both <12 cm in diameter, in ~2:1 ratio (fig. S2). The pavement is one rock course thick, but toward the bank, it trends upward and becomes two courses. It is probable that stones were manually transported to the site, possibly first for use in the large upland FAR-filled pit feature and then, once reduced to a size too small for roasting purposes (*27*), recycled for use in the rock pavement. The distribution of similarly sized stones is inconsistent with deposition by natural means, such as through water sorting (where cross-shore profiles consist of graded sediments) or slumping from the higher elevation bank and midden areas (where profiles exhibit irregular, spatially limited concentrations of slumped deposits). Sediment,

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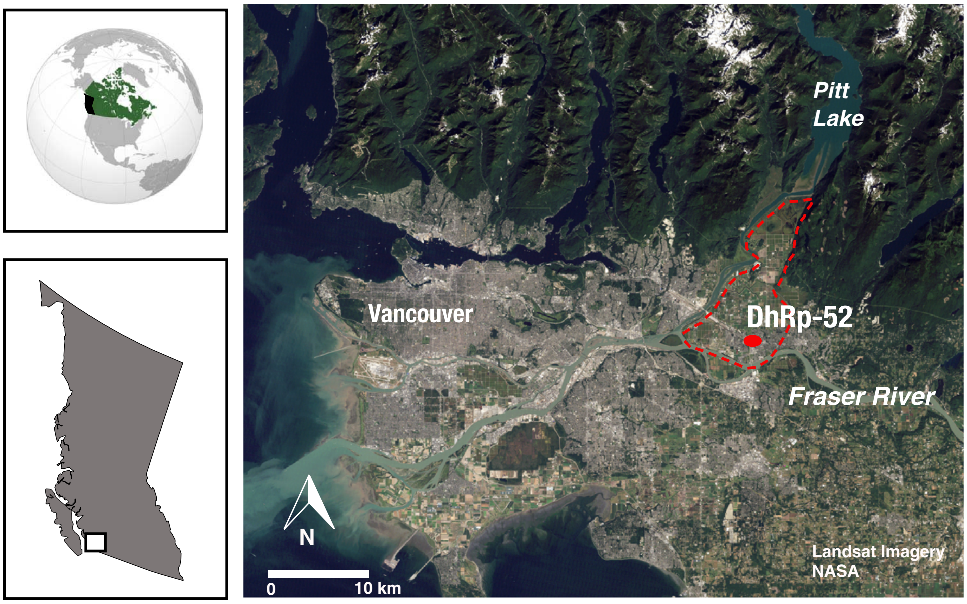

Fig. 1. Site location and setting. Dotted line represents the approximate historic extent of Pitt Polder wetlands.

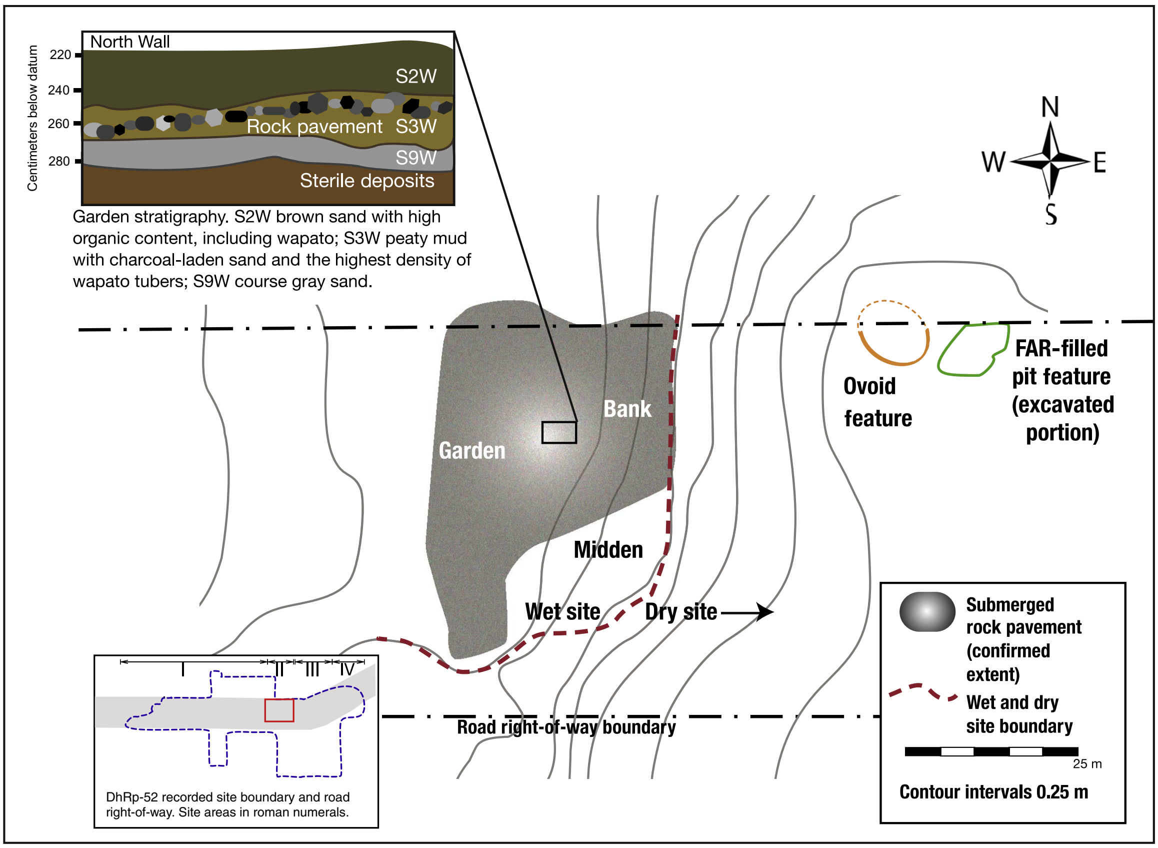

Fig. 2. DhRp-52 site topography, major Late Component (4100 cal B.P. to 3200 cal B.P.) features, wet-site activity areas, and garden patch stratigraphy.

microbotanical, and macrobotanical analyses reveal the presence of wetland environs that pre- and postdate the rock pavement and whose hydrological regimes are incapable of distributing stones in a pavement-like formation. The tightly packed arrangement of angular and rounded stones of uniform size in a consistent ratio and thickness suggests that the feature is not the result of casual discard processes by site residents but an intentionally engineered anthropogenic feature.

The rock pavement formed a human-made boundary for the cultivation of a geophyte ("root" food) locally known as wapato (*S. latifolia*, in the Alismataceae, water plantain family), a perennial aquatic to semiaquatic herb. Wet-site excavations recovered 3768 specimens of wapato within the wetland garden (Fig. 3). Wapato tubers, known colloquially as "Indian potato," were a historically prized and heavily traded food resource for indigenous populations along the Fraser and Columbia rivers, including the Katzie (*19–23*, *28*). Typically harvested from October to February, wapato was an important source of dietary starch through the winter months (*29*, *30*). Recovered specimens from DhRp-52 include fragmented rhizome pieces and rootlets as well as whole and fragmented tubers (fig. S3). Whole tubers range from 0.8 to 3.6 cm in diameter, comparable to contemporary specimens. The wapato were recovered in growing position, and their circular shape indicates a healthy growing environment. Across wet-site deposits, the highest overall counts of wapato were excavated from the garden area (71.8% or *n* = 2706). Of the garden specimens, 49.4% (*n* = 1337) were recovered from the S3W deposits.

Sediment descriptions and wetland succession

The S3W stratum, a charcoal-rich peat deposit with high densities of perishable artifacts, is found in direct association with (both beneath and above) the rock pavement feature (Fig. 2). The second highest count of wapato (*n* = 1252, 46.3%) in the garden area was recovered from stratum S2W, which caps the S3W deposits. Sediment analyses indicate that, although a stable, dry land surface existed in the upland portions of the dry site, the wet site was subject to varying hydrological regimes. An influx of coarse gray sand (S9W) followed by peat development suggests the presence of a channel or stream that was transformed, largely due to rising water levels, into a hydrological regime characterized by a lower transport energy and a greater accumulation of organic debris (S7W). The development of fibrous peat (sediment S3W) within a sandy matrix and an abundance of macrobotanical remains indicate that low-lying environs that characterize the wet site were inundated with water at depths sufficient to support a fully inundated wetland plant community.

Paleoethnobotanical analyses of sampled wet-site matrices revealed more than 10,000 seeds deposited as natural seed rain in the wet site, trapped and preserved in the densely packed layers of emergent vegetation that characterized the garden area. The wetland obligate species water nymph (*Najas flexilis*) best exemplifies the ecological succession of the wetland system (Fig. 4 and table S2). The basal deposits (S9W and S7W) reveal a low-energy freshwater system characterized by herbaceous emergent species, particularly sedges. The overlying stratum (S3W) exhibits a massive amplification of wapato (reflected more by tubers than seeds, which are subject to predation) and associated water nymph, supported by a now fully aquatic, marsh-like system at the slough edge. Careful attention to the garden's hydrology ceased when the plot was abandoned circa 3200 cal B.P. This caused the garden patch to dry up, acidify, and eventually become a lower-energy fen-like wetland, whose mucky peat deposits (S2W) preserved the remains of the ancient garden through subsequent millennia.

Wood tool fragments

A unique assemblage of perishable wood and bark artifacts was found intact and superbly preserved in the wet-site deposits (table S3). The assemblage includes wood tool fragments (*n* = 185) composed of (*n* = 149) distal ends or tips of once longer tools ranging from 0.49 to 3.26 cm in thickness, 1.03 to 28 cm in length, and 1.19 to 5 cm in diameter. Viewed in profile, most tips have one flat side and one slightly convex side. Most (70%) exhibit blackened distal ends, a result of fire hardening. Half of the tips (*n* = 74, 49.3%) were recovered from or were found directly underlying the rock pavement (S3W) in the garden area; most of the remaining tips (*n* = 45) were recovered from the adjacent midden zone. Implement orientation was recorded in situ for a sample of tools (*n* = 25) found in the garden area: 14 were oriented tip down, 1 tip up, and 10 lying flat. Most of the tips (*n* = 103) exhibit a hinge facture consistent with breakage resulting from a prying motion. Cellular analysis of a sample of tools (*n* = 9) revealed that they were manufactured from the strong, flexible compression wood of local conifers (*Abies* spp. and *Tsuga* cf. *heterophylla*) (table S4).

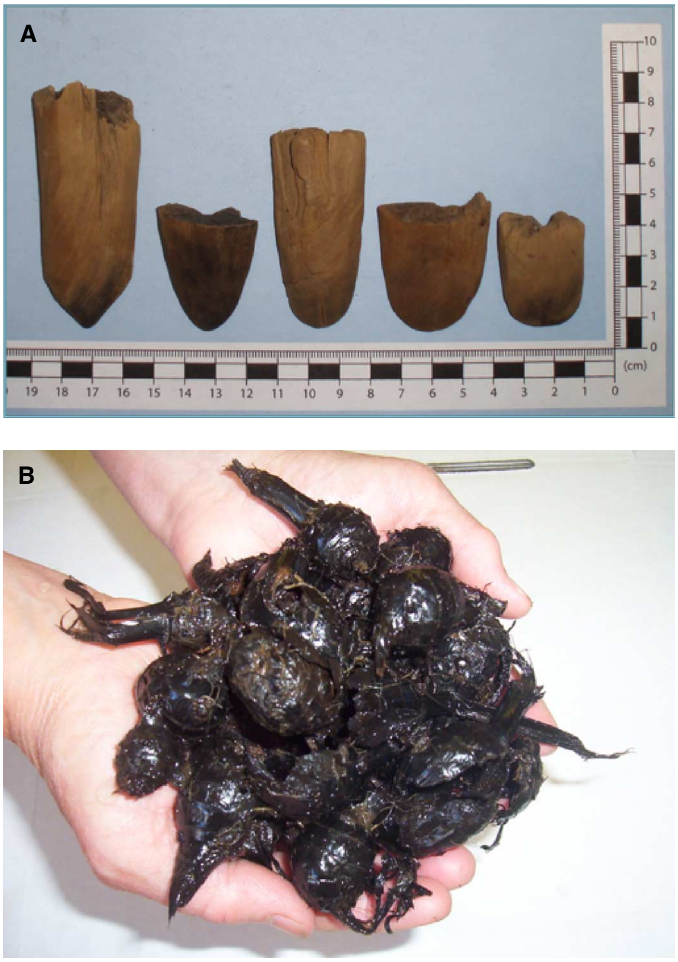

Fig. 3. Perishable materials from DhRp-52 wetland garden. (**A**) Sample of conserved wood digging stick tips. (**B**) Ancient wapato tubers (preconservation) excavated from DhRp-52 wet-site garden area deposits.

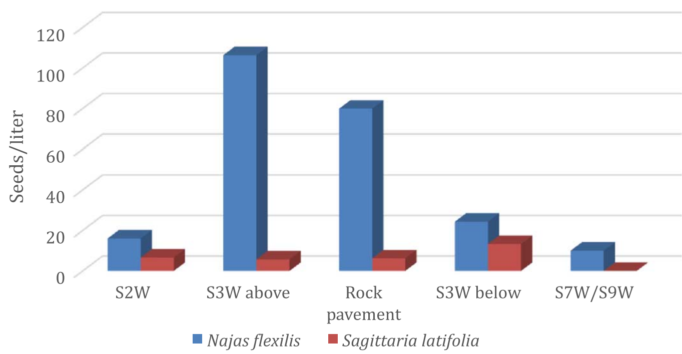

Fig. 4. Density distribution of water nymph (*N. flexilis*) and wapato (*S. latifolia*) from the oldest (S7W/S9W) to the most recent (S2W) deposits in the garden stratigraphic sequence at DhRp-52.

The rock pavement controlled the depth to which the wapato rhizomes could penetrate, allowing harvesters to more easily locate and release the tubers from the mucky substrate. The context, breakage pattern, and direct association with the rock pavement suggest that the wooden tips are the distal ends of digging sticks. Their stratigraphic provenience and orientation imply that wapato harvest involved pushing or thrusting digging sticks into the pavement, where a prying or rocking motion was used to break the wapato tubers free from the mat of rhizomes and muddy substrates. Once released, the tubers would float to the water's surface. When thrust through the pavement or caught between the pavement stones, some of the digging sticks broke and the tips of the fractured sticks were left in situ or discarded in the adjacent midden area.

Radiocarbon dating

Accelerator mass spectrometry (AMS) dates of wood implement tips (n = 3) cluster between 3840 cal B.P. and 3470 cal B.P. AMS dates derived from charcoal and wood directly associated with the rock pavement (n = 5) and wapato from associated strata S3W (n = 2) suggest that the rock pavement was established as early as 3800 cal B.P., and the most active period of plant cultivation occurred between 3800 cal B.P. and 3250 cal B.P. (table S1 and fig. S1). Radiocarbon dates of charcoal samples collected from the central hearth of the ovoid residential structure are contemporaneous with this period of intensive garden use (table S1).

DISCUSSION AND CONCLUSIONS

Our findings indicate that ancient inhabitants of DhRp-52 selected an existing wetland niche rich in biotic resources and engineered it to amplify its resource production. In so doing, they entered into a coevolutionary relationship with their environment, where deliberate manipulation of the wetland garden influenced wetland hydrology, biotic predictability, and growth conditions. A stone pavement was constructed to facilitate production and harvest of a naturally occurring and economically significant wild plant food. Close to 150 fire-hardened digging stick tips, several found embedded tip down in the pavement, demonstrate how the wapato tubers were harvested en masse. Paleoethnobotanical and sediment analyses suggest that the wetland thrived because of the engineering and maintenance of the hydrological regime by the site's inhabitants. These data represent the first direct archaeological evidence of wetland plant cultivation, production, and management on the Northwest Coast before ethnographically documented times. Both the nature and antiquity of this garden contribute to a regionally focused understanding of niche-based coevolutionary interactions among humans, plants, and animals.

MATERIALS AND METHODS

Georchaeological investigations and soil micromorphology of DhRp-52 wet-site sediments

Sediment analyses were carried out to determine depositional history and site chronology, to quantify organic content in wet-site deposits, and to verify sediment descriptions and stratigraphy identified in the field. Here, we report specifically on the methods and results of wet-site geoarchaeological investigations. Goals for wet-site analysis included identifying depositional periods of water inundation that would have provided ideal conditions for the growth and management of wapato (*S. latifolia*).

In the field, seven discrete strata were observed in the wet-site deposits, five of which were observed to occur in the garden portion of the wet site. In the garden deposits, contacts between most sediment units were clear but generally diffuse.

Sediment subsamples from previously collected column samples were chosen from units representing archaeologically distinct areas at DhRp-52. A total of five column samples and six discrete sediment samples from dry deposits within the upland area as well as three column samples from water-saturated deposits within the wet-site area were chosen for analysis. Sediment analyses were conducted for all depth intervals of each column sample, generally occurring at 5- to 10-cm intervals. In total, 112 sediment samples were analyzed for color, particle size (determined using the Udden-Wentworth grade scale), particle shape (qualitatively described in terms of sphericity), and pH level. Wherever possible, 1-liter samples were used for analysis, but in some cases, interval samples retrieved from the field were less than 1 liter to maintain the stratigraphic integrity of deposits. Loss-on-ignition (LOI) analysis was conducted to determine the total organic content in the sediments. LOI analyses were conducted in a muffle furnace with digital temperature display (Thermolyne F62700), and samples were weighed using a precision balance (Acculab VI-1 mg). Following standardization of LOI methods (*31*), consistent ignition temperature (550°C), exposure time (6 hours), and sample size (5.0-g wet weight) were applied across all samples.

Sediment descriptions based on the results of the analyses of the wet-site samples are as follows.

Sediment S1W.

Deposits identified as sediment S1W generally consisted of very dark grayish brown, poorly sorted, gravelly, muddy sand (mean G/S/M = 12.7:78.0:9.4%), with high quantities of organic inclusions (mean LOI550 = 41.8%). However, because of the small sample size (n = 2), generalizations should be taken cautiously in terms of typical and atypical properties defining this sediment; it was often found mixed with the underlying S2W deposit.

Sediment S2W.

Deposits identified as sediment S2W generally consisted of brown (brown to dark grayish brown), sand-sized particles (mean G/S/M = 0.1:88.7:11.3%), with very high quantities of organic material (mean LOI550 = 46.74 ± 2.77%). Compaction of fine-grained material and organics comprising the sediment made grain size processing difficult without damaging larger particles and macrobotanicals. Accordingly, the mud percentage was likely underrepresented in the grain size distribution for sediment S2W samples.

Sediment S3W/submerged rock pavement.

Deposits identified as S3W, including those within the submerged rock pavement (SRP) feature, generally consisted of grayish brown (brown to dark gray), very poorly to poorly sorted, gravelly, muddy sand (mean G/S/M = 18.4:69.6:12.0%), with high quantities of organic inclusions (mean LOI550 = 22.45%). Both total organic and charcoal content invariably decreased down profile, whereas the contribution of charcoal to the total organic content increased down profile. Similarly, appreciable quantities of charcoal from size fractions excluded from digestion treatment (medium sand to gravel size) were observed and have been noted in both paleobotanical and pollen analyses.

Sediment S5W.

Deposits identified as sediment S5W generally consisted of dark gray, very poorly sorted, gravelly, coarse sand (mean G/S/M = 30.9:62.4:6.6%). The sediment is characterized by high proportions of FAR and gravel-sized inclusions throughout the deposit. This sediment had been identified as a culturally associated deposit in the midden zone of the wet-site deposit.

Sediment S6W.

Deposits identified as sediment S6W generally consisted of gray (gray to dark gray), poorly to very poorly sorted, gravelly, muddy sand (mean G/S/M = 13.1:75.0:11.9%), with high quantities of wood material and macro-sized charcoal. This sediment had been identified as a culturally associated deposit in the midden zone.

Sediment S7W.

Deposits identified as sediment S7W generally consisted of gray (gray to grayish brown), very poorly sorted, gravelly, muddy sand (mean G/S/M = 25.3:64.8:9.8%), with moderate quantities of organic inclusions and macro-sized fibrous organic material.

Sediment S9W.

Deposits identified as sediment S9W invariably consisted of light greenish gray, poorly to moderately sorted, medium sand (mean G/S/M = 0.6:93.0:6.4%), with very few, if any, organic inclusions (mean LOI_{550} = 1.54 ± 0.23%).

Paleoethnobotanical analysis

Column samples obtained for paleoethnobotanical analysis were systematically collected in 10-cm levels within natural layers from five trench profiles in the wet site. A total of 60 samples was chosen (garden, n = 25; midden, n = 13; bank, n = 18; representing 30.5 liters of sediment) to examine questions about the plant associations and successions reflected in the macroremains across space and time. The focus of analysis was on the substantial assemblage of uncharred seed rain, which dominated the macroremains that were recovered from the wet site. We posited that seed rain from each wet-site area will generally reflect the plants growing in the immediate vicinity (*32*). Changes in the seed associations through the sequence of deposits in the wet site will also reflect the functional uses of different wet-site areas and the human influences to these areas through time.

Samples were placed in water to soak for at least 24 hours to loosen the fibrous wet-site matrix, wet-screened through nested geological screens (2, 1, and 0.425 mm), and carefully removed to lined flats to air dry. We witnessed very little cracking or breakage of waterlogged seeds as they dried. With a dissecting microscope (10 to 40×), the samples were sorted into their constituent parts—needles, seeds, buds, and other plant parts. We identified 36 plant taxa, including 31 seed taxa (n = 10,206.5 seeds total) from 22 plant families (*32*). Because of the density and richness of uncharred plant materials in the wet-site samples, redundancy curves were used to test when the sorting of each sample and deposit was sufficient (*33*). The curves were graphed by plotting the number of specimens against the number of identified taxa.

Table S2 shows patterning through time for water nymph, sedges, other abundant seed taxa, and wapato through the sequence of wet-site deposit in the garden patch. The most environmentally sensitive plant in the assemblage, wavy water nymph (*N. flexilis*), is a perennial aquatic herb and wetland obligate, growing in low-energy aquatic environments (*34*), often alongside wapato in the Pacific Northwest. Because it requires full inundation, water nymph was the most sensitive indicator plant in the assemblage, and its relative abundance through the sequence of deposits was a prime indication of the changes in the garden microenvironment. Water nymph seeds were identified throughout the garden deposits, with low abundance in the earliest deposits (<1.2% in S7W/S9W), very high abundance comprising upwards of 35 to 40% of the SRP and S3W-a (above rock pavement) deposits, and tapering off again in the uppermost S2W (with a low abundance of 5.5% in the garden locus). Proportions were very low (<1.2% throughout) in the adjacent, and drier, bank and midden areas. *N. flexilis* is an abundant seed producer, depositing seeds at the basal substrate from which it grows (*32*). This patterning reflected the anthropogenic management of the garden's hydrology by site inhabitants during their period of tenure. After the garden's abandonment, this state of perpetual inundation ended, and this microenvironment slowly moved toward a lower-energy system in the form of a sedge peat.

Forty-one 1-liter samples were also analyzed from the DhRp-52 dry site. These samples represented stratigraphic layers, hearths, large processing pits, and both hearth-like features and midden lenses from the Middle and Late Components. Standard flotation and processing techniques were used in the dry-site analysis (*35*). In addition to minimal charcoal and needles, 15 seed taxa from 11 plant families were identified in the dry-site assemblage, which were relatively distinct from wet-site taxa and far less abundant (n = 152 seeds total). About 30% of the dry-site assemblage included low frequencies of ethnobotanically documented taxa, such as salal (*Gaultheria shallon*), kinnikinnick (*Arctostaphylos uva-ursi*), wild rose (*Rosa* spp.), wild raspberry (*Rubus* spp.), red elderberry (*Sambucus racemosa*), and Oregon grape (*Mahonia* spp.). The other 70% of the seed assemblage was considered weedy taxa. Edible taxa that predominate in the wet site, such as wapato (tubers and achenes) and beaked hazelnut (shell; *Corylus cornuta*), were not identified in the dry-site assemblage.

This lack of correspondence between wet- and dry-site assemblages may relate to sample sizes, the far more limited preservation in the dry site, and/or the different depositional and taphonomic processes between site types. Lack of wapato achenes (seeds) in the dry site was probably related to phenology. Wapato plants in the wetland garden would have gone to seed in late summer, whereas the tubers were harvested in late fall and winter, long after the seeds had dispersed. Wapato is a prodigious seed producer, but the achenes have short longevity and are subject to intense predation by waterfowl, muskrats, and fish (*36*). An experimental analysis of modern wapato tubers, leaves, and stalks did not produce phytoliths. In the future, we will experiment with starch analysis for detecting wapato in the dry site in addition to further macroremain analysis.

Radiocarbon dating sample selection and preparation

The radiocarbon assays for DhRp-52 were conducted on three types of samples.

Charcoal and waterlogged plant materials.

Charcoal and waterlogged plant materials were collected specifically for radiocarbon dating. These samples were taken opportunistically, when suitable material associated with cultural features or artifacts was encountered in the excavations. The samples were excavated by trowel and placed on clean aluminum foil. Some pieces were washed with municipal water to remove adhering soil. Most charcoal samples were air-dried before they were packaged in foil, cataloged, labeled, and stored at room temperature. Nonartifact wood samples from water-saturated deposits were stored in a freezer. Before submission for dating, the samples were examined and any with evidence of mold were eliminated from consideration.

Waterlogged ecofacts and artifacts.

Specimens selected for dating include wapato tubers (*S. latifolia*), worked bark, and wooden artifacts. Small samples were removed from the wood artifacts for dating; wood bark and the selected tubers were submitted in their entirety. The waterlogged samples were stored wet, in cold water, and shipped in that condition to the radiocarbon dating laboratories.

Charcoal from matrix column samples.

The material for dating was removed by hand, using metal forceps, from dried and screened matrix samples. It was packaged in aluminum foil, cataloged, labeled, and stored at room temperature.

Samples (N = 106) were submitted for radiometric dating by the AMS method. They were submitted in batches to three professional radiocarbon laboratories (table S1). The batches represented stages of sample selection designed to establish and refine the timeline for cultural deposits at the site, to date particular cultural features and artifacts, and to confirm relationships within and between areas of the site.

Dates derived for DhRp-52 are presented in "cal B.P." All calibrations reported from DhRp-52 were calculated using the OxCal 4.1.3 radiocarbon calibration program (*37*). All wood charcoal dates were calibrated using the Northern Hemisphere calibration curve IntCal04 (*38*). The dates reported have been calibrated to 2 SDs (95.4% probability). Scientists refer to the SD (the number after "±") by σ; one σ denotes 68% probability.

Radiocarbon dating results, combined with those of stratigraphic, artifact, and feature analyses, suggest that DhRp-52 has three components. The Middle and Late Component occupations are separated by an approximately 200-year-long break in the radiocarbon date sequence (fig. S1).

Perishable artifacts and ecofacts

The unique assemblage of 12,959 perishable artifacts and macrobotanical economic ecofacts (table S3) recovered at DhRp-52 were in a superb state of preservation upon recovery. They were excavated within stratified, water-saturated matrices in the midden, bank, and garden zones, as well as in deep waterlogged sediments in adjacent areas I and IV. Radiocarbon dating placed these objects circa 4900–3100 cal B.P. (table S1). Some were associated with the Middle Component, but most were associated with the Late Component occupation of the site.

There are 3767 whole and fragmented *S. latifolia* (wapato) tubers, rhizomes, and rootlets. A sample of 210 whole (complete) tubers were measured. Whole tubers ranged from 0.8 to 3.6 cm in diameter, which is comparable to contemporary specimens that grow locally. Of the 210 whole tubers, 169 (80.4%) were circular in their overall shape and 41 (19.6%) were ovoid. The remains were dark brown to black in color, and although only the exterior shell or skin survived on many, some also had the starchy material inside.

The DhRp-52 assemblage included 184 fragments of wooden tools referred to here as implement tips. The portion of the recovered specimen varied within the assemblage; 75 (41%) had their complete tip intact, whereas 103 (56%) were recovered with only a portion of the tip. The remaining six (3.3%) specimens included the distal tip end (four of which had a complete tip intake) and a portion of the shaft to their proximal poll end.

There were similarities in break patterns located on the proximal end of the specimens; they appeared to have broken during use. There was no established break pattern typology for wooden implement artifacts; however, the most commonly occurring break was a hinge-type fracture—a term used in lithic analysis to describe a scar, which is a sharp dip usually found on a flat surface (*39*). There were 103 (56%) specimens that have a hinge fracture break pattern. Two (1.1%) had an angled break pattern. Six (3.3%) had a transverse break that looked like a clean snap across the grain of the wood, whereas 10 (5.4%) had a perpendicular break, which split the artifact along the wood grain. There were 18 (9.8%) specimens that were broken and cracked all over (6 of those were charred). The remaining 45 (24.4%) were pieces of tip ends with indeterminate break characteristics.

A total of 18 perishable artifacts was examined by cellular analysis (table S4). These were selected to include specimens from the range of artifact types in the assemblage. Samples from 17 perishable artifacts were analyzed by K. Hawes (wet-lab laboratory manager, South Puget Sound Community College, Department of Anthropology, Tumwater, WA). R. Hebda (Royal British Columbia Museum, Victoria) identified the wood species of one artifact.

Samples taken from basketry and cordage artifacts were stored in water for K. Hawes to thin-section and analyze. All thin sections were taken before conservation treatment except for those from wood chips, which had been treated with PEG-400 (polyethylene glycol, molecular weight 400) before sectioning. Single-edged razor blades were used to cut section samples (cross section, tangential, and radial). Section samples of worked wood and worked bark artifacts were either dry-mounted, premounted onto glass slides, or stored in water and transported to K. Hawes.

SUPPLEMENTARY MATERIALS

Supplementary material for this article is available at http://advances.sciencemag.org/cgi/content/full/2/12/e1601282/DC1

fig. S1. Radiocarbon sequence for DhRp-52.

fig. S2. Plan view of SRP feature from garden area.

fig. S3. Sample of conserved wapato (*S. latifolia*) tubers excavated from DhRp-52 wet-site deposits.

table S1. Radiocarbon dates from DhRp-52.

table S2. Frequency and distribution of abundant seed taxa in the garden deposits at DhRp-52.

table S3. Total counts of perishable artifacts from DhRp-52.

table S4. Species identification of a sample of perishable artifacts excavated from DhRp-52 wet-site (area II) deposits.

REFERENCES AND NOTES

1. B. D. Smith, The ultimate ecosystem engineers. *Science* **315**, 1797–1798 (2007).
2. F. J. Odling-Smee, K. Laland, M. W. Feldman, *Niche Construction: The Neglected Process in Evolution. Monographs in Population Biology 37* (Princeton Univ. Press, 2003).
3. K. N. Laland, F. J. Odling-Smee, M. W. Feldman, The evolutionary consequences of niche construction: A theoretical investigation using two-locus theory. *J. Evol. Biol.* **9**, 293–316 (1996).
4. R. C. Lewontin, *The Triple Helix: Gene, Organism, and Environment* (Harvard Univ. Press, 2000).
5. M. A. Zeder, B. D. Smith, A conversation on agricultural origins: Talking past each other in a crowded room. *Curr. Anthropol.* **50**, 681–690 (2009).
6. J. E. Arnold, S. Sunell, B. T. Nigra, K. J. Bishop, T. Jones, J. Bongers, Entrenched disbelief: Complex hunter-gatherers and the case for inclusive cultural evolutionary thinking. *J. Archaeol. Method Theory* **22**, 1–52 (2016).
7. K. N. Laland, M. J. O'Brien, Niche construction theory and archaeology. *J. Archaeol. Method Theory* **17**, 303–322 (2010).
8. M. Moss, *Northwest Coast: Archaeology as Deep History* (SAA Press, 2011).
9. B. D. Smith, Low-level food production. *J. Archaeol. Res.* **9**, 1–43 (2001).
10. P. Rowley-Conwy, Time, change and the archaeology of hunter-gatherers: How original is the 'original affluent society'?, in *Hunter-Gatherers: An Interdisciplinary Perspective* (Cambridge Univ. Press, 2001), pp. 39–72.
11. K. Gill, J. Erlandson, The Island Chumash and exchange in the Santa Barbara Channel region. *Am. Antiq.* **79**, 570–572 (2014).
12. S. E. Munoz, D. J. Mladenoff, S. Schroeder, J. W. Williams, Defining the spatial patterns of historical land use associated with the indigenous societies of eastern North America. *J. Biogeogr.* **41**, 2195–2210 (2014).
13. I. McNiven, J. Crouch, T. Richards, K. Sniderman, N. Dolby, G. Mirring, Phased redevelopment of an ancient Gunditjmara fish trap over the past 800 years: Muldoons Trap Complex, Lake Condah, southwestern Victoria. *Aust. Archaeol.* **81**, 44–58 (2015).
14. H. Lourandos, Swamp managers of southwestern Victoria, in *Australians to 1788* (Fairfax, Syme & Weldon, 1987), pp. 292–307.
15. D. Lepofsky, N. F. Smith, N. Cardinal, J. Harper, M. Morris, E. W. Gitla, R. Bouchard, D. I. D. Kennedy, A. K. Salomon, M. Puckett, K. Rowell, E. M. McLay, Ancient shellfish Mariculture on the Northwest Coast of North America. *Am. Antiq.* **80**, 236–259 (2015).
16. J. Williams, *Clam Gardens: Aboriginal Mariculture on Canada's West Coast* (New Star Books, 2004).
17. D. Lepofsky, K. Lertzman, Documenting ancient plant management in the northwest of North America. *Botany* **86**, 129–145 (2008).
18. N. J. Turner, "Time to burn": Traditional use of fire to enhance resource production by Aboriginal Peoples in British Columbia, in *Indians, Fire and the Land in the Pacific Northwest*, R. Boyd, Ed. (Oregon State Univ. Press, 1999), pp. 185–218.

19. M. Darby, The intensification of wapato (*Sagittaria latifolia*) by the Chinookan People of the Lower Columbia River, in *Keeping It Living, Traditions of Plant Use and Cultivation on the Norwest Coast of North America*, D. Deur, N. J. Turner, Eds. (University of Washington Press, 2005), pp. 194–217.
20. D. Deur, N. J. Turner, *Keeping It Living: Traditions of Plant Use and Cultivation on the Northwest Coast of North America* (University of Washington Press, 2005).
21. H. V. Kuhnlein, N. Turner, *Traditional Plant Foods of Canadian Indigenous Peoples: Nutrition, Botany, and Use* (Gordon and Breach, 1991).
22. D. Jenness, The faith of a Coast Salish Indian, in *Anthropology in British Columbia Memoir No. 3* (British Columbia Provincial Museum, 1955).
23. W. Suttles, Katzie ethnographic notes, in *Anthropology in British Columbia, Memoir No. 2* (British Columbia Provincial Museum, 1955).
24. W. Suttles, W. Sturtevant, Central Coast Salish, in *Handbook of North American Indians: Northwest Coast* (Smithsonian Institution, 1990), vol. 7, pp. 473–475.
25. J. J. Clague, J. L. Luternauer, S. E. Pullan, J. A. Hunter, Postglacial deltaic sediments, southern Fraser River delta, British Columbia. *Can. J. Earth Sci.* **28**, 1386–1393 (1991).
26. G. Coupland, D. Bilton, T. Clark, J. S. Cybulski, G. Frederick, A. Holland, B. Letham, G. Williams, A wealth of beads: Evidence for material wealth-based inequality in the Salish Sea region, 4000–3500 cal B.P. *Am. Antiq.* **81**, 294–315 (2016).
27. M. D. Petraglia, The heated and the broken: Thermally altered stone, human behavior, and archaeological site formation. *North Am. Archaeol.* **23**, 241–269 (2002).
28. T. Spurgeon, Wapato in Katzie traditional territory. *The Midden* **33**, 2–8 (2001).
29. A. Garibaldi, N. Turner, Cultural keystone species: Implications for ecological conservation and restoration. *Ecol. Soc.* **9**, 1–18 (2004).
30. N. J. Turner, *Ancient Pathways, Ancestral Knowledge: Ethnobotany and Ecological Wisdom of Indigenous Peoples of Northwestern North America* (McGill-Queen's Univ. Press, 2014).
31. O. Heinri, A. F. Lotter, G. Lemcke, Loss on ignition as a method for estimating organic and carbonate content in sediments: Reproducibility and comparability of results. *J. Paleolimnol.* **25**, 101–110 (2001).
32. A. G. Van Der Valk, C. B. Davis, A reconstruction of the recent vegetational history of a prairie marsh, Eagle Lake, Iowa, from its seed bank. *Aquat. Bot.* **6**, 29–51 (1979).
33. D. Lepofsky, K. Lertzman, More on sampling for richness and diversity in archaeobiological assemblages. *J. Ethnobiol.* **25**, 175–188 (2005).
34. T. C. Brayshaw, *Pondweeds, Bur-Reeds, and Their Relatives of British Columbia* (Royal British Columbia Museum, 2000).
35. D. M. Pearsall, *Paleoethnobotany: A Handbook of Procedures* (Left Coast Press, 2015).
36. J. E. Marburger, Biology and management of *Sagittaria latifolia* Willd (broad-leaf arrow-head) for wetland restoration and creation. *Restor. Ecol.* **36**, 248–255 (1993).
37. C. B. Ramsey, Bayesian analysis of radiocarbon dates. *Radiocarbon* **51**, 337–360 (2009).
38. J. P. Reimer, M. G. L. Baillie, E. Bard, A. Bayliss, J. W. Beck, C. J. H. Bertrand, P. G Blackwell, C. E Buck, G. S Burr, K. B. Cutler, P. E. Damon, R. L. Edwards, R. G Fairbanks, M. Friedrich, T. P. Guilderson, A. G. Hogg, K. A. Hughen, B. Kromer, G. McCormac, S. Manning, C. B. Ramsey, R. W. Reimer, S. Remmele, J. R. Southon, M. Stuiver, S. Talamo, F. W. Taylor, J. van der Plicht, C. E. Weyhenmeyer, IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. *Radiocarbon* **46**, 1029–1058 (2004).
39. G. H. Odell, *Lithic Analysis: Manuals in Archaeological Method, Theory, and Technique* (Kluwer Academic/Plenum Publishers, 2004).

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