The Paisley Caves: A Paleoethnobotanical Approach to Textiles Studies in the Northern Great Basin, Oregon

by

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DISSERTATION ABSTRACT

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Title: The Paisley Caves: A Paleoethnobotanical Approach to Textile Studies in the Northern Great Basin, Oregon

Paleoethnobotanical remains from the Paisley Caves offer an opportunity to explore how people engaged with plant communities over time. Fiber identification of textiles, together with radiocarbon dating, contributes new information about landscape use in the Northern Great Basin. Expanded marshlands during the terminal Pleistocene/early Holocene created suitable plant communities ideal for fiber technology, specifically wetland monocots and herbaceous dicots including dogbane and stinging nettle by 11,000 years ago. A change in fine cord technology during the early Holocene supports previous arguments of cultural change around 9000 years ago, but overall, continuity in fiber technology is key to subsistence activities and craft production throughout the Holocene. Despite climatic events during the middle Holocene, in which people transitioned from caves to sites centered around lakeshores and wetlands, the suite of fiber plants and their technological application remains constant. During the late Holocene, bast fiber material diversified with the addition of flax and milkweed. The presence of flax in particular, a high elevation plant, may reflect the increased use of upland root collection areas as populations increased. Cotton cordage and plaiting dating within the last 1000 years, and a more diverse textile assemblage overall, suggests expanded social contacts with groups farther south and east.

This study also tests the feasibility of previously established fiber identification methods, including polarized light microscopy and energy dispersive X-ray spectroscopy, and their suitability for analysis of archaeological cordage from the Paisley Caves in Eastern Oregon. The methods were applied to herbarium reference samples for four key plants: *Apocynum* (dogbane), *Urtica dioica* (stinging nettle), *Asclepias* (milkweed), and *Linum lewisii* (blue flax). These plants are known historically and archaeologically as the primary sources of fibers used in fine cord-making throughout the Northern Great Basin. Results from the control study were then applied to samples from 180 fine cordage artifacts from the Paisley Caves. This study provides long-term data on culturally significant native plants used in the manufacture of fiber-based textiles over the last 14,000 years. The dissertation includes previously published material, and co-authored material.

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Connolly, Thomas J., Chris Ruiz, Guy Tasa, Jeanne McLaughlin, and Elizabeth Kallenbach
2010 The Archaeology of a Pioneer Family Cemetery in Western Oregon, 1854-1879, *Historical Archaeology* 44(4).

Connolly, Thomas J., Chris Ruiz, Elizabeth Kallenbach, and Mark Swisher
2009 Window on the Past (with Thomas Connolly, Chris Ruiz, and Mark Swisher), in *Journal of Northwest Anthropology* 43(2).

Kallenbach, Elizabeth
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Connolly, Thomas J., Pat Barker, Elizabeth Kallenbach, and Susan J. McCabe
2017 Netting in the Northern and Western Great Basin. *Journal of California and Great Basin Anthropology* 37(2):143- 167

Smith, Geoffrey M., Sara Sturtz, Anna Camp, Kenneth D Adams, Richard Hughes, Elizabeth Kallenbach, and Richard Rosencrance
2022 Leonard Rockshelter Revisited: Evaluating a 70-year-old Claim of a Late Pleistocene Human Occupation in the Western Great Basin, *American Antiquity*, 1-18.

Kallenbach, Elizabeth
2023 Testing the Feasibility of Fiber Identification for Fine Cordage Artifacts from the Paisley Caves, Oregon. *Journal of Archaeological Science*, 158 (105855).

Kallenbach, Elizabeth
2023 Dogbane (*Apocynum*), *Oregon Encyclopedia* (The OE), Oregon Historical Society.

Kallenbach, Elizabeth

In press, 2024. Fiber Artifacts of the Paisley Caves: 14,000 Years of Plant Selection in the Northern Great Basin. Submitted to *American Antiquity*.

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DEDICATION

This dissertation is dedicated to my husband Christopher L. Ruiz, for his encouragement and support.

TABLE OF CONTENTS

Chapter Page

I. INTRODUCTION

IV. CORDAGE AND NETTING FROM THE PAISLEY CAVES: PLANT MATERIALS, TECHNOLOGY, AND CULTURAL INDICATORS

LIST OF FIGURES

Figure Page

LIST OF TABLES

Table Page

CHAPTER 1

INTRODUCTION

Project Overview

The Paisley Caves are an archaeological site consisting of a series of rock shelters overlooking Summer Lake Basin in eastern Oregon, within the ancestral homelands of the Klamath, Modoc, and Northern Paiute peoples (Figure 2.1). University of Oregon field school excavations at the caves between 2002 and 2011 generated new evidence for pre-Clovis occupations (14,500-13,200 years ago), with radiocarbon dates placing the earliest known use of the caves at 14,500 years ago (Jenkins et al. 2017). Paleoethnobotanical remains from ancient basketry and cordage were recovered during field school excavations, spanning the late Pleistocene and Holocene eras. Great Basin cave sites are known for their excellent preservation of organic remains due to arid and protected conditions. The antiquity of the preserved Paisley Caves textile assemblage offers an excellent opportunity to explore how plants were used for technology by first Americans and subsequent cave occupants.

Paleoethnobotany, also referred to as archaeobotany, is the study of past human-plant relationships and is a rapidly developing field in the study of early hunter-gatherers due to advancements in archaeobotanical methods, new site discoveries, and an interest in exploring more diverse lifeways of early foragers (Chilton 2004; Vanderwarker et al. 2016). Material identification for textiles is an underutilized yet effective approach to the field of paleoethnobotany, as it can define culturally significant resources for manufacturing fiber-based technologies, illuminating how people interacted with their landscape over time in more nuanced and complex ways.

To explore these human-environmental relationships as it applies to textile production, the following research questions were addressed: 1) what plant taxa are represented in Paisley Caves archaeological textiles; 2) is there change in plant selection for textiles over time; 3) what can plant selection tell us about how people engaged with diverse and changing landscapes; and 4) how does fiber technology and artifact function/structure correlate to raw materials? To address these research questions, I draw from paleoecological, archaeological, and ethnographic data. I first established fiber identification methods and developed a reference collection. Secondly, I identified plant materials used in approximately 300 textiles (primarily basketry and cordage) from the Paisley Caves field school collections. Plant fibers from artifacts were analyzed using a combination of polarized light microscopy and scanning electron microscopy with consecutive energy dispersive X-ray spectroscopy. Third, a radiocarbon dating approach was designed to define chronology of plant selection. Twenty-nine new radiocarbon dates for selected artifacts were acquired, resulting in a total of 70 dates for Paisley Caves fiber artifacts. Fourth, identified taxa were grouped by ecology and chronology, and evaluated within the context of previously established settlement-subsistence models and climatic changes for the Northern Great Basin. Lastly, metrics and other artifact attributes were documented to investigate the relationship between raw material choice and technological applications of cordage.

Results of this work show that fiber identification of textiles, together with radiocarbon dating, contributes new information about landscape use, fiber industries, and cultural change in the Northern Great Basin. Expanded marshlands during the terminal Pleistocene/early Holocene (~12,000-11,000 years ago) (Table 1) created suitable plant communities within the Chewaucan Basin ideal for fiber technology, specifically wetland monocots and herbaceous dicots, including dogbane (*Apocynum* sp.), stinging nettle (*Urtica dioica*), and tule (*Schoenoplectus* sp.), also known as bulrush (*Scirpus* sp.). A change in fine cord technology during the early Holocene (11,700-8,200 years ago) supports previous arguments of a cultural shift around 9,000 years ago, but overall, continuity in fiber technology is key to subsistence activities and craft production throughout the Holocene. Despite increased aridity during the middle Holocene (8,200-4,200 years ago), in which people transitioned from caves to open air sites centered around lakeshores and wetlands, the suite of fiber plants and their technological application remains constant. During the late Holocene, bast fiber material diversified with the addition of blue flax (*Linum lewisii*) and milkweed (*Asclepias* sp.). The presence of flax particularly, a high elevation plant, may reflect the increased use of upland root collection areas as populations increased. Milkweed and cotton cordage and plaiting dating within the last 1000 years, and a more diverse textile assemblage overall, suggests expanded social contacts with groups farther south and east. This research illustrates the significance of native plants to Northern Great Basin lifeways; the antiquity and continuity of textile technologies spans millennia and is also evident in 19th century and contemporary Klamath, Modoc, and Northern Paiute artistic traditions.

Archaeology of the Paisley Caves

In 1935, archaeologist Luther Cressman established the Department of Anthropology at the University of Oregon (UO) and was the founding Director of the Oregon State Museum of Anthropology, now Museum of Natural and Cultural History (MNCH). Prior to the advent of radiocarbon dating, Cressman suggested a Terminal Pleistocene occupation of the Great Basin (10,000 years before present) based on excavations at Paisley Caves, Lovelock Cave, Fort Rock Cave, and other sites (Cressman 1942). Cressman's work at

Paisley Caves in the 1940s uncovered evidence of a pre-Mazama (prior to 7,700 years ago) living surface containing Pleistocene mammal bone and obsidian tools. Cressman's hypothesis of the early occupation of the Northern Great Basin has since been confirmed through ongoing excavations by University of Oregon archaeological field schools and the advancement of AMS dating and DNA studies over the last three decades (Gilbert et al. 2008; Jenkins et al. 2012; Shillito et al. 2020). Recent research generated from the Paisley Caves has also expanded our understanding of the Western Stemmed lithic tradition (Beck and Jones 2010; Graf 2007; Jenkins et al. 2017; Rhode and Louderback 2007, Wriston and Smith 2017), which, at Paisley Caves dates to 13,100 years ago (Jenkins et al. 2012).

The Paisley period is defined as 15,700 to 12,800 years ago, based on dates acquired from Paisley, Connley, and Fort Rock Cave sites, located in close proximity to each other in southeast Oregon (Aikens et al. 2011) (Table 2.1). The terminus of the Paisley period marks the end of a pre-Clovis human occupation, with the onset of the Younger Dryas cold snap between 12,900–11,600 B.P. when the earth's climate returned temporarily to a glacial state (Jenkins et al. 2016; Madsen 2015; Rosencrance et al. 2019). The site has been described as one of many stops along a Younger Dryas seasonal round in which occupants extracted grass seeds from upland sites in summer and fall (Jenkins et al. 2016; Kennedy 2018). Ongoing work between 2002 and 2011 has recovered intact human coprolites, a sagebrush rope dating to 12,000 cal B.P., and basketry weft fragment dating to 14,200 cal B.P. (Jenkins et al. 2016; Shillito et al. 2020). The Paisley and Connley period (12,800-11,500 years ago) artifacts include cordage, bone tools, botanical remains, obsidian and chert flakes, stemmed points, and Pleistocene animal bone.

A Younger Dryas botanical layer of sagebrush matting, dating to 11,960 and 12,930 cal B.P., is located between two mud lenses within Cave 2. The matting contains pronghorn hair, jackrabbit, and other mammal fur and hide, with an abundance of other faunal and botanical material, as well as obsidian flakes and two unlined hearth features. Fauna includes a diversity of animals, though pronghorn and jackrabbit were predominate, along with grouse, fish, and waterfowl (Jenkins et al. 2016:6). Evidence of fiber industries is also present in the botanical lens, including sagebrush braided rope and strips of sagebrush bark (likely material for textiles or fuel). A bone needle or awl in the lens was also likely used in the production of sagebrush artifacts such as sandals, clothing, and matting. Pinecones and nutshells were also present, along with other wood implements.

Later occupations of the Paisley Caves have been closely tied to environmental trends (Aikens et al. 2011; Jenkins 2004). The Fort Rock period (11,500-9000 years ago) and Lunette Lake period (9000-6000 years ago) textiles are characterized by fine cordage, rope, and tule basketry. However, during the more arid Lunette Lake period, hearths with limited faunal bone and sparse lithic scatters suggest brief, seasonal visits to the caves. Textiles are the most diverse during the Bergen period (6000-3000 years ago) and Boulder Village period (3000 years ago to historic era), with most of the fine cordage and netting, and basketry, dating to the late Holocene. Chapters 3 and 4 further define these later occupations.

Paleoethnobotany of the Northern Great Basin has been well documented (Cummings 2004; Fowler and Rhode 2011; Kennedy 2018; Rhode and Louderback 2007; Smith 2001; Stenholm 1994). At Paisley Caves, archaeobotanical studies through seed, pollen, and phytolith analysis suggest a diverse diet. Human coprolites from Paisley Cave 2 were analyzed by Taylor et al. (2020); coprolites were subdivided into two sets: a late Holocene group dating to 2124±25 cal B.P. and a late Pleistocene set with dates of 9620±30 and 10,833±59 cal B.P. Edible taxa from both sets of coprolites include greasewood (*Sarcobatus vermiculatus*), sunflower family (Asteraceae), mustard family (Brassicaceae), carrot family (Apiaceae), Great Basin wild rye (*Leymus cinereus*), wild buckwheat (*Eriogonum* sp.), and evening primrose family (Onagraceae). Of these, only carrot, wild rye, and *Chenopodium* were present in the late Pleistocene set, while few *Chenopodium* were present in the late Holocene set (Taylor et al. 2020). Arboreal pollen from both sets indicates a mid-level elevation of several taxa, including pine (*Pinus* sp.), poplar (*Populus* sp.), fir (*Abies* sp.), hemlock (*Tsuga* sp.), alder (*Alnus* sp.), and juniper (*Juniperus* sp.); however, pollen from these taxa are anemophilous (wind pollinated). Beck et al.'s (2018) pollen analysis of sediment from Paisley Caves suggests that the Younger Dryas climatic event did not affect all areas of the Great Basin in the same way, and around Paisley Caves, it was slightly wetter and cooler, with higher counts of conifer pollen during this period than afterwards. Cheno-ams and bunch grass (Poaceae) seeds were an important dietary plant along with several other upland grass seeds. Younger Dryas macrofloral remains from Paisley Cave 1 hearth suggest a diverse diet of *Chenopodium*, bunch grass, needlegrass (*Achnatherum),* borage (Boraginaceae), and saltbush (Kennedy 2018). Kennedy (2018:286) describes all of these charred seed taxa as upland plants, which reflects the seasonal use of the caves during early spring and fall when these plants would have been collected (Jenkins et al. 2016).

Northern Great Basin Textiles

Historically, Great Basin peoples used plants in the construction of much of their material culture, including fishing, fowling, and hunting nets, sewing thread, fishing line, clothing, storage containers, boat construction, bow strings, snares, and infant carriers. The Northern Paiute, Klamath, and Modoc peoples of eastern Oregon and western Nevada relied on valley floor marsh ecosystems around lakeshores and seasonal springs for subsistence and materials. Water-loving plants used in basketry such as tule (also known as bulrush), cattail (*Typha* sp.), rush (*Juncus* sp.), and sedge grass (*Carex* sp.), thrived in these dynamic environments, which in turn were home to a diversity of waterfowl and other mammals.

Additionally, bark from alder (*Alnus),* cottonwood (*Populus*), aspen (*Populus tremuloides*), cliffrose (*Purshia* sp.), willow (*Salix* sp.) and sagebrush (*Artemisia* sp.), was stripped and processed for fiber items (sticks and roots were also used). People made cord for netting and other purposes from the inner bark of several plant stems. Dogbane (*Apocynum cannabinum*) was most frequently used throughout much of the Great Basin. Sagebrush, bulrush, cattail, and willow could also be used for coarser rope and braids, but fine cords for sewing, fish lines, and nets were made from soft bast fibers (Barrett 1910). Stinging nettle fiber (*Urtica dioica),* milkweed (*Asclepias* sp.), Rocky Mountain flax, also known as blue or prairie flax (*Linium lewisii*) were used by Northern Great Basin peoples (Anderson 2005; Barrett 1910; Coville 1897; Cummings 2004; Downs 1966; Fowler and Fowler 1970; Jenkins 1994; Stewart 1941; Wheat 1967), but rarely are these fibers identified in archaeological cordage.

Archaeological textiles have been recovered from many dry cave sites throughout the Great Basin, and collectively, fiber artifacts from these sites make up one of the largest archaeological textile collections in the world. In Oregon alone, assemblages from Roaring Springs Cave, Catlow Cave, Dirty Shame Rockshelter, Paisley Caves, Fort Rock Cave, Connley Caves, and Cougar Mountain Cave have defined fiber technologies for the Northern Great Basin (Connolly and Barker 2008; Connolly 1994, 2013; Connolly et al. 2016; Ollivier 2016). Research generated from these collections and others has focused on subsistence, mobility, adaptations, cultural attributes, and regional chronologies (Adovasio 1986a, 1986b, Adovasio and Pedler 1994; Adovasio, Andrews, and Illingsworth 2009; Connolly and Barker 2008; Connolly 1994, 2013; Connolly et al. 2016; Ollivier 2016). Most well-known are Fort Rock style sandals, named after the cave site, which were first recovered by Luther Cressman in 1938 and 1939 and date to around 10,000 B.P. This sandal type is limited geographically to the Northern Great Basin.

Adovasio (1970) first proposed three basketry regions: the Northern, Western, and Eastern Great Basins, and chronological stages as: Stage 1: 11,000-6,500 BP; Stage 2: 7,000-1000 BP; and Stage 3: 1000 BP to the historic contact period. Stage 1 Western and Northern Great Basin basketry is characterized as undecorated, simple twining, open and closed Z-twist basketry. Coiling is absent, and diagonal twining and decorative elements occur late in this stage. In the Northern Great Basin, Stage 1 (pre-Mazama) basketry is all plain twined and undecorated. Termed “Catlow twining”, this basketry is close twined with Z-twist tule wefts, and Z-twist, s-spun tule cordage warps. Catlow twined basketry has incredible antiquity and continuity; this technology decreased in frequency in the Western Great Basin starting around 4000 B.P. (Camp 2018) but remained dominant in the Northern Great Basin and is present in historic Klamath and Modoc weaving.

As part of the ongoing Great Basin Radiocarbon Dating Program, Thomas Connolly oversaw the acquisition of new dates from a variety of Northern Great Basin textile types, which provide a more thorough and complex picture of early Holocene basketry (Connolly and Barker 2004; 2008). These dates offer new insight into the timing and occurrence of decorated basketry (overlay and false embroidery) and elaborations on plain twining, including diagonal and cross-warp twining. Though small in number, basketry with these decorative elements date to the terminal pre-Mazama period. Most noteworthy is the abrupt change from Fort Rock style to Multiple Warp and Spiral Weft styles around 9,000 B.P., followed by the occurrence of decorative basketry styles around 8,000 years ago.

Paisley Caves Textile Assemblage

Basketry, cordage, and other textiles from the Paisley Caves number approximately 549 artifacts. The UO field school excavations, conducted between 2002 and 2011 under the direction of Dennis Jenkins, include roughly 430 fiber artifacts. The UO MNCH legacy collections include an additional 125 fiber artifacts; eight were first acquired by amateur collector Walter J. Perry in 1937 (Accession 100BP), followed by Luther Cressman's excavations in 1938 and 1939 (Accessions 60 and 61), which resulted in an additional 77 artifacts. Cressman's collections include fine cordage, rope, Catlow twined basketry, and Multiple Warp style sandals that have been dated to the late Holocene. Fort Rock and Spiral Weft style sandals are not present in any of the collections. In 2012, the Museum was gifted a small collection of a dozen fiber artifacts originally collected in the 1950s, including another Multiple Warp sandal, basketry, and cordage (Accession 2642). Perishables from these legacy collections and recent gifts also include leather, rabbit fur, arrow shafts, an atlatl, and pointed sticks; these are excluded from the total counts.

Chapters 2, 3, and 4 only include data from the field school excavations, as these materials have the best chronological controls. Cordage, both fine and coarse cord, makes up most of the assemblage, with approximately 330 catalogued specimens; the cordage technology and raw materials are detailed further in Chapter 4. Fine cordage and netting are made from dogbane, stinging nettle, flax, milkweed, and cotton. Medium cord is almost exclusively made from tule stem, and coarse cordage (more rope-like) is made primarily from sagebrush bark (but also bitterbrush and sumac). The collection also includes early Holocene sagebrush bark three-strand braids, twined basketry, matting, weft and warp elements, knotted, folded, and twisted fibers, and coils. There are also approximately 574 cataloged unmodified macrobotanical remains from the field school excavations; cursory review of this material did not reveal any definitive basket or cord-making raw material. Specimens include shredded bark, grass, twigs, and sticks, and are excluded from the analysis in the following chapters.

Theoretical Framework

Historical Ecology

Historical ecology is the diachronic study of human-environmental interactions (Balée 1998; Balée and Erickson 2006; Crumley 1994; Szabó 2015); this research program is characterized by its multidisciplinary approach to understanding landscape management, adaptive resource use, and current and past climatic and ecological conditions (Deur and Turner 2005; Fitzpatrick and Keegan 2007; Kirch 2004, Redman et al. 2004; Thompson and Waggoner 2013). Historical ecology operates under the premise that humans are a keystone species and serve as a catalyst for ecological change by actively managing or modifying their environment (Balée and Erickson 2006; Thompson and Waggoner 2013). Chapters 3 and 4, which are built on methodology established in Chapter 2, draw from historical ecology to examine the long-term relationship between people and their local environment, using material remains from fiber arts and technology. While plant selection is constrained by environmental factors and subject to changing landscapes, textile production and raw material choice is based in decision-making processes formed largely by cultural traditions and ecological knowledge that places human agency at the forefront. To what extent people modified or altered plant habitats as they returned seasonally is an important next question outlined in Chapter 5.

The integration of anthropology and ecology primarily begins in the mid-20th century with Julian Steward's cultural ecology, Leslie White's cultural evolution, and Andrew Vayda's human ecology. Cultural ecology, however, assumes a one-way adaptation to the environment, and along with ecological anthropology (behavioral ecology) concepts, lacks human agency (Szabó 2015). Historical ecology operates under the premise that our relationship with our environment is not inherently destructive nor sustainable (Balée 1998). Humans do not necessarily decrease biodiversity nor sustain it. Foragers and horticulturalists have impacted their environment in detrimental ways (e.g., decreased biodiversity), especially in island settings in which colonists introduce new species (Crumley 1994; Fitzpatrick and Keegan 2007; Fitzpatrick and Erlandson 2019; Redman et al. 2004). Conversely, a plethora of studies illustrate traditional ecological management activities that sustain or enhance biodiversity (Anderson 2005; Balée 1994; Fowler and Lepofsky 2011; Turner and Deur 2005).

Recent developments in historical ecology include reevaluation of baseline studies (Hanazaki 2013; Pauly 1995), studies regarding biodiversity and extinction of certain species (Braje et al. 2017; Kirch 1997; 2004), environmental engineering (Deur and Turner 2005), landscape transformations (Gill et al. 2019), and the collapse or destabilization of socio-economic systems (Thompson 2013). Historical ecology applications in archaeology and paleoecology have also contributed to understanding the role of human agency in a diversity of past environmental conditions to better inform future environmental policies.

Traditional resource and environmental management

Within historical ecology, ongoing research in environmental management by small scale societies has contributed to the changing perceptions of Native Americans and other Indigenous people as active managers of their landscapes (Anderson 1993, 2005; Boyd 1999; Deur and Turner 2005; Lepofsky and Armstrong 2018; Lightfoot et al. 2013; Turner 1999). Studies in traditional resource and environmental management (TREM) examine ways in which people have modified landscapes or engineered their environments to enhance the productivity and abundance of desired resources (Fowler and Lepofsky 2011; Lepofsky and Armstrong 2018). TREM falls under the umbrella of traditional ecological knowledge (TEK), which is an accumulation of knowledge about the natural environment that has been passed down through generations. TEK is usually part of a traditional or indigenous communities' way of viewing the world around them and can be characterize as cumulative, historical, local, holistic, and spiritual (Fowler and Lepofsky 2011; Menzies and Butler 2006; Nazarea 1998). In non-agrarian societies, it is more difficult to document TREM archaeologically because the process of resource management can mimic natural processes, and archaeological evidence is often ephemeral or non-existent (Adams 2004). Common ways in which people enhance or modify their environment is through landscape burning, weeding, coppicing, thinning of roots, and rock and earth formations to modify the hydrology of tidal zone resources. To explore TREM through time, researchers employ a diverse set of approaches, including ethnography, historic accounts, archaeology, paleoethnobotany, paleoecology, zooarchaeology, and fire ecology.

Niche construction theory and human-engineered ecosystems

Chapters 2, 3, and 4 all provide foundational research that can be applied to future studies of managed plant habitats, specifically stands of dogbane, stinging nettle, and tule. In Chapter 5, an experimental approach to documenting traditional resource management is described under future research directions. A predictive model of human niche construction can help identify between natural and anthropogenic phenomena. Smith identifies six patterns of niche construction worldwide, including: 1) modification of plant communities; 2) broadcast sowing of annual seeds; 3) transplantation of wild perennial nut and fruit species; 4) in-place enhancement of perennial nut and fruit species; 4) transplantation and in-place manipulation of perennial roots; and 6) environmental engineering to increase prey abundance (Smith 2011a:837). Niche construction theory (NCT) is a perspective that emerged from evolutionary biology that assumes the organism plays an active role in shaping evolutionary processes through complex interactions between environmental factors and species over time. In this reciprocal relationship, animals and their environments are not separate entities, but are co-dependent; species modify their own niche and surrounding niches by a continuous dynamic of choices, activities, and metabolisms (Smith 2011a; Zeder 2012). Proponents of human NCT (Smith 2011a, 2011b, 2014; Laland, Matthews, and Feldman 2016; Zeder 2012) argue that it is a driver of evolutionary processes resulting in demonstrable genetic change and is a major factor in human evolution (Boivin et al. 2015).

Throughout history, humans have modified their environments to enhance the health or abundance of desired resources, from thinning roots and pruning to domestication of plants and animals. For example, redbud has been used in basketry in central and northern California as a primary material in basketry for generations, and has been managed by the Sierra Miwok, Western Mono, and other indigenous California groups for generations (Anderson 2005). The tradition of basket weaving is dependent upon access to a significant amount of plant materials, and healthy plants best suited for fiber technologies can require annual weeding, pruning, root thinning, and burning (Anderson 2005; Dobkins et al. 2017). Many studies that employ NCT focus on foragers and small-scale societies to understand how humans have modified their environment or engaged in ecosystem engineering as ways to enhance resources to create sustainable and predictable subsistence economies (Deur and Turner 2005; Smith 2011a, 2011b). Examples include human modification of estuarine environments and selection pressures on the recipient tidal marsh plants in the Pacific Northwest (Deur 2005), and root processing and cultivation on the Northwest Coast, where foraging societies have engineered their environment to enhance the growth and abundance of plants and animals by expanding their natural habitat, including wapato (Darby 2005), camas (Turner and Peacock 2005), and shellfish (Groesbeck et al. 2014; Lepofsky et al. 2015).

Partnerships with Tribal Communities

Partnerships with tribal communities have played an important role in the inception of this project. Conversations with contemporary weavers and descendant communities over the years have significantly informed this research, including work with Myra Johnson Orange (The Confederated Tribes of Warm Springs, Northern Paiute and Sahaptin elder and basketweaver), Stephanie Craig (Confederated Tribes of

Grand Ronde, basketweaver), Perry Chocktoot (The Klamath Tribes), Sara Siestreem (Confederated Tribes of Coos, Lower Umpqua, and Siuslaw Indians, weaver and multidisciplinary artist), and Kathy Wallace (Karuk, Yurok, and Happy Valley basketweaver, California Indian basketweavers Association founding member). In both formal and informal settings, Tribal members and weavers shared their knowledge, perspectives, and ideas about the past, present, and future of weaving, native plants, and the ways in which research is shared and applied. Kathy Wallace's life work in environmental justice and access to native plant communities illustrates the deep connections to landscape and the tradition of weaving. Sara Siestreem's modern approach to ancient traditions showcases her communities' long-term relationship with fiber plants. Through our connections with museum basketry exhibits, she generously contributed to my plant reference collection. During a cattail gathering event in October of 2023, Perry Chocktoot described how to collect and process stinging nettle, which we were able to do along the shore of the Klamath River.

In 2021 and 2022, MNCH partnered with the UO Library to develop a test project for *Mukurtu* Content Management System, an open-source digital heritage platform designed to empower Indigenous communities to manage and share digital heritage, following ethical guidelines and practices (https://mukurtu-west.libraries.wsu.edu/digital-heritage). As a museum employee at MNCH, I shared basketry images and data, co-hosted with the UO Northwest Indigenous Language Institute and several Oregon Tribes. A second phase of this project included conversations with Myra Johnson-Orange about these baskets, her family's tradition of weaving, and the plants collected. This was the beginning of a relationship that has continued throughout this project; future work with Ms. Johnson-Orange is detailed in Chapter 5 under future work.

Stephanie Craig conducted work at MNCH to identify weaver's names in archives associated with Grande Ronde baskets. This has informed her current research, in which she is developing fiber identification methods for plants used in her family's baskets. In conversations about our parallel projects, we developed an idea for a collaborative project, detailed in Chapter 5 under future work. All of these discussions have shaped the trajectory of this project, in which an archaeological approach is used to understand the tradition of weaving and people's changing relationships with their environments, in the past as well as today.

Chapter Overviews and Structure of the Dissertation

The dissertation consists of three related articles, each addressing one or more of the interrelated research questions above. Chapter 2, "Testing the Feasibility of Fiber Identification for Fine Cordage Artifacts from the Paisley Caves, Oregon," focuses on fiber identification methods. This article was published in 2023 in *Journal of Archaeological Science*, volume 158. Chapter 3, "Fiber Artifacts from the Paisley Caves; 14,000 Years of Plant Selection in the Northern Great Basin," provides an overview of the relationship between humans and plant communities over time within the context of changing climatic conditions and established settlement-subsistence models for this region. This chapter was accepted for publication in *American Antiquity* in November of 2023. Chapter 4, "Cordage and Netting from the Paisley Caves: Plant Materials, Technology, and Cultural Indicators," co-authored with Thomas J. Connolly, will be submitted to a peer-reviewed journal in 2024. Chapter 4 evaluates cordage technology, including raw material, to explore changes and continuity in cordage industries in the Northern Great Basin.

Historically, a greater number of fiber plants have been described in the literature than have been documented archaeologically (Barret 1910; Cummings 2004; Fowler 1981; Jenkins 1994; Stewart 1941; Wheat 1967). Prior to this current study, fiber artifact descriptions for Paisley Caves were limited to sagebrush (*Artemisia* sp.), unspecified "hemp," and tule. Tule is often used as a default for any hard stem plant. This lack of plant identification in textiles is generally true of other cave sites in the Northern Great Basin. Cordage and netting are generally made from herbaceous dicot plant stems, including those in the Paisley Caves assemblage. Vascular fiber bundles (bast) are much softer than monocot stems (tule, cattail) and bark (sagebrush) making them ideal for string, cordage and loom-woven fabric. A pilot project was conducted in 2000-2001, in which methods for fiber identification were evaluated. Methods for bark and monocot stem fiber have been well developed for Northern Great Basin plant taxa, however, identification of bast fibers, specifically those native to the Great Basin, was found to be generally absent in North American archaeology. Thus, the study presented in Chapter 2 tests the efficacy of previously established bast fiber identification methods when applied to archaeological cordage from the Paisley Caves.

While many Northern Great Basin textiles such as sagebrush rope and tule stem basketry require minimal processing, and can often be identified macroscopically, fine cordage (string-like) made from bast fibers (the inner phloem fiber from herbaceous dicots) such as dogbane, usually require microscopic analysis. Polarized light microscopy and energy dispersive X-ray spectroscopy were the primary methods explored following Jakes et al. (1994), Jakes and Mitchell (1996), Jakes (1996), Bergfjord and Holst (2010), and Haugan and Holst (2013). These methods were first applied to herbarium control samples for dogbane, stinging nettle, milkweed, and flax, four well-known sources for cord fiber used throughout the Northern Great Basin. Results from the control study were then applied to Paisley Caves fine cordage and netting artifacts. Results reveal continuous use of stinging nettle and dogbane since the early Holocene, with flax and milkweed occurring much later, within the last 3000 years.

Chapter 3 includes all textile artifacts from the field school collections in the analysis, approximately 430 items, including the 180 bast fibers identified as part of the Chapter 2 study. While not discussed in Chapter 2, fiber characteristics were established for a set of common bark and monocot textile plants based on reference collections (Appendix B); these methods are included in Chapter 3. I then considered the ecology of the represented taxa (e.g., wetland, dryland) (Appendix A), and refined the chronology through radiocarbon dating of selected artifacts. This chapter describes the radiocarbon dating procedure for the current project and includes a summary of new dates acquired and previously reported dates, with plant material identification (Table 3.1). Results contribute new information about settlement-subsistence models for the Northern Great Basin as it relates to climatic changes, offer a more nuanced look at seasonality throughout the Holocene, and suggest continuity of plant selection for technology. Artifacts were grouped by type (e.g., fine and coarse cordage, basketry, knotted fiber) to evaluate plant use over time, as specific plants are targeted for different applications, however, artifact measurements and technological variations were not assessed. This was beyond the scope of the Chapter 3 study, which is already a broad approach to paleoethnobotanical practice spanning the Terminal Pleistocene and Holocene. However, technological attributes are discussed in Chapter 4.

Chapter 4 builds on the studies presented in Chapters 2 and 3, in which artifact function/structure, technological attributes, and raw material are evaluated. Co-author Thomas Connolly and I cataloged the fiber assemblage from the field school collections, recording metrics (e.g., cord diameter, length, number of twists per cm) and artifact attributes (e.g., twist direction, number and type of knot). This catalog served as the basis for a diachronic study of the correlation between cordage technology and raw material. While there are several previous studies on Great Basin cordage technology (Coe 2021; 2023; Connolly et al. 2017; Haas 2006; Jolie 2005), raw material as a variable is usually not included, nor are there studies with the size and temporal reach comparable to that of the Paisley Caves.

Chapter 5, Conclusions, highlights significant findings from Chapters 2, 3, and 4, and provides direction for future research framed within historical ecology, as well as collaborative projects with contemporary weavers. Appendices present relevant data that was excluded from chapter articles due to size limitations of the journals. Appendix A. Ecology of Textile Plants, includes habitat and technical applications for Northern Great Basin plants, and Appendix B. Fiber Reference Collection, provides a catalog of taxa included in the reference collection. References Cited is a combined list of all references cited in each chapter.

CHAPTER 2

TESTING THE FEASIBILITY OF FIBER IDENTIFICATION FOR FINE CORDAGE ARTIFACTS FROM THE PAISLEY CAVES, OREGON

Previously published in *Journal of Archaeological Science*, volume 158, 2023, authored by Elizabeth Kallenbach.

1. Introduction

The Paisley Caves, located in the Northern Great Basin of eastern Oregon, is one of the earliest archaeological sites in North America, with site occupation spanning 14,000 years (Gilbert et al. 2008; Jenkins et al. 2012; Jenkins et al. 2016; Shillito et al. 2020) (Figure 1). Textiles from the Paisley Caves have exceptional preservation and antiquity, and identified botanical remains from these fiber artifacts offer new insight into how people engaged with their landscape through time. Collectively, dry cave sites in the Great Basin have produced some of the largest archaeological fiber collections in the world; fine cord (string-like) used in sewing and net-making has been found at most of these sites (Adovasio 1986;

Figure 1. The Paisley Caves are located in south central Oregon, with the Northern Great Basin.

Adovasio, Andrews, and Illingsworth 2009; Coe 2021; Connolly and Barker 2008; Connolly 1994, 2013, 2022; Connolly et al. 2016; Fowler and Fowler 2008). Many fiber artifacts such as ones made of *Schoenoplectus acutus* (tule) stem and *Artemisia* (sagebrush) bark are manufactured with minimal processing, and thus often retain macroscopically identifiable features.

This study focuses on processed bast (phloem) fibers extracted from plant stems, which are often indistinguishable from each other after being twisted into fine cordage. Plant fiber identification for fine cord has generally not been conducted in this region, and in some cases, macroscopic identifications have led to erroneous assumptions and misidentifications. This study tests the feasibility of applying previously established fiber identification methods to the Paisley Caves assemblage, including transmitted light microscopy (TLM), polarized light microscopy (PLM) and scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDS).

The four plants selected for the study were *Apocynum* (dogbane or Indian hemp) (Figure 2a), *Urtica dioica* ssp. *gracilis* (stinging nettle) (Figure 2b), *Asclepias* (milkweed) (Figure 2c), and *Linum lewisii* (blue flax or Rocky Mountain flax) (Figure 2d). Species-level differences were not considered for *Apocynum* and *Asclepias* genera, as multiple species were used for fiber. Subspecies *gracilis* is the native nettle to the Americas, hereinafter referred to as only *Urtica dioica*. These plants are known historically and archaeologically as the primary sources of fibers used in fine cord-making throughout the Northern Great Basin (Anderson 2005; Barrett 1910; Coville 1897; Cummings 2004; Downs 1966; Fowler and Fowler 1970; Stewart 1939; Wheat 1967) (Figure 2). Dogbane, nettle, and milkweed are well represented in Klamath twined basketry and caps, and in Columbia Plateau Wasco and Wishram soft twined bags (Schlick 1994). *Amsonia tomentosa* (Woolly bluestar) produces a strong fiber similar to dogbane and was used by the Owens Valley Paiute but is much less common to the north (Rhode 2002; Steward 1933). *Chamerion augustifolium* (fireweed) is also indigenous to Oregon and was used by Northwest Coast peoples (Hammond-Kaarremaa 2018; Turner 1971) but is not documented ethnographically in the Great Basin.

Few studies document the microscopic structure of herbaceous dicot plant stems used for fine cordage, yarn and loom-woven cloth (Bergfjord and Holst 2010; Haugan and Holst 2013; Jakes et al. 1994; Jakes 1996; Suomela et al. 2018; Suomela et al. 2022). Museum textile conservation and archaeological fiber analysis in Northern Europe has focused on *Cannabis sativa* (hemp), *Urtica dioica*, *Linum usitatissimum* (flax), and *Gossypium* sp. (cotton). “Hemp” has been used to refer to dogbane and bast fibers generally in North American archaeological literature (Connolly et al 2016, 2017; Kelly and Fowler 1986; Lawlor 2020; Wheat 1967); for this study, hemp refers to *Cannabis sativa*, not *Apocynum*. The few studies on plant fiber specific to North American archaeological fiber identification have focused on *Apocynum*, *Urtica dioica*, *Asclepias*, *Yucca* sp. (yucca), *Gossypium hopi*, and animal hair (Coe 2012; Florian et al. 1990; Haas 2001; Jakes 1996; Jakes et al. 1994; Jakes and Mitchell 1996; Song et al. 2017). Coe (2012) and Lawlor's (2020) fiber studies in the Eastern Great Basin also included *Linum lewisii*.

Figure 2. Bast fiber plants of the Great Basin: a. *Apocynum cannabinum* (dogbane); b. *Urtica dioica* (stinging nettle); c. *Asclepias speciosa* (showy milkweed); d. *Linum lewisii* (blue flax).

For the current study, I observed microscopic characteristics of reference fiber samples from the selected four plants (Figure 2) following procedures described in the literature (Bergfjord and Holst 2010; Florian et al. 1990; Goodway 1987; Haugan and Holst 2013; Jakes et al. 1994; Jakes 1996; Suomela et al. 2018). Secondly, I observed elemental compositions following methods presented by Jakes et al. (1994), Jakes and Mitchell (1996), Jakes (1996), and Bergfjord and Holst (2010). I applied results from the control study to 180 fiber cordage artifacts from the Paisley Caves, one of oldest and most continuous textile assemblages in North America, with cordage dating as early as 11,000 years ago to as recent as 300 years ago. Results from the archaeological fiber identification stands to inform anthropological research in textile technology, the paleoenvironment, human-environmental interactions, and ecological knowledge that spans deep time.

2. Fiber Cordage from the Paisley Caves

The Paisley Caves consist of eight rock shelters located above what once was pluvial Lake Chewaucan, which provided ideal conditions for organic preservation of artifacts for millennia. The perishable fiber artifact assemblage numbers over 500 specimens, including basketry, sandals, rope, braids, knots, twisted and coiled fibers, and fine cordage. There are approximately 180 fragments of fine cordage, defined as 8-14 twists per cm, ranging in diameter from 0.6 to 3.3 mm with a median of 1.6mm; a range that represents an unusual number of very fine, string-like cords, all made from bast fiber (Figure 3a-d). Non-bast cordage excluded from the study, is represented by medium size cord (2.6mm in average diameter), up to rope-like cord (7-12mm in diameter). Forty-nine specimens of fine cord have at least one weaver's knot (Figure 3a), those with two or more sequential knots are considered fragments of a net mesh. Radiocarbon dates for two-ply fine cord from the Paisley Caves confirm its continued use since the early Holocene, about 11,000 years ago (Figure 3). Fine cordage made by Klamath, Modoc, and Northern Paiute peoples of the Northern Great Basin was a craft instrumental to subsistence technology, clothing, and housing. Great Basin peoples used cord in sewing, net manufacture (Figure 3a, f), for bow strings, fishing line, snares, basketry cordage warps (Figure 3e), for the mesh of snowshoes, and in lashing and tying tule matting (Barrett 1910; Colville 1897; Connolly et al. 2017; Fowler and Fowler 1970; Kallenbach 2013; Oetting 1994; Rosencrance et al. 2019; Rhode 2002; Spier 1930; Stewart 1939; Wheat 1967).

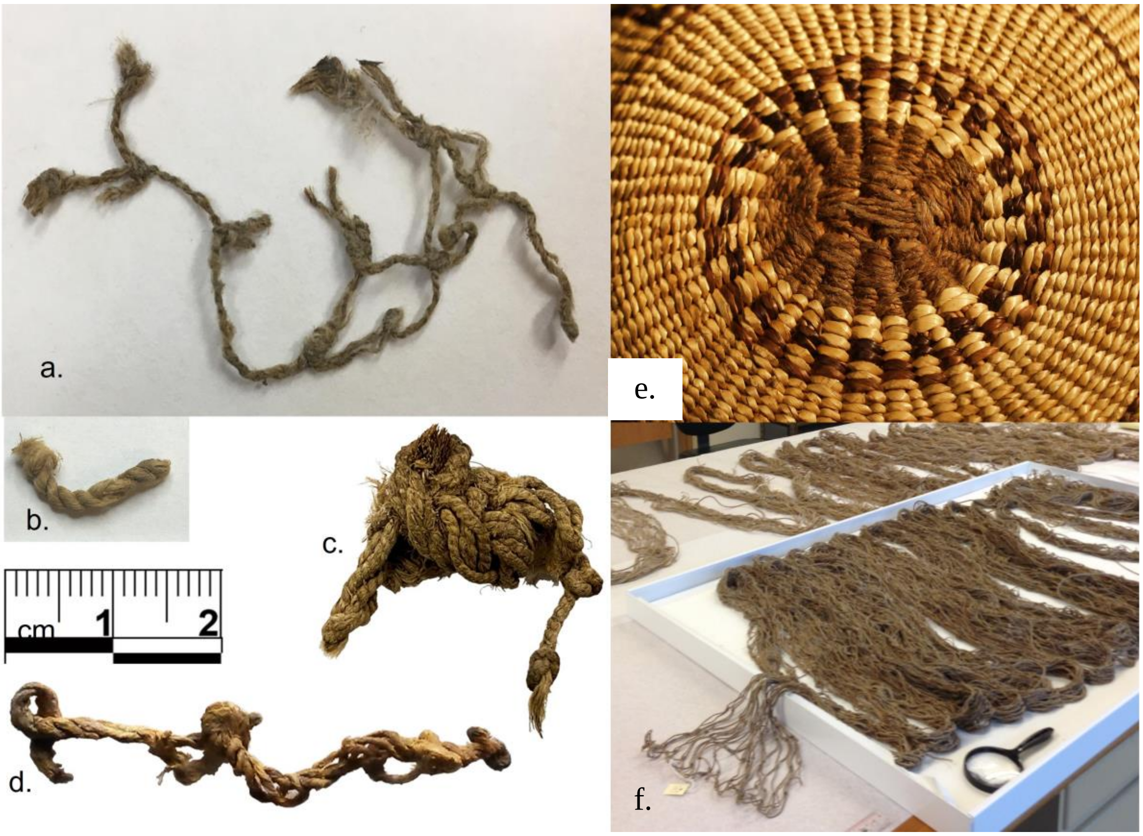


Figure 3. a. dogbane net fragment from the Paisley Caves; b. stinging nettle cordage from the Paisley Caves dating to 11,070-10,715 cal B.P; c. dogbane cordage bundle from the Paisley Caves; d. dogbane, with possible simple looping from the Paisley Caves dating to 10,279-10,212 cal B.P. (Jenkins et al. 2013); e. 19th century Klamath woman's hat (view of top) with dogbane cordage warp start, University of Oregon Museum of Natural and Cultural History (MNCH); f.

dogbane and stinging nettle long nets from Chewaucan Cave, Oregon dating to 400 cal B.P. (MNCH).

3. Previous Studies in Archaeological Bast Fiber Identification

Polarized light microscopy has been used in fiber identification in museum artifact conservation, forensic science, and archaeology since the 1950s, and continues to be one of the primary methods used in archaeological bast fiber identification (Coe 2012; Florian et al. 1990; Goodway 1987; Jakes et al. 1994; Schaffer 1981). However, plant fiber can be challenging to identify even microscopically as fibers are often highly processed (i.e., retting, hammering, peeling), and archaeological fibers in particular have often undergone chemical and morphological changes over time (Jakes et al. 1994). Morphological features of bast fibers are often very similar and can vary greatly even within the same species (Bergfjord et al. 2010; Rast-Eicher 2016; Catling and Grayson 1998) due to differing growth rates and collection season. Archaeological fibers are additionally subjected to further degradation which can physically alter the fibers. For best results, a combination of techniques is used in the identification process to examine morphological features and elemental composition of fibers and inorganic inclusions (Bergfjord and Holst 2010; Jakes and Mitchell 1996; Markova 2019), including TLM, PLM, and SEM with EDS. Infrared spectroscopy has been used for examining textile particulates (such as mineralization from dyes) from the Seip Mound group in Ohio (Jakes et al. 2010), and wide-angle X-ray scattering to study the nanostructure of hemp, flax, and nettle from Finnish archaeological textiles (Viljanen et al. 2022). DNA is not commonly used to identify plant fibers in archaeological textiles, as aDNA is often destroyed by retting (Berfjord et al. 2010; Dunbar and Murphy 2009; Lindahl 1993) or other post-depositional conditions, though DNA extracted from modern rope flax fibers has been applied in forensic studies (Dunbar and Murphy 2009) and to archaeological mulberry bark cloth (Peña-Ahumada et al. 2020).

3.1 Fiber morphology

Early work in North American archaeological fiber identification was done on Hopewellian mound textiles, which included rabbit hair, dogbane, milkweed, and nettle (Willoughby 1938), though methods of identification are unclear (Jakes et al. 1994). Jakes et al. (1994) acknowledge the difficulty and inconsistencies in fiber identification and thus developed a reference collection of common eastern North American fibers used in textiles. Observations were used to create the on-line Fiber Reference Image Library (Jakes n.d) which demonstrates these identification methods using polarized light microscopy (Jakes et al. 1994; Jakes 1996). Like direct light, PLM is used to observe a fiber's diameter, surface morphology, and frequency and spacing of dislocations (a wrinkle or uneven region in the cell wall) (Figure 4b, c) and surface cross markings (Figure 4a, d). Polarization, however, allows light waves to travel only in one direction, and while studying the bast fibers, the polarizer and analyzer are crossed, so light travels horizontally and vertically. PLM is thus also used to identify birefringence in the cell wall, isotropic and anisotropic qualities, lumen shape, the presence or absence of crystals, and the naturally occurring S or Z twist in the microfibrillar layer. *Urtica dioica* fiber diameter is usually significantly wider than other bast fibers, typically between 30-40µm, and as wide as 100µm, and can have numerous

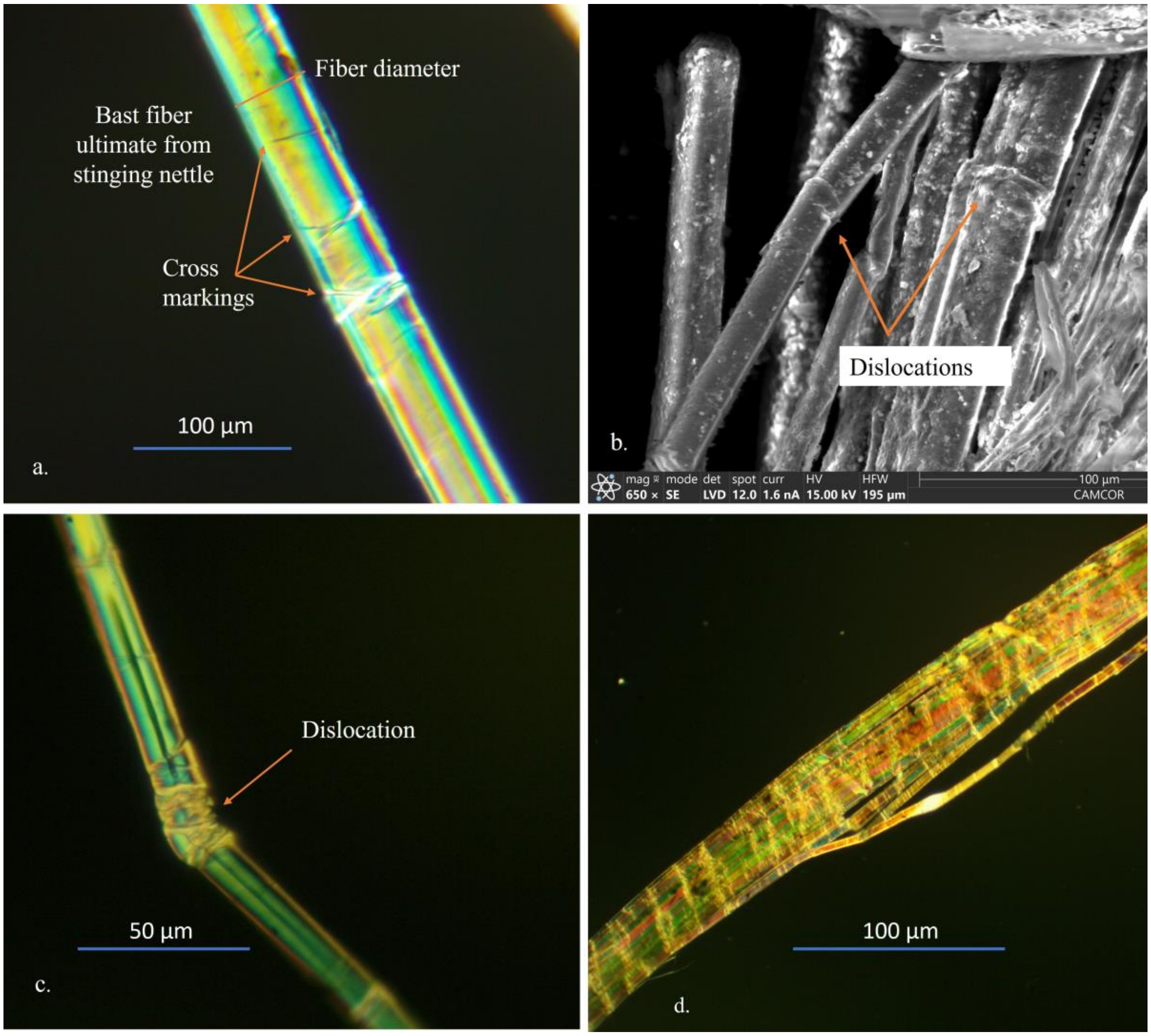


Figure 4. a. fiber ultimate under polarized light showing diameter and cross markings; b. fiber bundle under SEM showing dislocations or nodes; c. fiber showing dislocation; d. stinging nettle fibers showing numerous cross markings.

cross markings on the fiber surface; *Linum lewisii* is generally much smaller in diameter (between 5-20µm) and shows fewer dislocations, and *Asclepias* can have a narrow lumen and fibers are often clumped together and difficult to separate (Florian et al. 1990).

Apocynum is one of the most common fibers used in North America (Anderson 2005) (Figure 5c). All species of *Apocynum* can show a consistent, disrupted, ridged surface (surface folds), probably from the removal of the cambium layer. Though this feature can appear as cross markings in *Asclepias* and *Urtica dioica*, only in *Apocynum* does it appear with frequency and uniformity (Florian et al. 1990; Jakes et al. 1994; Jakes 1996) thus making this a highly distinguishing feature (Figure 5a, b). Bast stem fiber processing in North American indigenous cultures requires removal of the outer bark, usually by scraping, followed by separation of the inner pith from the soft fiber strands. This is done by retting or hammering to crack open the stem, then splitting or separating the stem into two or three sections and peeling away the pith. Jakes (1996) processed stems by both retting and hammering techniques, soaking, and boiling, to document possible changes in fiber morphology. Most notable is the ridged surface of *Apocynum* that remained intact even after these treatments (Jakes 1996).

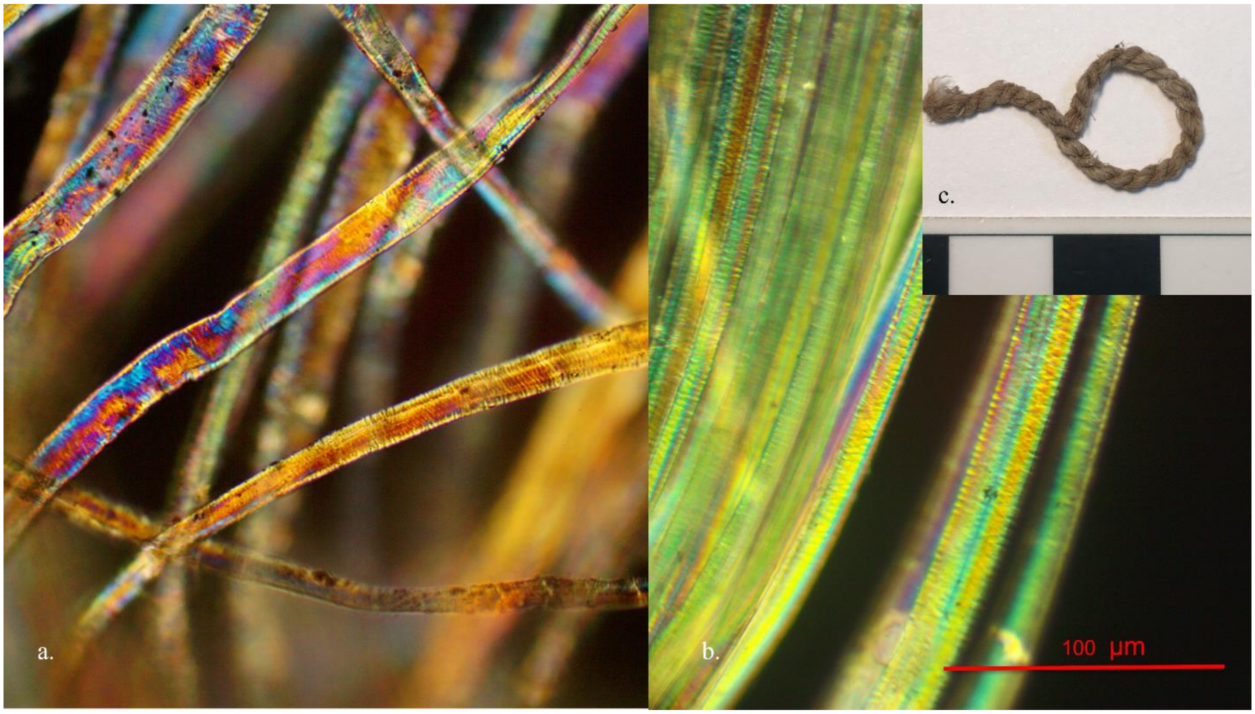


Figure 5. a-b. *Apocynum* (dogbane) fiber bundles extracted from Paisley Caves cordage, showing surface folds or ridges under polarized light; c. macroscopic image of *Apocynum* cordage from Paisley Caves.

3.2 The Modified Herzog Test

Individual fibers are made up of three distinct cellular layers; the naturally occurring twist direction (microfibrillar orientation) of the dominant cell wall (usually the second) can vary between plant species and is described as either S or Z twist (not to be confused with the twist direction employed by the weaver, referred to as S or Z twisted cordage). The Modified Herzog test, or red plate test, is a procedure designed to identify this naturally occurring S or Z twist using polarized light. When a fiber is positioned in extinction horizontally (Figure 6a), and the red plate inserted, the blue color indicates an S-twist in the microfibrillar orientation (Figure 6b), and yellow indicates the Z-twist. When the fibers are turned 90 degrees, the color appears the opposite (International Organization for Standardization [ISO], 2019). (Figure 6c). This test is highly reliable and fairly easy to perform, although each microscope calibration should always be tested with reliable reference samples (Goodway 1987; Haugan and Holst 2013).

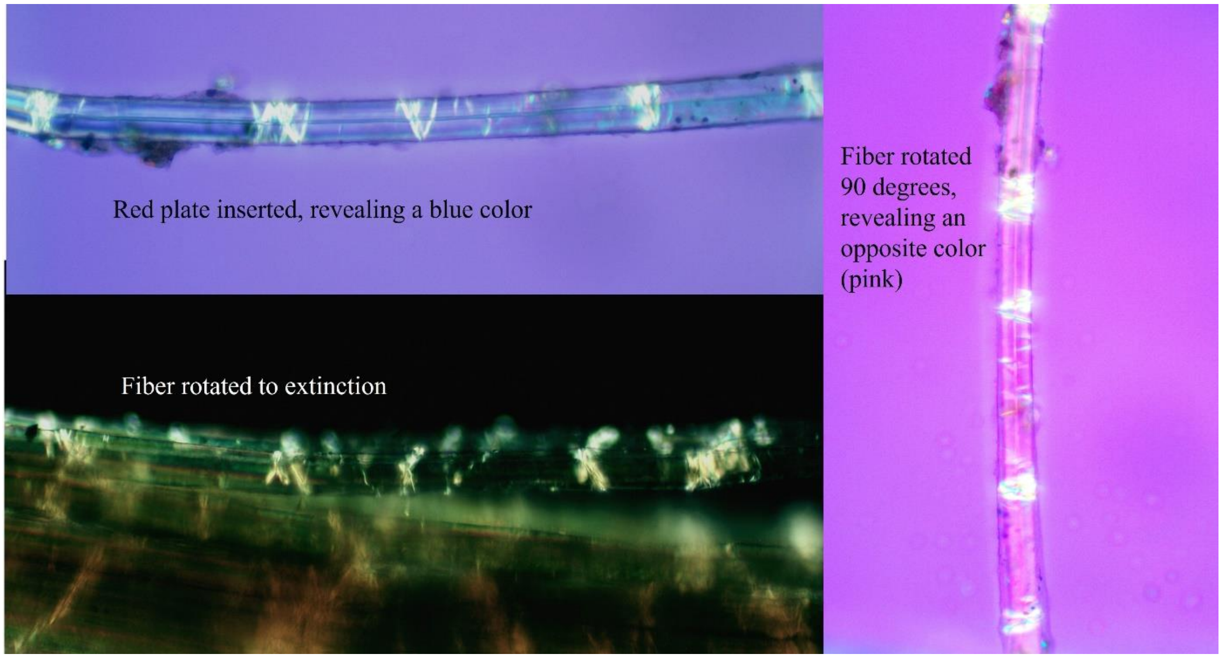


Figure 6. Modified Herzog test: a. under polarized light, fiber is rotated to extinction (when it reaches its darkest); b. red-plate compensator is inserted revealing a blue color indicating an S-twist microfibrillar orientation; c. color change occurs when the fiber is rotated 90 degrees.

In some cases, *Urtica dioica* can be distinguished from *Cannabis sativa* based on their opposite microfibrillar layers; *Urtica dioica* has an S-twisted microfibrillar layer, while *Cannabis sativa* has a Z-twist (Bergfjord and Holst 2010; Bergfjord et al. 2012; Skoglund and Holst 2013). Using the Modified Herzog test, Skoglund et al (2013) identified hemp in Viking and Middle Ages textiles from Scandinavia, including the Överhogdal Viking wall hanging. Other studies which successfully tested the efficacy of the Modified Herzog test in identification, include monocots commonly used in Maori textiles (Paterson et al. 2017) and *Humulus lupulus* (hop) fiber used in European textiles (Lukešova et al. 2018).

3.3 Fiber cross-sectioning

Suomela et al. (2018) have also identified *Urtica dioica*, *Cannabis sativa*, *L. usitatissimum* (flax), and cotton from Finnish textiles using a combination of the Modified Herzog test with cross sectioning. The shape of a fiber cross section can aid in identification in some cases (Goodway 1987); however, the cross section of a fiber ultimate (a single fiber cell within a fiber bundle) can vary within the same species depending on growth conditions and plant maturity or can become distorted during plant fiber processing or the sampling procedure (fiber extraction and cutting). Cross sections and lumen shape for bast fibers have been considered an unreliable characteristic in some studies based on this variability within individual fibers of the same species (Haugan and Holst 2013; Lukešová and Holst 2021). However, Suomela et al. (2022) advise fiber cross sections be interpreted holistically, using multiple cross sections of fibers from the sample textile, together with other methods.

3.4 Inorganic inclusions

SEM can show surface morphology of fibers, as well as inorganic inclusions such as crystal structures that can serve as one identifying characteristic. Phytoliths present in some plants within the Urticaceae and Cannabinaceae families may have taxonomic specificity (Jakes and Mitchell 1996; Piperno 1985). *Urtica dioica* in particular can show rows of druse crystals, a type of calcium oxalate crystal (CaC_2O_4) in a single cell or parenchymatous tissue (Tütüncü et al. 2014) (Figure 7a, b, c). This distinguishes it from *Linum usitatissimum*, which does not contain druse crystals (Bergfjord and Holst 2010; Bergfjord et al. 2012; Florian et al. 1990; Jakes and Mitchell 1996; Suomela et al. 2018; Tütüncü et al. 2014). Crystals are also observed in *Asclepias* fibers (Florian et al. 1990; Jakes 1996). However, druse crystal structures are usually not visible under crossed polars in retted or archaeological fibers, as they often become fragmented or dissolved (Bergfjord and Holst 2010; Florian et al. 1990). Additionally, druse crystals are usually found within the parenchymatous tissue, which is often removed in the cord-making process. If crystals cannot be identified using PLM, samples can be prepared for SEM with consecutive EDS. Cold-plasma ashing is best suited for observing inorganic inclusions because the process does not alter the morphology of phytoliths (Bergfjord and Holst 2010; Jakes and Mitchell 1996), however, this destructive method should only be employed when fibers less than 5mg (typically less than is required for AMS radiocarbon dating) can be extracted from archaeological textiles without visibly altering the artifact.

3.5 X-ray diffraction

X-ray diffraction (XRD) is a nondestructive method to measure the arrangement of crystalline structures in microfibrils; differences in these ultrastructural properties can be one way to compare fibers (Jakes et al. 2010; Viljanen et al. 2022). Wide-angle X-ray scattering (WAXS), an XRD method, can measure direction of the microfibril layer, crystalline width, and relative amount of crystallinity within a fiber. Viljanen et al. (2022) observed some differences in crystalline widths and relativity in their study of modern nettle compared to Finnish historic and archaeological hemp and flax. WAXS, together with PLM and TLM, offers a promising new method to aid in fiber identification.

3.5 Elemental composition

EDS is used in conjunction with SEM and is most useful when fiber morphology observed with polarized light alone is insufficient for identification. Jakes (1996) used EDS to compare surface composition and inorganic inclusions for a number of plants, including several species of *Asclepias*, *Apocynum*, and *Urtica*, and found that *Asclepias tuberosa* shows localized surface potassium, observed in samples that underwent a pretreatment cleaning with potassium carbonate solution, as well as samples that did not. Bergfjord and Holst (2010) combined SEM with EDS to confirm the presence of calcium oxalates in *Urtica*, with spectra illustrating a clear presence of calcium.

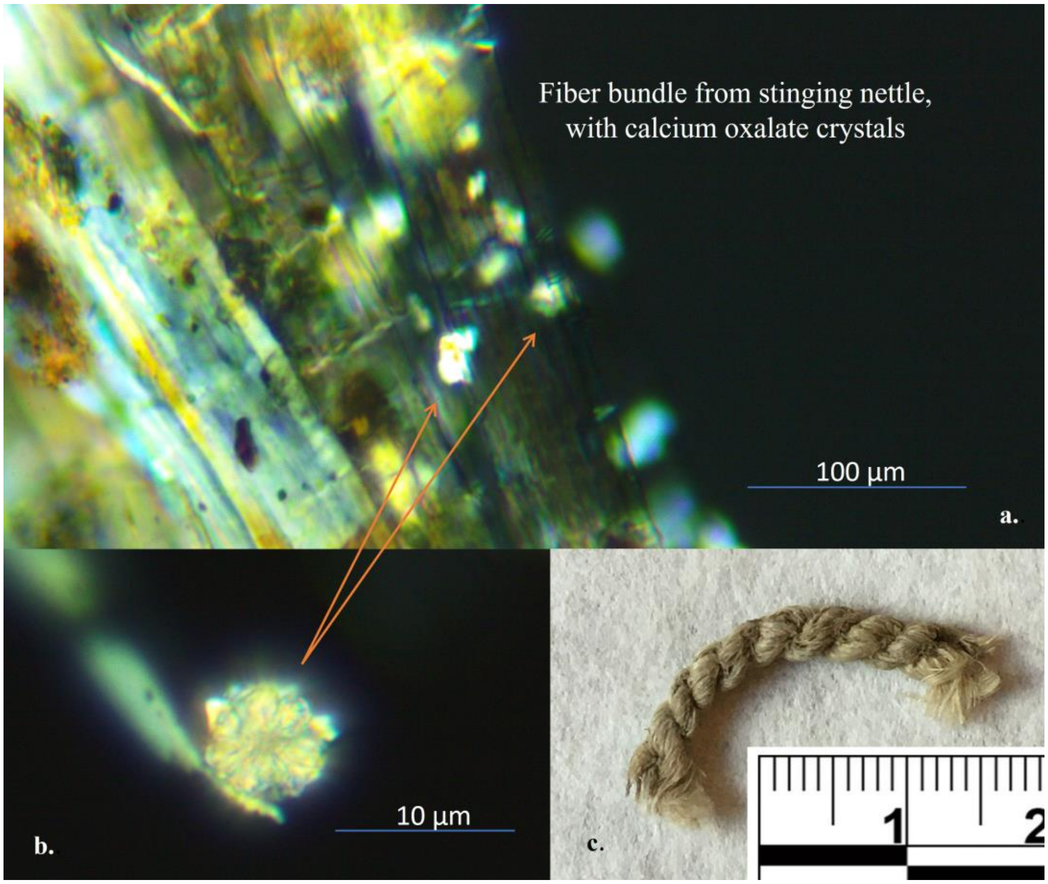


Figure 7. a-b. calcium oxalate crystals in a fiber bundle extracted from stinging nettle cordage from the Paisley Caves, visible under polarized light; c. macroscopic image of the stinging nettle cordage.

4. Methods and Materials – Reference Samples

In this paper, I evaluate existing methods of bast fiber identification, including TLM, PLM and SEM with EDS. I accomplished this through examination of reference samples to establish a set of fiber characteristics and then applied these characteristics to archaeological samples from the Paisley Caves. Fiber characterization is how fibers are described based on a set of criteria (e.g., fiber width, lumen shape, elemental composition). Previously published fiber characteristics were also considered (Coe 2012; Florian et al. 1990; Lawlor 2020) along with observations discussed through personal communication (Marion Coe 2022; Anne Lawlor 2022; Hana Lukešová 2022) (Table 1). The reference samples were obtained from herbaria at Washington State University and Oregon State University, and from field collections that included *Apocynum cannabinum, Linum lewisii*, *Urtica dioica*, *Asclepias speciosa* (showy milkweed), *Amsonia tomentosa* (Woolly bluestar), *Typha* sp. (cattail seed hair/fluff), *Chamerion angustifolium* (fireweed stem and seed hair), *Gossypium hopi* (cotton seed hair), and *Corchorus* (jute). While reference samples for *Apocynum cannabinum* and *Asclepias speciosa* are documented to the species level, archaeological fiber for these two plants are only documented to the genus level.

4.1. Specimen preparation for polarized light microscopy

a. Unprepped fibers (hair-like, less than 0.5cm) were extracted directly from the stem fiber using a clean razor blade or tweezers.
b. Fibers were spread/fanned out on glass slides and encased in permanent mounting medium (Entellen New, with refractive index of n = 1.49-1.50) with cover slips.

4.2. Polarized light microscopy

The following observations were made using a Leica DM polarizing microscope with rotating stand and first order red plate at the University of Oregon:

a. twist direction of the microfibrillar layer using the Modified Herzog test (e.g., *Urtica dioica* has an S-twist) (Bergfjord and Holst 2010; Bergfjord et al. 2012; Skoglund and Holst 2013). The Modified Herzog test was conducted repeatedly for herbarium reference samples and previously identified fibers from ethnographic basketry cordage warps using the same Leica DM microscope with the same calibrations.
b. presence or absence of a consistently disrupted, ridged surface (indicative of *Apocynum*) (Jakes 1996);
c. frequency and pronouncement of dislocations and cross markings (e.g., frequent cross markings indicative of *Urtica dioica*) (Florian et al 1990), and pronounced dislocations typical of *Linum* sp. (Rast-Eicher 2016);
d. fiber diameter (e.g., *Urtica dioica* often has a wider diameter than other basts, typically 30-40µm, *Linum* sp. a narrow diameter, typically 5-20µm) (Coe 2012; Lawlor 2020; Rast-Eicher 2016; Florian et al 1990);
e. lumen shape when visible (e.g., *Urtica dioica* has a long, flat lumen, *Asclepias* has a small lumen, *Linum* sp has a narrow lumen) (Viljanen et al. 2022);

f. the presence or absence of calcium oxalate crystals (indicative of *Urtica dioica* or *Asclepias*) (Bergfjord and Holst 2010; Bergfjord et al. 2012; Florian et al. 1990; Jakes and Sibley 1994; Jakes and Mitchell 1996; Suomela et al. 2018).
g. fiber cross sections (e.g., *Apocynum* cells are usually rounder than *Asclepias, L. usitatissimum* is typically polygonal, and *Urtica dioica* oval. (Florian et al. 1990; Rast-Eicher 2016; Suomela et al. 2018, 2022);
h. other features (e.g., *Asclepias* can appear softer and whiter, *Linum lewisii* can appear waxy) (Coe 2012, 2021; Lawlor 2020).

4.3. Energy-dispersive x-ray spectroscopy

SEM with EDS were performed at the Center for Advanced Materials Characterization in Oregon (CAMCOR), University of Oregon. EMS and EDS were performed to: 1) identify the presence or absence of calcium oxalate crystalline inclusions in *Urtica dioica*, *Linum lewisii*, and *Asclepias* sp; and 2) observe chemical characterizations for *Apocynum*, *Urtica dioica*, *Linum lewisii*, and *Asclepias*. The first group of reference samples were plasma etched using a March CS-1701, where the fiber sample (a maximum of 5 mg) was placed on copper tape on a glass slide and ashed at 180w for 120 minutes. Following the ashing procedure, these same samples were viewed with a scanning electron microscope (Helionanolab 600i), with consecutive elemental analysis. A second set of untreated reference samples (extracted from phloem fibers of herbarium specimens) were then examined under SEM with EDS without plasma ashing, to focus on chemical compositions (Figure 8). Additionally, EDS was performed for two samples each of *Asclepias speciosa* and *Linum lewisii* at the McCrone Associates, IL.

4.4. X-Ray Diffraction

X-Ray diffraction (XRD) is used to observe the arrangement of atoms and can be used to identify a crystal structure. This was performed at CAMCOR for three of the above *Urtica dioica* reference samples to see if calcium (Ca) is bonded to oxalate (O4) ($CaC_2O_4{\cdot}(H_2O)_x$.

4.5. Cross-sectioning

Three fibers were cross sectioned. Fibers (less than 1 mm in diameter) were cut under a stereo microscope using a razor blade, placed inside the narrow end of a cut pipette, and melted on a hot plate. The melted pipette was cut with a razor blade under a stereo microscope to reveal the encased fiber cross section, which was then viewed under direct light at 10× and 40× objective.

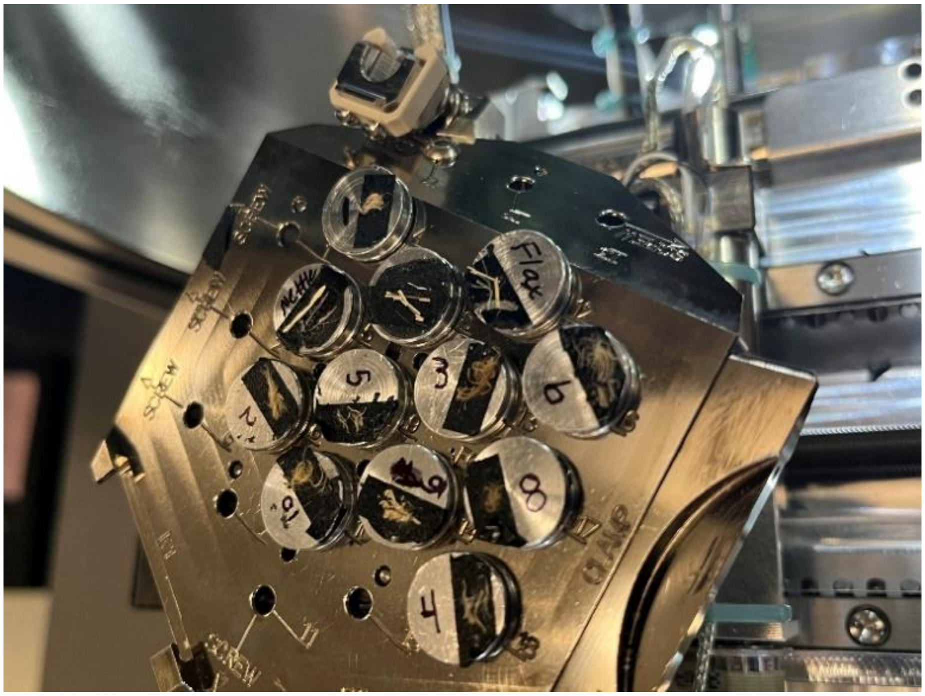


Figure 8. Fiber samples less than 5mg placed on stubs for viewing with SEM.

5. Results-Reference Samples

5.1. Polarized light microscopy

Using the Modified Herzog test, I observed *Apocynum*, *Linum lewisii*, *Urtica dioica*, and *Asclepias* to all have an S-twist microfibrillar layer. Interference color results correlate with second order indigo and first order orange on the Michel-Levy birefringence chart. Due to S-twist results for all four, it was determined that the Herzog test alone cannot be used to differentiate these taxa. However, this proves to be useful in ruling out other fibers with a Z-twist, such as *Cannabis sativa* and commercial jute string. The Herzog test was also conducted on *Chamerion augustifolium* (fireweed), which was observed to have a Z-twist.

Evaluation of characteristics b-h as outlined above found that all four fibers are anisotropic and show high birefringence, as is expected for bast fibers generally. Most noteworthy are the consistent surface folds or ridges present in all samples of *Apocynum*, distinguishing it from the other taxa; this supports previous findings (Florian et al. 1990; Jakes et al. 1994; Jakes and Sibley 1993) (Figure 5a-b,

Figure 9a). In some samples, *Apocynum* also exhibits small reddish flecks from outer bark still remaining, and in some cases can be seen macroscopically.

Urtica dioica exhibited druse crystals with PLM in only one sample from ethnographic cordage. Cross markings were highly visible and numerous (Figure 9c, e); this feature was previously reported by Jakes (1996). *Urtica dioica* fibers are also much wider in diameter (Figure 9c) than other bast fibers (typically 30-40µm and as wide as 50 µm) and show many dislocations.

Asclepias fibers adhere more firmly together than *Apocynum* and can be difficult to separate. Fiber diameter is narrow like *Linum lewisii*, and in most cases, *Linum lewisii* and *Asclepias* were indistinguishable under crossed polars alone (Figure 9b, d). Parenchymatous tissue of *Asclepias* cells have a high tannin content, as reported by Florian et al. (1990); however, this was observed in only one sample under SEM (Figure 10). Macroscopic features can aid in identification, as *Asclepias* is characteristically whiter and softer than other basts, but this can lead to assumptions when examining archaeological buried material.

Lawlor (2022) and Coe (2012) described *Linum lewisii*, the flax species indigenous to the Great Basin and documented ethnographically (Coville 1897; Spier 1930), in their research on cordage from Bonneville Estates Rockshelter and Four Siblings Rockshelter in Utah. These observations include fiber diameter and general morphology of the longitudinal view using TLM. The current study supports these observations, and taken together, include small fiber diameters (10-20µm), some tapering at ends, some tendrils off of individual fibers, and thinning and thickening of fiber, but usually fibers are even and straight with very few cross markings and dislocations (Table 1) (Figure 9b, f). All other previous studies of flax concern the species *L. usitatissimum*, which lacks calcium oxalates (Hock 1942). These druse crystals are a distinguishing feature of *Urtica dioica* (Bergfjord et al. 2012; Suomela et al. 2018), and thus can be one way to distinguish it from *L. usitatissimum.* However, *L. lewisii* has no previously reported observations with PLM or EDS, and no reports of the presence or absence of calcium oxalates. I thus attempted to first confirm the presence or absence of CaO in *L. lewisii*. Phloem fibers from two different *L. lewisii* herbaria samples and one field collection were macerated (bleach baths) following methods described by Zhang et al. (2014), and observed under crossed polars. Observations under PLM did not confirm the presence of crystals, so additional samples underwent plasma-ashing, followed by SEM with EDS.

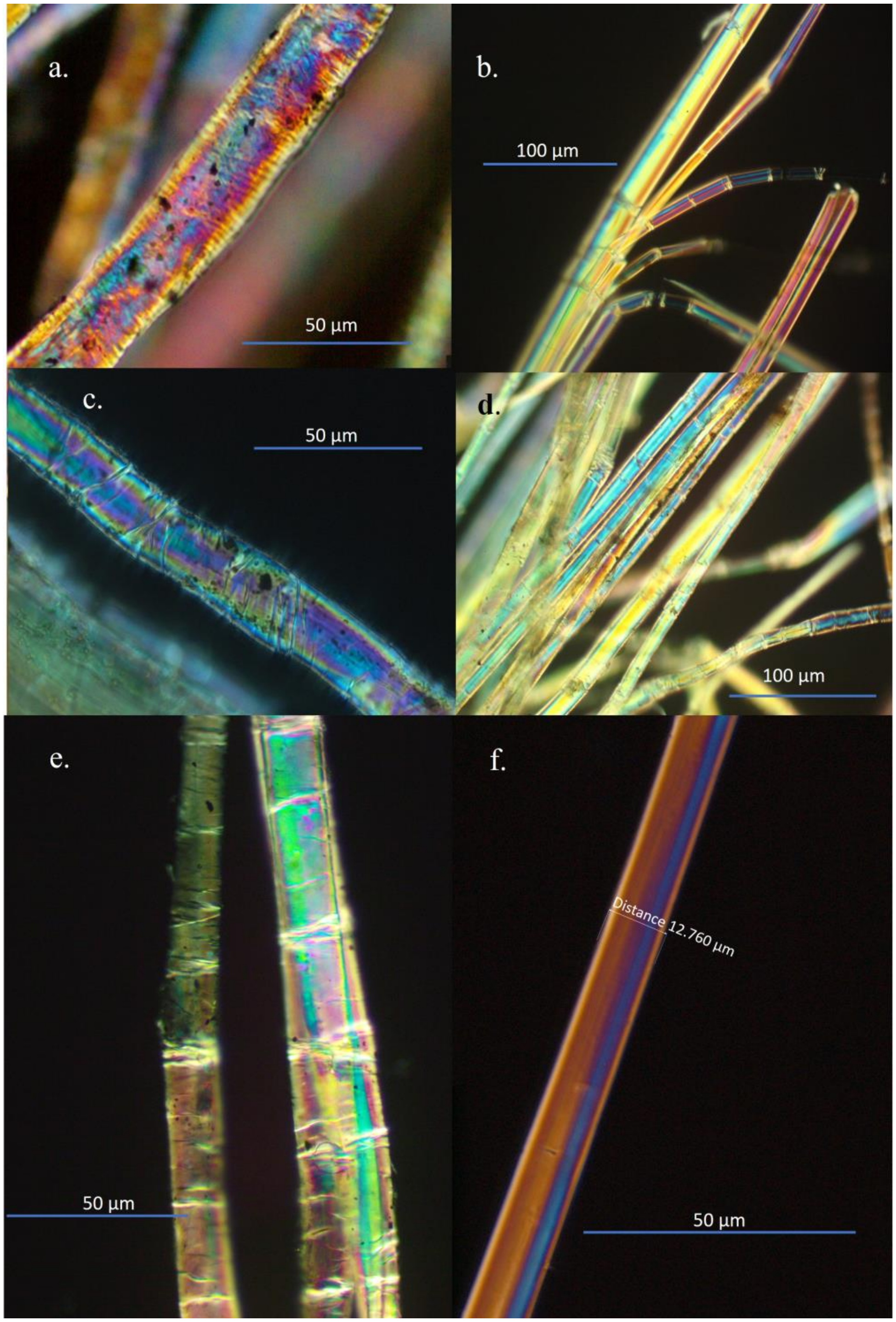


Figure 9. a: dogbane showing disrupted surface folds; b. flax showing narrow fiber diameter, few cross markings and few dislocations; c. and e. stinging nettle showing wide fiber diameter, many cross markings; d. milkweed showing similarity to flax; f. flax showing small fiber diameter and few cross markings.

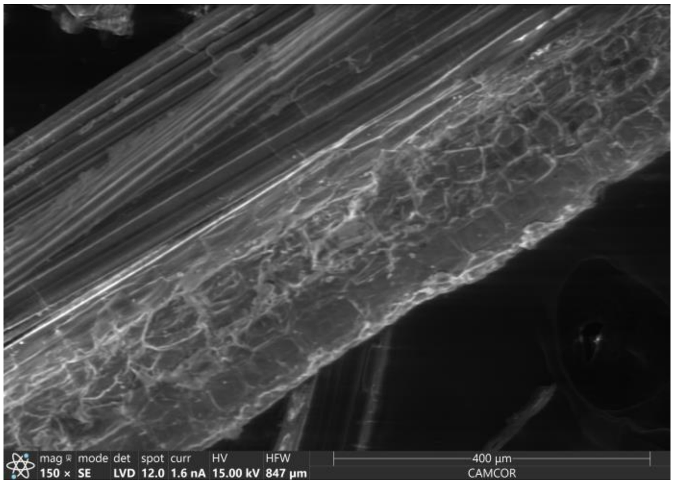


Figure 10. Milkweed fibers with parenchymatous tissue visible under SEM.

5.2. Energy-dispersive x-ray spectroscopy (EDS)

Inorganic inclusions were visible under SEM for most samples, including *Urtica dioica*, *Apocynum*, and *Asclepias*; however, it was not possible to identify druse crystal structures. Chemical composition using EDS was performed to compare *Linum lewisii*, *Asclepias*, and *Urtica dioica* (Table 2).

The first set (Set 1) of eight plasma-ashed samples included *Linum lewisii* (n=2), *Apocynum* (n=3), *Asclepias* (n=1), and *Urtica dioica* (n=2). *Linum lewisii* shows a significantly lower percentage of potassium by weight, ranging between 2.01-3.05 (with an error +/- 1 Sigma), while the other three taxa show slightly higher amounts. *Apocynum* ranges between 6.87-13.67; *Asclepias* at 23.26; and *Urtica dioica* between 13.85-14.24. Calcium is higher for *Linum lewisii* than the others, but overall, it varies greatly and was not considered a distinguishing feature based on these samples.

The second set (Set 2) of six untreated (non-plasma-ashed) samples included *Linum lewisii* (n=2), *Asclepias* (n=2), and *Urtica dioica* (n=2). Weight % for *Linum lewisii* shows trace amounts of potassium (0-0.6), the other two taxa show a higher percentage. *Asclepias* ranged between 3.82-13.18, and *Urtica dioica* between 2.6-16.45. For calcium, *Linum lewisii* is comparable to *Urtica dioica*, and *Asclepias* less.

The two untreated *Asclepias* and *Linum lewisii* samples (Set 3) evaluated by Sandra Koch at McCrone Associates suggest low amounts of potassium in *Asclepias* (1.43-3.32 weight %), and only trace amounts in *Linum lewisii* (0.04-0.11 weight %), but the difference is significant. Spectra from all three sets, both untreated and treated samples, are consistent in reporting trace amounts of potassium in *Linum lewisii*, and higher amounts in *Asclepias*. Levels of calcium were considered inconclusive as a means to differentiate between these four taxa.

5.3. X-Ray Diffraction

X-Ray diffraction was fairly inconclusive. The copper tape used may have interfered, and samples were too small, as XRD works better when the fiber sample covers an area the size of a quarter. I did not continue this method knowing that a sample of this size would not be available for most archaeological specimens. This process could be further explored with new samples, possibly using WAXS employed by Viljanen et al. (2020) (see 8.4 *Future work*).

5.4 Cross-sectioning

I was not able to clearly observe fiber cross sections, likely due to the difficulty in arranging the small fiber within the pipette, followed by difficulty in slicing the melted pipette in a way that properly exposes a cross section. I chose not to pursue this method because of the difficulty in obtaining a clear view of such a small fiber's cross section, but also given that the fiber cross section can be an unreliable variable where shape can vary within the same species (Lukešová and Holst 2021). Archaeological fibers may be additionally altered due to the burial environment.

6. Methods and Materials-Paisley Caves Archaeological Fibers

Fiber characteristics observed in the reference samples described above were then applied to 180 fiber samples, each from individual artifacts from the Paisley Caves fine cordage assemblage.

6.1. Specimen preparation for polarized light microscopy

I first considered macroscopic features (Table 1). Whole artifacts, when possible, were first examined under a stereo microscope to assess general characteristics and preservation issues.

a. Fibers (hair-like, less than 0.5 cm) were extracted directly from the artifact using a clean razor blade or tweezers. Fiber extraction was done using a stereo microscope at 10× objective in many cases to select the most optimal fibers for mounting with the least destruction to the artifact.

b. Fibers were extracted from more than one location on the artifact when possible to account for mixed fibers and preservation issues. Fiber extraction was conducted without visibly altering the artifact or changing its measurements, with less than 5.0 mg removed. When possible, parenchymatous tissue was included in the sample, as this can further aid in identification. Photos were taken prior to sampling.

c. Fibers were spread/fanned out on glass slides and encased in permanent mounting medium (Entellen New, with refractive index of n = 1.49-1.50) with cover slips.
d. Slides were marked with the sampled artifact's catalog numbers and are curated by the University of Oregon Museum of Natural and Cultural History.

6.2. Polarized light microscopy

Using the same Leica DM polarizing microscope as with the reference samples, I identified fibers as vegetal versus animal fiber (hair, sinew) using TLM and PLM. If vegetal, fibers were identified as bast, seed hair (cotton, cattail fluff), monocot (e.g., tule), bark (e.g., sagebrush, juniper, bitterbrush), or unknown. If bast, I recorded observations a-h as described under reference sampling methods. If bast fiber has both an S-twisted microfibrillar orientation, and shows a consistent, disrupted, ridged surface, I recorded it as *Apocynum*. If the fiber did not show a presence of these surface folds, I considered the other morphological characteristics (c-h). Specimens with mixed materials (mixed plant taxa, inclusion of animal hair) were also noted.

6.3. Energy-dispersive x-ray spectroscopy

If the above observations using PLM were not able to distinguish between *Urtica dioica*, *Linum lewisii*, and *Asclepias*, samples were observed using SEM with EDS at CAMCOR; the objective was to identify the presence or absence of calcium oxalate crystals, and levels of potassium.

7. Results-Paisley Caves Archaeological Fibers

A total of 180 fine cords and cord elements were sampled from the Paisley Caves, 49 of these include at least one knot (those with two or more are considered net fragments) and seven are single ply twists of fiber. Identified bast fiber cordage numbers 171, and includes *Apocynum* (Figure 11h; Figure 12b, c, d), *Urtica dioica* (Figure 11a, c, k; Figure 13b, c, d), *Linum lewisii* (Figure 11b, j), *Asclepias*, (Figure 11d, e, f), mixed *Apocynum* and *Urtica dioica*, commercial jute, and undetermined bast fibers (Figure 11g). Other fibers include *Gossypium* (cotton) (Figure 11i), monocot stem fiber, and unidentified fibers (Table 3). Archaeological *Gossypium* was distinguished from modern intrusions based on AMS radiocarbon dating, in which four samples dated between 1060±40 BP to 330±15 BP. *Apocynum* (46%), *Urtica dioica* (26%) and mixed *Apocynum* /*Urtica dioica* (11%) cordage make up more than 85% of archaeological fine cordage, while *Linum lewisii* and *Asclepias* make up less than 6%. PLM was first used to identify non-bast fibers, which included cotton (n=4) and monocot fibers (n=3).

Taxa	Common Name	Count	%
Apocynum sp.	Dogbane	77	43
Urtica dioica	Stinging nettle	42	23.4
Asclepias sp.	Milkweed	5	2.7
Linum lewisii	Flax	5	2.7
Gossypium sp.	Cotton, archaeological	4	2.2
	Monocot stem	3	1.6
	Mixed dogbane and nettle	20	11.1
	Undetermined bast	21	11.7
	Unidentified	3	1.1
Total		180	

Table 3. Paisley Caves fiber from fine cordage

7.1. The Modified Herzog Test

I then performed the Modified Herzog test on bast fibers. Of the 171 bast fiber cords, all but four revealed an S-twisted microfibrillar orientation. The four Z-twisted fibers indicate a bast fiber other than the four selected for the study. Three of these are twisted fibers or cord elements that may be an indigenous plant such as *Chamerion augustifolium* (fireweed) native to Oregon and used by Northwest Coast peoples. Reference samples of fireweed all indicate a Z-twist microfibrillar layer; however, its identification in the Paisley fiber assemblage has yet to be confirmed. Another cord fiber is attributed to a modern intrusion of *Corchorus* (jute). Both *Corchorus* and *Cannabis sativa* (hemp) have been previously documented as Z-twist (Bergfjord and Holst 2010; Florian et al. 1990; Haugan and Holst 2013; Rast-Eicher 2016).

7.2. Apocynum surface morphology

A consistent disrupted ridged surface indicative of *Apocynum* is present on 46% of bast fibers. *Apocynum* fibers are well preserved (Figure 12b, c, d) and show a clear presence of consistent ridges or surface folds (Figure 12a). In some cases, the surface folds are so distinctive that the Modified Herzog test was difficult to perform.

Figure 11. Paisley Caves fine cordage: a. stinging nettle; b. flax; c. stinging nettle; d. milkweed; e. milkweed; f. milkweed; g. undetermined; h. dogbane; i. cotton; j. flax; k. stinging nettle.

Figure 12. a. *Apocynum* fiber showing consistent surface folds; b-d. *Apocynum* cordage artifacts from the Paisley Caves.

7.3. Morphological features for Urtica dioica, Linum lewisii, and Asclepias

The frequency and spacing of dislocations and cross markings vary greatly for bast fibers. Most fibers observed had a high frequency, or close spacing of cross sections, and were usually wider in diameter, indicative of *Urtica dioica*. Fibers that had very few dislocations and cross sections were often very straight and narrow in diameter indicative of *Linum lewisii* (Figure 9f).

Fiber diameter was used conservatively, and measurements were taken from multiple fiber ultimates within the same sample. A wide diameter, indicative of *Urtica dioica*, ranged between 30-50μm (Figure 13a); a narrow diameter, indicative of *Linum lewisii*, ranged between 5-20μm. The presence of numerous cross markings (indicative of *Urtica dioica*) was observed on nearly all wider fibers.

Figure 13. a. Stinging nettle fiber from the Paisley Caves showing wide diameter and pollen, possibly cattail; b-c. stinging nettle cordage and netting artifacts from the Paisley Caves.

Lumen shape was often not clearly visible. Observed lumen shape was inconsistent within the same genera, so was not considered a viable feature to aid in identification. The presence or absence of calcium oxalate crystals (indicative of *Urtica dioica* or *Asclepias*) were also not clearly observed under PLM or SEM.

In many cases, I could not easily distinguish between *Asclepias*, *Linum lewisii*, and *Urtica dioica* when a range of different characteristics were observed within the same fiber bundle, as is expected in archaeological fibers (Bergfjord et al. 2010; Rast-Eicher 2016; Catling and Grayson 1998). Because of this difficulty, additional features proved to be important characteristics in identification. For example, *Asclepias* fibers were difficult to separate, whereas *Apocynum* fibers separated easily. *Asclepias* also appears macroscopically whiter and softer than other basts, but not in all cases. In some cases (just under 13%), I could not identify bast fibers, but are likely *Urtica dioica*, *Linum lewisii*, or *Asclepias* (Table 3). (see Figure 14. for identification process).

7.4. Energy-dispersive x-ray spectroscopy

A subset of untreated fibers from 20 artifacts was examined under SEM with EDS to further distinguish between *Urtica dioica*, *Linum lewisii*, and *Asclepias*. Some crystal inclusions were observed, but these could not be identified as calcium oxalates. Contaminants from buried contexts could be reflected in the EDS results, however, the analysis specifically focused on identifying a high percentage of calcium by weight (Table 4). Spectra for the 20 sampled artifacts includes plant identifications based on EDS results together with fiber morphology observed under PLM. Six were attributed to *Urtica*, four to *Asclepias*, one to *Apocynum* (previously identified with PLM), two to either *Apocynum* or *Urtica*, five to *Linum lewisii*, and three remained undetermined. The *Linum lewisii* samples were all significantly lower in surface potassium than the other samples, illustrated in a cluster analysis of potassium levels by weight in Table

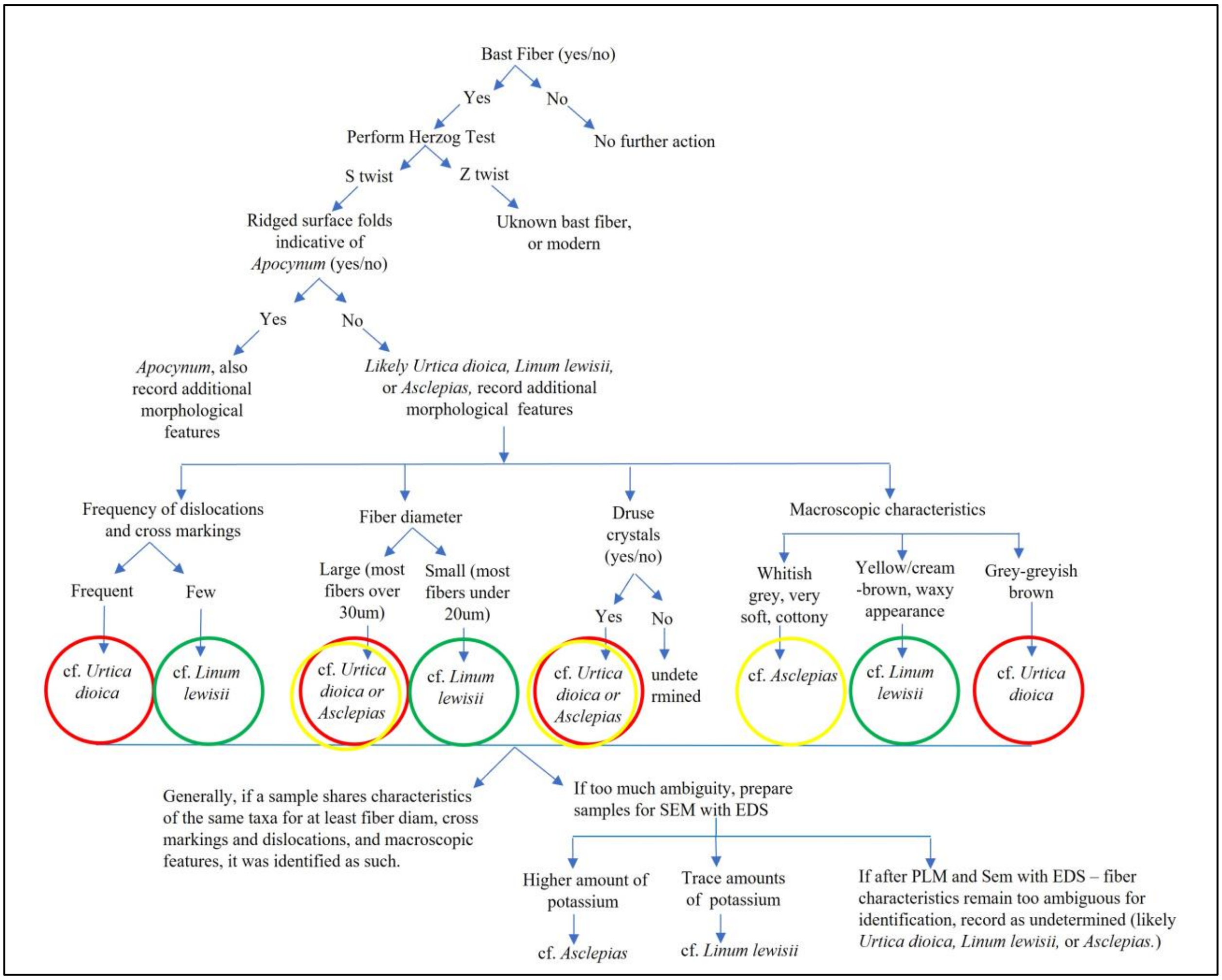


Figure 14. Flow chart for identification process for archaeological fiber.

5. EDS showed a strong presence for calcium in all samples but varied widely even between two points from the same sample. Table 4 presents the complete spectra for archaeological samples.

8. Discussion and Conclusions

8.1. Feasibility of fiber identification

I applied previously established fiber identification methods using PLM and EDS to reference samples of *Apocynum*, *Urtica dioica, Asclepias*, and *Linum lewisii* to test their efficacy when applied to archaeological fiber from cordage from the Paisley Caves. Fiber characterization acquired from the control study was considered together with previously documented characteristics for these four taxa. This study confirmed that PLM is a highly effective tool for identifying intrusive and non-native bast fibers, and in the identification of *Apocynum* in particular. In some cases, fiber morphology observed using PLM can further differentiate between *Urtica, Asclepias*, and *Linum lewisii*. However, elemental analysis offers a secondary, but key method that in some cases can further aid in making these distinctions.

8.2. Fiber morphology

Apocynum, *Urtica dioica*, and *Asclepias* fiber morphology for reference samples is consistent with previous studies. *Apocynum* fibers have a consistent, ridged surface, as previously observed (Florian et al. 1990; Jakes et al. 1994). This was clearly observed in archaeological cordage that had been preliminarily identified as such based on macroscopic appearance. *Urtica dioica* is often distinguished based on a wide fiber diameter, and a high number of cross markings and dislocations. *Asclepias* fibers were often difficult to separate from each other. *Linum lewisii* was observed to have a narrow fiber diameter, tendrils off of individual fibers, and can be very straight with very few cross markings.

The Modified Herzog test shows that *Apocynum, Asclepias, Urtica dioica*, and *Linum lewisii* all have an S-twisted microfibrillar orientation; this test cannot be used alone as a means to distinguish between these four taxa, as it can with *Cannabis sativa* and *Urtica dioica*. However, this test proves useful in the identification of Z-twisted modern or intrusive fibers such as *Corchorus* (jute) and potentially other native bast fibers such as *Chamerion augustifolium*.

In some cases, fiber morphology observed under PLM was not sufficient to differentiate between some archaeological bast fibers, most often between *Asclepias* and *Linum lewisii*, and thus it is necessary to consider multiple fiber characteristics when making an identification (Table 1), including macroscopic appearance and elemental composition. Poor preservation and buried context, variability in fiber morphology, and differing growth conditions can greatly affect the appearance of fibers, however, the Paisley collection was chosen based on excellent preservation of plant remains, and the large assemblage of cord made from bast fiber. The examination of such a large sample size (180 sampled artifacts), coupled with excellent preservation, allowed for typical features and averages to be observed across the collection.

5.5 *SEM with EDS*

Scanning electron microscopy was not successful in positively identifying calcium oxalate crystals in plasma-ashed reference samples or sampled artifacts, though inorganic inclusions were visible. EDS results indicate the presence of CaO in all four taxa, and because inorganic inclusions were not identified under SEM, the presence and levels of calcium could not be used in this study as one means to distinguish *Urtica dioica* from *Linum lewisii.*

EDS was used to further explore notable differences in elemental compositions for reference samples. Spectra from *Asclepias* indicate a slightly higher amount of surface potassium than *Linum lewisii*, which shows trace amounts; Jakes (1996) also noted levels of surface potassium in *Asclepias turbosa*. *Urtica dioica*, and *Apocynum* also showed slightly higher levels of surface potassium, but not necessarily as high as *Asclepias*. This notable difference in surface potassium between *Asclepias* and *Linum lewisii* stem fiber was used as one distinguishing characteristic for archaeological fiber.

8.4. Future work

Additional EDS with a larger sample of both reference and archaeological samples would greatly aid in confirming or disputing results of the current study regarding surface potassium as an identifying characteristic. WAXS is another promising technique (Viljanen et al. 2022) that, together with PLM and EDS could aid in the identification of North American bast fibers.

Linum lewisii is documented ethnographically and archaeologically across the Great Basin and deserves further study. Systematic documentation of its microscopic features by more than one independent researcher would benefit future textile analysis. Calcium oxalates are not present in *L. usitatissimum* based on previous studies in Europe; however, this study did not confirm their absence in *L. lewisii*, and should be further explored. Other indigenous fibers used in fine cordage that require study using PLM and EDS include *Chamerion augustifolium* (fireweed), *Amsonia tomentosa* (Woolly bluestar), *Iris tenax,* (iris), *Juncus effusus* (Juncus rush), and *Yucca* spp. (yucca).

The scope of the current study was limited to untreated fibers, and the longitudinal view of a fiber ultimate. It did not include systematic observations of parenchymatous tissue or cross sections, which can provide additional features to aid in identification. Many fibers from fine cordage, due to bark removal during processing, lack parenchymatous tissue, though this may not always be the case. The study of phytoliths observed in ashed or macerated fiber bundles may also offer another avenue for identification. Lastly, fiber preparation and processing methods following ethnographic examples was not performed for this study; this addition to future analysis, following similar procedures to Jakes (1996), would be beneficial.

8.5. Significance to Great Basin archaeology and textile studies more broadly

The Great Basin is a region rich in organic perishables preserved in dry cave sites, many of which have deep antiquity. Identified plants from the Paisley Caves textile assemblage, together with radiocarbon dating, provide long-term data on culturally significant native plants, spanning the last 14,000 years, with bast fiber in particular spanning the last 10,000 years. *Apocynum* and *Urtica dioica* fiber account for about 90% of fine cordage from Paisley, and by the early Holocene, *Apocynum* and *Urtica dioica* are well established as the primary riparian/wetland bast fiber resources for fine cordage and netting. *Asclepias* and *Linum lewisii* represent less than 6% of the assemblage, occurring within the last 3000 years. The small amount of *Asclepias* and *Linum lewisii* at the Paisley Caves is notably different from cordage assemblages in the Eastern Great Basin, in which *Asclepias* and *Linum lewisii* are more prevalent (Coe 2012, 2021; Lawlor 2020).

PLM and elemental analysis are powerful yet underutilized applications in North American archaeological textile analysis. PLM in particular is a fairly simple and inexpensive method for distinguishing bast fibers from other vegetal fibers, and in the identification of specific bast plants in many cases. There are thousands of fiber artifacts housed in curatorial repositories across the Great Basin and the Americas that offer the potential for similar analysis. Rarely is this kind of analysis performed, yet this approach can significantly inform the study of textile technology, landscape use, paleoethnobotany, and historical perspectives of traditional ecological knowledge.

Bridge

Chapters 3 and 4 draw from methods developed for fiber identification outlined in the current chapter. These methods were developed for native plant fibers specific to the Paisley Caves and other Northern Great Basin textile assemblages. Chapter 3 incorporates these methods for fine cordage and expands on plant identifications for bark and monocots.

Taxa	Herzog test	Disrupted surface, folds	Frequency/ spacing of dislocations	Fiber Diameter (µm)	Transverse cross-markings	Lumen shape	Calcium oxalate crystals	Other features	Spectra	Macroscopic appearance of archaeological cordage
Stinging nettle (Urtica dioica)	S	Yes, but not consistent, not as common as dogbane.	Many, more than other basts.	Wider than other basts (30-40µm), can be as wide as 100µm.	Many	Lumen is flat and long.	Yes (1 sample)	Can have flexions (undulating, uneven fibers).	CaO, small K	Grey, brown, or cream colored.
Dogbane (*Apocynum*)	S	Yes, consistent, even.	Many, but can be difficult to observe due to surface folds.	20-80µm, varies greatly	Many	Wide lumen diameter relative to fiber diam.	not observed.	Fiber ultimates loosely together and easily separated. Thickening of cell walls sometimes.	CaO, small K	Reddish/brown, can also appear cream colored, can have small reddish-brown flecks of outer bark.
Blue flax (*Linum lewisii*)	S	No	Fewer than other basts.	5-20µm	Few	Small	not observed.	Some fibers show tapering at ends, thinning and thickening of fiber, tendrils off individual fibers, and also can show very even, straight fibers.	CaO, trace amounts of K	Yellow, waxy appearance, can have yellow hue, very soft.
Milkweed (*Asclepias*)	S	No	Some	25µm (10-30).	Some	Narrow lumen relative to fiber diameter.	not observed, though previous studies confirmed presence.	Shows distinctive hypodermis with tannin-rich cells contents (Florian). Fiber ultimates more firmly together than dogbane.	CaO, K	White/grey, very soft.
Fireweed (*Chamerion augustifolium*)	Z	not observed.	Few	20-25, as wide as 50µm.	not observed.	not observed.	not observed	Straight, small tendrils off fiber ultimate.	not observed.	Yellow, waxy appearance.
Cotton (*Gossypium*)	n/a	No	n/a	12-25µm.	n/a	n/a	n/a	Seed hair, not a bast fiber. Isotropic, wavy, ribbon-like appearance.	not observed.	White/grey, fuzzy.

Table 1. Fiber Characterization

EDS points detect surface area only and does not reflect depth.

Untreated (non-plasma ashed) control samples

Sample designation	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	F	Ni	Fe	Ti
flax 2_pt1	43.47	52.85			1.24			0.54			1.9				
flax 2_pt2	42.63	50.75	0.06		1.48	0.17	0.39	0.36		0.6	3.57				
flax 1	36.27	49.65	0.21		2.92	1.05	0.53	0.31		0.6	8.46				
milkweed ref site 2_pt1	30.21	55.47	0.33	0.36	0.13	0.1	0.43	0.28	1.34	11.34					
milkweed ref site 2_pt2	30.45	57.61		0.18	0.32		0.53	0.61	1.37	8.93					
milkweed ref_pt1	33.22	60.36	0.2	0.2	0.13	0.05	0.35	0.1	0.79	3.82	0.77				
milkweed ref_pt2	31.87	51.91	0.29	0.36	0.23	0.18	0.41	0.24	1.32	13.18					
milkweed ref_pt3	32.53	59.86		0.16	0.17		0.4	0.1	0.91	4.92	0.95				
nettle 1_pt1	36.2	36.05			0.57		0.27	0.1	0.69	2.63		23.48			
nettle 1_pt2	36.98	41.78		0.19	0.66		0.76	0.24	0.73	4.45	2.08	12.14			
nettle 1_pt3	35.61	35.34			0.52		0.22	0.12	0.64	2.6		24.96			
nettle 2_pt1	32.55	51.25		0.24	0.37	0.14	0.53	0.21	1.62	8.33	3.74		1.02		
nettle 2_pt2	32.48	36.6		0.29	0.66		0.94	0.43	3.03	16.45	7.34		1.78		

Plasma-ashed control samples

Sample designation	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	F	Ni	Fe	Ti
REF4_dogbane(1)_pt1	19.31	28.29	1.03	3.51	0.18	3.52	0.54	1.1	1.7	13.67	6.34	20.82			
dogbane 1_pt1	8	30.71	2.16	1.53	0.88	4.41	3.17	2.27	4.07	9.54	23.58	9.7			
I(1) dogbane	11.34	37.34	4.99	1.2	2.96	12.2	1.86	2.13	5.72	6.89	5.05			8.32	
REF5_milkweed(1)_pt1	10	23.44	0.95	1.06	0.21	5.26	1.46	1.13	2.56	23.26	6.83	23.5			0.36
REFA_flax site2(1)_pt1	21.31	40.04	0.69	0.59	0.23	2.22	1.14	2.55		2.33	16.42	12.48			
REFA_flax site2(1)_pt2	19.56	36.99	1.82	0.55	0.26	3.15	1.12	2.64	0.2	3.05	15.49	15.17			
REFA_flax site2(1)_pt3	19.12	39.2	0.85	0.63	0.23	2.34	1.4	2.97		2.4	17.47	13.39			
REF3B_flax(1)_pt1	16.24	29		0.75	1.2	4.41	1.3	1.74	0.12	2.01	14.99	1.49		26.75	
nettle 2(1)_pt1	11.46	29.45	1.39	5.03	0.23	2.14	0.91	1.62	3.58	14.24	9.75	20.21			

All EDS data was acquired at 10kV on a ThermoFisher Apero 2 S SEM, using Pathfinder EDS software (V2.6)

Table 2. Spectra weight % plant fiber from control samples

Table 4. EDS Spectra weight % for sampled artifacts, untreated plant fiber.
EDS points detect surface area only, does not reflect depth.

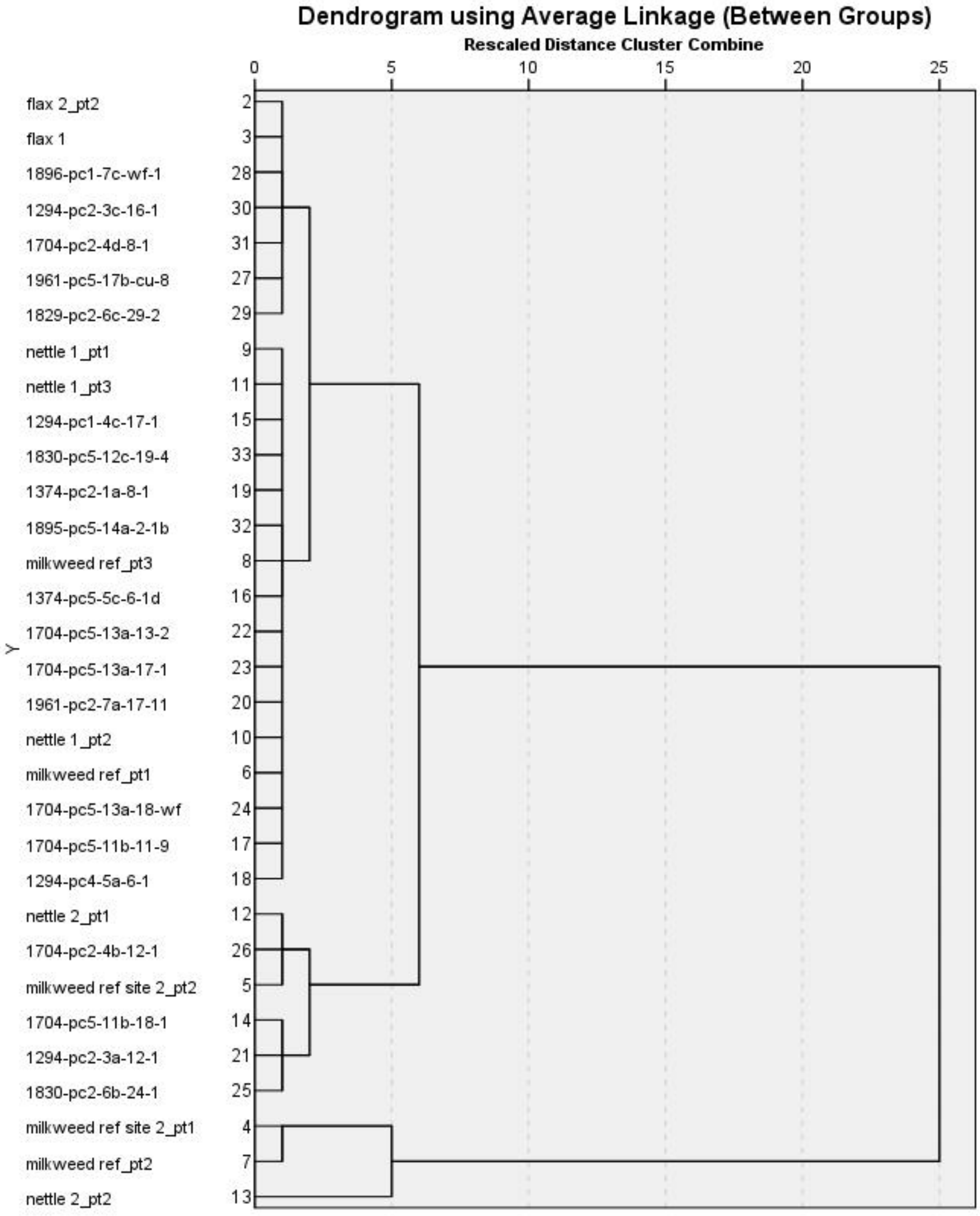
Cat No.	Taxa	Sample No.	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe	Ti
1704-pc5-11b-18-1	*Asclepias*	artifact 5 site 2_pt1	36.6	39.86	4.59	0.73	0.79	1.96	0.6	1.8	3.02	6.1	3.49	0.5	
		artifact 5_pt1	36.3	41.56	2.03	0.56	1.69	1.79	0.3	0.7	3.06	5.9	4.51	1.6	
1294-pc1-4c-17-1	*Asclepias*	artifact 9 site 2_pt1	26.3	41.4	0.77	0.5	2.5	1.58	3.9	0.9	2.04	2.8	15.3	2	
		artifact 9_pt1	25.4	49.37	0.85	0.56	1.11	1.61	4.1	1.7	0.46	2.5	11.5	0.9	
1374-pc5-5c-6-1d	*Asclepias*	artifact2 site 2_pt1	31	46.03	0.82	0.51	2.66	1.36	0.4	0.6	4.5	7	5.13		
		artifact2_pt1	35.7	51.31	1.76	0.29	0.94	0.82	0.3	0.5	2.04	2.9	2.69	0.7	
1704-pc5-11b-11-9	*Asclepias*	artifact 4 site 2_pt1	35.9	34.51	0.53	0.42	2.41	3.28	0.4	0.6	3.03	5.4	6.27	3.4	3.9
		artifact 4 site 2_pt2	47.5	41.96	2.36	0.35	0.69	1.34	0.3	0.4	1.13	2.1	1.44	0.5	
		artifact 4_pt1	35.7	35.64	0.73	0.31	2.51	2.27			0.8	4.1	10.1	7.8	
1294-pc4-5a-6-1	*Apocynum*	artifact 8 site 2_pt1	23.2	45.46	5.7	0.6	2.93	6.29	0.3	0.9	5.13	4.8	2.05	2.4	0.2
		artifact8_pt1	31.1	48.41	5.43	0.41	1.77	3.58	0.2	0.8	3.11	2.9	1.02	1.1	0.1
		artifact8_pt2	32.1	48.86	4.99	0.44	1.82	4.17	0.2	0.7	2.06	2.9	0.96	0.9	
1374-pc2-1a-8-1	*Urtica dioica*	artifact1 sit2_pt1	38.6	36.43	0.43	0.68	1.63	1.46	0.3	0.7	1.93	3.2	13	1.6	
		artifact1 sit2_pt2	39	37.7	0.5	0.64	1.57	0.96	0.2	0.4	1.94	3.4	12.8	1	
		artifact1 sit2_pt3	34.1	33.84	0.43	0.47	2.18	1.17	0.2	0.7	1.78	4.4	17.8	2.9	
		artifact 1_pt1	25.2	47.07	0.96	1.44	1.95	4.22	0.4	2.8	1.4	2.1	10.6	1.9	
		artifact 1_pt2	28	49.08	1.08	1.22	2.25	3.62	0.3	1.5	1.4	2.1	7.83	1.6	
1961-pc2-7a-17-11	*Urtica dioica*	artifact10_pt1	26.5	49.13	1.73	0.65	2.97	7.56	0.8	0.4	1.51	2.7	1.88	3.9	0.3
		artifct10 site 2_pt1	26.9	54.64	2.26	0.64	2.62	6.45	0.5	0.4	1.16	1.5	1.03	1.8	0.2
1294-pc2-3a-12-1	*Urtica dioica*	sample 11(1)_pt1	31.9	43.54	4.08		1.31	1.74	0.1	2.9	3.19	7.7	2.1	1.4	
		sample 11(1)_pt2	32	41.8	8.61	0.01	0.5	0.96		2.9	7.79	4.5	0.97		
1704-pc5-13a-13-2	*Urtica dioica*	sample 14(1)_pt1	28.6	45.23	2.38	0.72	2.02	5.38	0.9	0.7	1.86	5.1	4.9	2.1	0.2
		sample 14(1)_pt2	21.2	49.57	1.83	1.07	2.14	7.09	1.5	0.4	1.2	3.6	8.46	1.8	0.2
1704-pc5-13a-17-1	*Urtica dioica*	sample 15(1)_pt1	28	48.3	3.15	0.3	2.16	1.31	0.3	0.7	4.53	5.3	6.04		
		sample 15(1)_pt2	29.1	53.5	3.07	0.33	1.54	1.44	0.4	0.5	2.43	3.2	3.69	0.8	
1704-pc5-13a-18-wf	*Urtica dioica*	sample 16(1)_pt1	26.2	52.98	2.79	1.05	1.65	2.98	2.1	0.3	0.92	2.9	5.31	0.8	0.1
		sample 16(1)_pt2	28	46.21	2.73	0.89	2.22	1.55	2.6	0.6	1.49	4.7	8.01	1	
1830-pc2-6b-24-1	*Urtica or Asclepias*	sample 18(1)_pt1	28.4	45.85	4.06	0.92	1.38	1.31	0.9	1.4	1.01	7.6	7.07		
		sample 18(1)_pt2	18.5	43.33	2.58	1.48	2.04	4.22	1.4	1	1.55	6.5	15.6	1.8	
1704-pc2-4b-12-1	*Urtica* or *Asclepias*	artifact3 site 2_pt1	32.8	47.48	2.15	0.41	2.29	3.52	0.5	1	2.73	2.2	3.5	1.5	
		artifact3_pt1	32.3	43.43	2.36	1.02	2.44	5.28	1.1	1.6	1.44	3.2	3.94	1.9	
		artifact3_pt2	33.7	43.08	2.37	0.61	3.03	3.16	0.7	1.4	2.99	3.1	4.26	1.6	
1961-pc5-17b-cu-8	*Linum lewisii*	sample 21(1)_pt1	31	50.92	0.5	0.75	2.57	7.46			0.18	1	2.17	3.1	0.3

Table 4. EDS Spectra weight % for sampled artifacts, untreated plant fiber, continued

Cat No.	Taxa	Sample No.	C	O	Na	Mg	Al	Si	P	S	Cl	K	Ca	Fe	Ti
		sample 21(1)_pt2	29	50.35	0.51	0.82	2.84	8.07	0.2		0.19	1.1	3.43	3.1	0.4
1896-pc1-7c-wf-1	*Linum lewisii*	sample 20(1)_pt1	29.6	37.39	0.28	0.29	1.08	2.77	5.6	0.8		0.3	20.6	1.3	
		sample 20(1)_pt2	34.4	49.97	0.21	0.16	0.81	1.47	2.5	0.4	0.12	0.3	9.14	0.6	
1829-pc2-6c-29-2	*Linum lewisii*	sample 17(1)_pt1	24.4	43.22	6.32	0.8	2.07	7.28	1	2.3	1.96	1.4	7.63	1.6	0.1
		sample 17(1)_pt2	30.2	32.62	8.95	0.38	1.75	5.04	0.7	1.3	13.5	1.3	3.2	1.2	
1294-pc2-3c-16-1	*Linum lewisii*	sample 12(1)_pt1	49.6	40.97	2.09	0.24	1.06	1.99	0.1	0.5	1.08	1.1	0.8	0.5	
		sample 12(1)_pt2	34.3	53.2	1.71	0.27	1.53	3.28		0.5	1.72	1.2	0.94	1.2	0.2
1704-pc2-4d-8-1	*Linum lewisii*	sample 13(1)_pt1	20.8	48.79	1.75	0.7	3.06	9.8	0.4	0.2	0.42	1.6	9.28	2.7	0.4
		sample 13(1)_pt2	26.2	56.41	2.22	0.51	1.77	6.07	0.2		0.32	0.8	4.46	1.1	
1895-pc5-14a-2-1b	undeter.	sample 19(1)_pt1	22.5	41.97	1.54	1.19	4.21	13.4	1.2	1.1	1.23	2.4	5.73	3.2	0.5
		sample 19(1)_pt2	22.6	41.4	1.44	1.06	4.13	11.7	1.2	1	1.17	2.1	7.62	4.2	0.4
1830-pc5-12c-19-4	undeter.	sample 7(1)_pt1	33	55.31	0.96	0.35	1.28	1.99	0.1	0.2	0.74	1.7	3.91	0.6	
		sample 7(1)_pt2	41.3	37.74	0.12		3.96	1.15	0.2		1.28	3.8	7.91	2.6	

All EDS data was acquired at 10kV on a ThermoFisher Apero 2 S SEM, using Pathfinder EDS software (V2.6)

Table 5. Cluster analysis for potassium levels in reference samples and archaeological fiber.



CHAPTER 3

FIBER ARTIFACTS FROM THE PAISLEY CAVES; 14,000 YEARS OF PLANT SELECTION IN THE NORTHERN GREAT BASIN

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Introduction

The extraordinary antiquity of the fiber artifact assemblage from the Paisley Caves (Figure 1) offers a unique opportunity to document what plants were used for technological applications (principally basketry and cordage) by First Americans and later cave occupants. In this study, microscopic fiber

Figure 1. Map of sites discussed in the text: 1. Paisley Caves; 2. Fort Rock Cave; 3. Connley Caves; 4. Cougar Mountain Cave; 5. Roaring Springs; 6. Dirty Shame Rockshelter; 7. Paulina Lake Site; 8. Chewaucan Cave; 9. Buffalo Flats; 10. Boulder Village; 11. Bergen Site; 12. Catlow Cave; 13. LSP-1 Rockshelter; 14. Bergen Site; 15. DJ Ranch; 16. Big M Village.

identification, together with radiocarbon dating, serves as an effective means to understanding landscape use and plant selection for fiber-based technologies. Preservation of fiber artifacts in cave sites throughout this region has driven decades of research in Great Basin basketry, focusing on population movements, subsistence and mobility, and cultural attributes (style and structure), with an ongoing radiocarbon dating program that continues to advance regional chronologies (Adovasio 1986; Adovasio and Pedler 1994; Camp 2018; Connolly and Barker 2008; Connolly 1994, 2013, 2022; Connolly et al. 2016; Fowler and Hattori 2011; Ollivier et al. 2017; Smith et al. 2016). Despite the substantial body of work that has contributed to basketry studies, less attention has been given to which plants were used in textile manufacture. Textiles are often documented only by artifact type; specific plant materials are generally not identified, or assumptions are made based on macroscopic observations, and fine cordage is most often described as “bast” or “hemp” fiber. Exceptions to this include analysis of Basketmaker II Yucca and *Apocynum* fiber cordage from Boomerang Rockshelter in Southeast Utah (Haas 2006), identification of bast, bark, and monocot fiber cordage and raw materials from Four Siblings Rockshelter in Nevada (Coe 2012), Bonneville Estates Rockshelter (Coe 2021), and Hogup and Danger Cave textiles in Utah (Lawlor 2020).

Extensive fiber assemblages from Roaring Springs Cave, Catlow Cave, and Dirty Shame Rockshelter have served as iconic collections on which Northern Great Basin (NGB) typologies are based (Andrews et al. 1986; Connolly et al. 1998; Cressman 1942), yet systematic identification of plant taxa has yet to be conducted beyond cursory macroscopic analysis. By contrast, archaeobotanical research using seed, phytolith, and pollen datasets has flourished in recent years in the NGB, offering new insights on human health, diet, landscape use, and the paleoenvironment (Beck et al. 2018; Blong et al. 2020; Kennedy and Smith 2015; Kennedy 2018; McDonough 2019; McDonough et al. 2022; Taylor et al. 2020), particularly at sites such as LSP-1 Rockshelter, Connley Caves, Cougar Mt. Cave, and Paisley Caves. This focus on paleobotanic microscopy and lack of taxa identification for textile technologies has prompted a systematic approach to fiber identification of the Paisley Caves archaeological textiles using direct and polarized light microscopy, and scanning electron microscopy (SEM) with energy-dispersive x-ray spectroscopy (EDS).

This study addresses the following research questions: 1) *What plant taxa are represented in Paisley Caves archaeological textiles; 2) is there change in plant selection for textiles over time;* and *3) what can this tell us about landscape use in relation to changing climatic conditions?* To address these research questions, I systematically examined and identified over 300 fiber artifacts using microscopy, considered the ecology of the represented taxa (e.g., wetland, dryland), and refined the chronology through radiocarbon dating of selected artifacts. Results offer a more nuanced look at seasonality and settlement-subsistence models within the Summer Lake Basin throughout the Holocene, and suggest continuity of plant selection for technology, in particular, the use of stinging nettle and dogbane in the construction of fine cord by 11,000 years ago.

Textile Plants of the Northern Great Basin

For millennia, people have collected fiber from a wide range of plant communities within the NGB. Sagebrush (*Artemisia* spp.), bitterbrush (*Purshia tridentada*), cliffrose (*Purshia mexicana*), sumac (*Rhus* spp.), and milkweed (*Asclepias* spp.) were collected from dry steppe shrub zones, and juniper (*Juniperus occidentalis*) and blue flax (*Linum lewisii*) from mid to high elevation open forests. Monocots from wetlands include Juncus rush (*Juncus effusus*), tule (*Schoenoplectus acutus*), cattail (*Typha latifolia* and *T. angustifolia*), sedge (*Carex* spp.) reed or cane (*Phragmites communis*) and riparian corridors and lowlands included black and white cottonwood (*Populus* spp.), willow (*Salix* spp.), stinging nettle (*Urtica dioica)*, and dogbane (*Apocynum* spp.). Hard-stem bulrush is commonly used in anthropological literature (Fowler 1990) to refer to tule (*Schoenoplectus acutus*, formerly *Scirpus acutus*), a large sedge with rounded, hard stems.

Figure 2. A representative sample of Paisley Caves textiles.

Sagebrush and tule twined basketry (e.g., containers, mats, bags, footwear, infant carriers) characterize much of NGB textiles (Figure 2), a region well-known for the Fort Rock style sagebrush sandals (rarely tule) dating to ca. 9,400 cal BP (based on an average of 58 dates). The introduction of Multiple Warp and Spiral Weft tule sandals around 9,400 cal BP, continuing to the late Holocene (LH), were accompanied by the regionally diagnostic Catlow Twined tule basketry (Connolly et al. 2016), described as plain twined basketry with Z-twist tule wefts and Z-twist, s-spun tule cordage warps (Figure 2, 3).

Klamath and Modoc tule caps, bowls, and trays were often made with nettle or dogbane cordage starts; decorative elements include peeled and split reed or cane, white bear grass, feather quill, porcupine quill dyed yellow with wolf lichen, and mud-dyed tule stem or root (Mathewson, personal communication 2018). Tule mats were also made with nettle or flax cordage warps (Spier 1930). In early summer, sedge was peeled and split for making mats (Colville 1897). Round Juncus rush (common name) stem is stiffer but also used in mats.

While twined tule basketry is associated with Klamath and Modoc peoples, coiled willow basketry is associated with Northern Paiute and Shoshone. Late Holocene Lovelock Cave wickerware in western Nevada is also peeled willow rod and peeled and split willow (Tuohy and Hattori 1996). Willow sticks were also used in open twined seed beaters, burden baskets, fish traps, and in making snowshoe frames (Barrett 1910; Colville 1897).

Coarse cordage (twine and rope) was often made from shredded sagebrush bark, juniper, antelope bitterbrush or cliffrose, but also willow, juncus rush, cottonwood, sumac, and grasses (Poaceae). Like bitterbrush and juniper, sagebrush bark was peeled and shredded before being twisted into cord. The Nez Perce in the Columbia Basin and Northern Paiute and Klamath peoples used bitterbush and cliffrose in cordage and basketry. Woody stems were split and could be used as warp or weft elements in basketry (Chamberlain 1911; Cummings 2004; Kelly 1932; Rhode 2002).

Strong and pliable fine cordage made from the inner fibers of herbaceous dicots was needed for sewing thread, nets, fishing line, snares, hairnets, bowstrings, warp elements in twined basketry and matting, and in lashing, and tying (Barrett 1910; Colville 1897; Downs 1966; Fowler 1992; Fowler and Lawrence 1986; Rhode 2002; Spier 1930; Stewart 1939; Wheat 1967). Historically, Klamath, Modoc, and Northern Paiute peoples used long, linear nets to catch rabbits, fish, and waterfowl (Adovasio et al. 2009; Coville 1897; Oetting 1994; Spier 1930). In the NGB, the most common bast fibers used historically were dogbane and stinging nettle, though blue flax and milkweed were also used (Barrett 1910; Colville 1897; Downs 1966; Fowler and Fowler 1970; Rhode 2002; Spier 1930; Stewart 1939; Wheat 1967).

The Paisley Caves

The Paisley Caves are located within the ancestral homelands of the Klamath, Modoc, and Northern Paiute peoples, and geologically consist of eight wave-cut rockshelters that were at one time located along the shoreline of pluvial Chewaucan Lake in eastern Oregon, now overlooking a mostly dry Summer Lake. Fieldwork by the UO Field School between 2002 and 2011 provides evidence of pre-Clovis human occupations, based on DNA and biomarkers from a coprolite around an ash feature in Cave 5 dating to 14,200 cal BP, and a tule basketry weft element (Gilbert et al. 2008; Jenkins et al. 2012; 2013; 2016; Shillito et al. 2020). Early occupation periods of the caves are interpreted as brief, temporary visits during fall and spring for upland seed collecting (Kennedy 2018). Caves 2 and 5 were the most prolific for the Paisley Period occupation (15,700-12,800), including cordage, bone tools, botanical remains, obsidian and chert flakes, Pleistocene animal bone, and stemmed points (Beck and Jones 2010; Jenkins et al. 2012; Wriston and Smith 2017). The Paisley Period is thus defined as 15,700 to 12,800 years ago, Connley Period as 12,800-11,500, and Fort Rock Period as 11,500-9000 based on dates acquired from Paisley, Connley, and Fort Rock sites (Aikens et al. 2011; Jenkins et al. 2004).

A Younger Dryas botanical lens rich in organic material in Cave 2 offers a unique glimpse into the lives of early occupants. The lens is a matrix of sagebrush matting with hairs, coprolites, and rat and bat feces located between two mud lenses with dates of 11,960 and 12,930 cal BP (Hockett et al 2017; Jenkins et al. 2016). The lens also contains butchered pronghorn and cut hair, jackrabbit cut bone, fish bone, insects, obsidian flakes, and two unlined hearth features (Hockett et al. 2017). Evidence of fiber industries includes sagebrush braided rope and strips of sagebrush bark–likely material for textiles or fuel. A bone needle or awl may relate to the production of sagebrush artifacts such as sandals, clothing, and matting, or sewing activities with sinew or bast fiber (Gahr 2006; Puseman and Cummings 2003).

Artifact assemblages spanning the Fort Rock period (11,500-9000 years ago) and Lunette Lake period (9,000-6,000 years ago) include an abundance of fine cordage for netting and sewing, coarser rope, and tule basketry. However, brief occupations characterize the Lunette Lake period, evident by hearths with limited faunal bone and lithic scatters. Textiles become more diverse and prolific during the later Bergen period (6000-3000 years ago) and Boulder Village period (3,000 years ago to the post-contact era).

The Paisley Caves Textile Assemblage

The fiber artifact assemblage generated from the 2002-2011 UO field school excavations total 453 specimens (Table 2). The Museum's legacy collections and private donations (an additional 125 fiber artifacts) are excluded from the current study. Most twined structures were recovered during the 1930s and 1940s by Museum curator Luther Cressman and other amateur collectors, possibly due to the higher number of LH basketry in higher strata, or to periodic looting of the caves. This includes all of the sandals, which are Multiple Warp style dating to the LH. The field school collections include just thirteen additional Catlow twined basketry fragments, one decorated with overlay and feather quill false embroidery (7,560-7,420 cal BP) (Connolly et al. 1998) and three fragments of Z-twist open-twined matting.

Fine cordage makes up 33% of the collection, though this number may be inflated due to fragmented segments from the same structure (Figures 2, 5, 6). Fine cordage (string-like) is defined as 8-14 twists per cm, ranging in diameter from 0.6 to 3.3mm, is most often z-spun, S-twist, with some exceptions, and almost exclusively made from bast plant fiber (Connolly et al. (2016; Emery 1966). Of the 135 fine cord fragments, 49 have at least one weaver's knot; only twelve have two or more knots (interpreted as a net fragment) in which a mesh gauge measurement was recorded. One possible looped cordage may be from a knotless net or other structure (Figure 6a).

Coarse cordage and braids include both the wider rope-like cords (greater than 7mm in diameter) primarily made from sagebrush bark, and medium-sized cords (mean diameter of 2.6mm) that are often made from tule or other monocots. Medium-sized cordage fragments made from monocot stems are likely basketry warp trimmings (Connolly et al. 2016) (Figure 2, 7). Three-strand braids from Paisley Caves are all temporally unique to the late Pleistocene/early Holocene (EH) and are also contemporaneously present at Cougar Mountain Cave (Rosencrance et al. 2019), the average date of braids from both sites (*n*=23) is 11,985 cal BP, though braids from other sites such as Roaring Springs Cave, also date much younger.

Other modified fibers (*n*=92) include twisted and bent fiber, coils, and over-hand knots. Most notable are two coils, a fiber-wrapped quill, four bent elements that are likely basketry elements, a hide strip wrapped with fiber at one end (Figure 2, 8), and five fragments of plaited cotton fabric, two of which were radiocarbon dated to the LH (Jenkins et al. 2013) (Table 1).

Materials and Methods

Fiber artifacts were divided into 1) phloem fibers from herbaceous dicot plant stems (used in making nearly all fine cordage); 2) bark and leaves used in making coarse rope, braids and some knotted fibers; and 3) monocots used in making most basketry and coarse cordage. Reference collections were established based on herbarium samples and loose fibers collected from nineteenth century basketry housed at MNCH. Specimens were first examined under low magnification to select those requiring further analysis. Approximately 328 were sampled for examination with a Leica DM polarizing light microscope; 125 were not sampled (mostly tule basketry, cordage, and sagebrush coarse rope and knots).

Bast fiber identification

Bast fiber identification was conducted by the author at MNCH and the Center for Advanced Materials Characterization in Oregon (CAMCOR) following previously established methods (Bergfjord and Holst 2010; Florian et al. 1990; Haugan and Holst 2013; Jakes and Mitchell 1993; Jakes et al. 1994; and Suomela et al. 2018). Control samples for dogbane, nettle, flax, milkweed, and fireweed from herbaria were first examined using polarized light microscopy (PLM) and scanning electron microscopy (SEM) with consecutive energy dispersive x-ray spectroscopy (EDS) to establish fiber characteristics. Results from the control samples, together with previously reported characteristics, were then compared to fibers from artifacts (Kallenbach 2023). Fibers too difficult to identify using only PLM were also examined under SEM with EDS. Elemental composition provided an additional tool to aid in distinguishing between nettle, milkweed, and flax in some cases. Assistance in flax and milkweed characterization was also provided by Sandra Koch (McCrone Institute). All samples obtained from artifacts for plasma-ashing and for SEM with EDS were less than 5 mg.

Bark identification

Bark identification was conducted in consultation with wood scientist Suzana Radivojevik (UO, Historic Preservation Program), in which salient microscopic characteristics were established for three taxa of bark: sagebrush, bitterbrush, and juniper based on herbarium reference samples, literature, and wood anatomy databases. Longitudinal view of both unprepped bark and macerated bark fiber were examined. It was not feasible to examine bark cross sections due to the small fiber samples and to avoid unnecessarily altering the artifacts. Subsets of samples were also analyzed by archaeobotanists Kathryn

Puseman (Paleoscape Archaeobotanical Services Team) and Linda Scott Cummings (PaleoResearch Institute), as independent verifications of the author's identifications.

Monocot identification

Microscopic identifying criteria were established for three monocots: tule stem, cattail leaf, and juncus, based on herbarium reference samples, literature, and online sources. Additionally, a subset of samples was analyzed by archaeobotanists Kathryn Puseman (Paleoscape Archaeobotanical Services Team) and Linda Scott Cummings (PaleoResearch Institute).

Results-Fiber Identification

The textile assemblage includes 453 artifacts. Sagebrush, tule, dogbane, and stinging nettle account for 74% of all taxa, the remainder includes milkweed, flax, cattail, grass, bitterbrush, sumac, juniper, cottonwood or willow, cotton (commercial/modern and ancient), commercial jute, animal hair, and unidentified fibers (Table 2). Unidentified taxa (about 13%) were documented as monocot, bark, or bast fiber, or unidentified plant fiber. Modern jute (*n*=1) and cotton cord (*n*=25) were identified, these are not included in the analysis, with the exception of cotton cordage and plaiting (*n*=7) that returned precontact

Figure 3. Cattail matting, possible edge, open twined, 6660-6485 cal BP.

Woven structures

Woven structures include twined matting and basketry constructed of tule stem (13%), sagebrush bark (2%), cattail leaf (1%), and cotton plaiting (4%) (Figure 3, 4). Some twisted and bent fibers grouped under "Other" may be basketry weft or warp elements. Catlow twined basketry is constructed of tule stem, two matting fragments are made from cattail leaf and sagebrush bark.

Fine cordage and netting

Fine cord and netting (*n*=182) are constructed almost exclusively from bast fibers (Figure 5, 6), primarily dogbane (47%) and stinging nettle (28%), followed by flax (2.6%) and milkweed (2%). Other fibers

Figure 4. Woven structures: a. tule matting; b. whole tule matting selvage; c. sagebrush weft element; d. tule Catlow twined basketry; e. tule weft element; f. tule Catlow twined basketry; g. unidentified fiber, weft element.

include unidentified bast fibers (7.8%), cotton (2.6%), unidentified plant fiber (2.6%), tule stem (1.6%), and unidentified bark (1%). All 49 cords with at least one weaver's knot are constructed of dogbane or nettle, or a mix of these two plants. Fifteen cords include blended dogbane and nettle fibers (Table 2); based on the current study, it is unclear if mixing of these two taxa was intentional. Very few fine cords are made from non-bast fibers, but still fall within the metrics defined for fine cordage, with more than eight twists per cm and less than 3.3mm in diameter. These include tule stem (*n*=3), unidentified bark (*n*=1), unidentified plant fiber (*n*=4), and cotton (*n*=5). Of the 18 cotton cords identified, 15 are considered modern intrusions based in evenness of ply, coloration, and disturbed contexts, and are likely remnants from articles of clothing or string left behind by the numerous visitors to the caves since the

Figure 5. a. Polarized light microscopy; dogbane cordage: b. 11,105-10,700 cal BP and c. 7785-7615 cal BP; stinging nettle cordage: d.; e. 11,070-10,715 cal BP; f. 670-560 cal BP; g. 670-560 cal BP; milkweed cordage: h, i. j and k. 2670-2350 cal BP; l. dogbane; m. flax, 1825-1630 cal BP; n. flax, 685-570 cal BP; o. flax, 560±20 BP; p. dogbane, 3230-3070 cal BP; q. dogbane, 8520-8360 cal BP; r. dogbane, 11,270-11,205 cal BP; s. quill-wrapped with dogbane cordage; t. flax, 6295-6115 cal BP.

early 20th century. Five cotton cords were included in the analysis based on precontact radiocarbon dates.

Coarse cordage and braids

Coarse cordage and braids (*n*=128) are constructed almost exclusively from tule stem (39.8%) and sagebrush bark (30.4%), followed by sumac stem (2.3%), bitterbrush bark (1.5%), juniper bark (1.5%), cattail leaf (1.5%), grass (0.7%), unidentified monocot (7%), unidentified bark (3.1%), and unidentified fiber (11.7%) (Figure 7). Rope-like and coarser cord is most often constructed from bark, while medium sized coarse cordage is constructed from tule stem, and in some cases, these cords could be basketry elements. Sumac cord (Figure 7i. j) is constructed from whole stems. All braids are constructed from sagebrush bark.

Figure 6. Netting and knotted cordage: a. dogbane cordage with loops, suggesting unknotted net/bag, 10,279-10,212 cal BP; b. dogbane, 10,250-10,205 cal BP; c. dogbane net fragment in knotted bundle; d. stinging nettle; dogbane: e-h; i. dogbane, 2345-2180 cal BP; j. dogbane net with three knots; k. dogbane net with multiple knots; dogbane: l-p; and q. dogbane, 625-515 cal BP.

Figure 7. Coarse cordage and braids: a. tule; b. bitterbrush knot; c. sagebrush three-strand braid, 12,585-12,045 cal BP; d. sagebrush three-strand braid, 12,100-11,988 cal BP; e. sagebrush; f. juniper, 12,440-11,815 and 11,995-11,820 cal BP; g. unidentified bark, 11,970 -12,310 and 11,860-12,110 cal BP; h. juniper bark; i. sumac stem; j. sumac stem, 1180-1060 cal BP; k. tule possible weft with warp element.

Other

Other fiber artifacts include twisted, crimped, and bent fiber, coils, wraps, and knots, and represent a more diverse group of fiber material, perhaps because of the diversity in structure types which likely represents a wide range of artifact functions, though these are unknown (Figure 8). Sagebrush (28%) includes primarily overhand knots, a half hitch knot, folded bark, twisted fibers, and one coil. Tule (34%) includes twisted, crimped, and bent fibers (likely weft or warp elements), one knot and coil. Bitterbrush (2.2%) includes two knots; goosefoot (2.2%) includes twisted fibers likely from a structure; cattail (1.1%) and unidentified grass (1.1%) include twisted fiber; cottonwood or willow (2.2%) includes two coils; unidentified monocots (10.1%) and unidentified plant fiber (5.6%) include bent and crimped fibers, and

Figure 8. Other fiber artifacts: a. twisted animal hair; b. twisted or bent animal hair; c. multiple s-spun tule roots in loose knot; d. sagebrush Zss cord with loop start of Zssss 4 ply; e. s-spun split tule strand in loose knot; f. tule wrapped stem or coil; g. monocot wrapped stick or coil; h. two willow coils.

wrapped sticks and stems. Five fiber twists or wads were identified as animal hair; only two of these five (5.6%) are interpreted as intentionally twisted.

Radiocarbon Dates and Temporal Distributions of Plant Taxa

Table 1 lists 54 radiocarbon dates from fiber artifacts from field school assemblages, both previously reported dates and 34 new dates. Previously unpublished dates acquired between 2018- 2023 by the UO field school (*n* =17) are included in consultation with Dennis Jenkins and Thomas Connolly. The 28 dates obtained for this study were sampled in consultation with Richard Rosencrance (University of Nevada, Reno) who oversaw sample pretreatment and combustion to CO_2 at the University of Nevada, Reno

Human Paleoecology and Archaeometry Lab (HPAL), following standard protocol (McDonough et al. 2022). The HPAL then sent the CO_2 to the Penn State Radiocarbon Lab for graphitization and measurement. All results listed in Table 1 are rounded following the conventions of Stuiver and Polach (1977) and calibrated with OxCal v4.4 (Bronk Ramsey 2009) using the IntCal20 curve.

Previously reported early dates from the Paisley Caves include a basketry weft fragment, likely tule, dating to 14,660-14,080 cal BP (Shillito et al. 2020), unidentified Szz cordage (12,584-12,231 cal BP), twisted grass (12,390-12,655 cal BP), three-strand sagebrush braids (12,398-12,016 cal BP and 12,100-11,988 cal BP) and middle and LH tule basketry and cotton plaiting (Jenkins et al. 2013). Dates obtained for the current study provide new evidence for the use of dogbane, stinging nettle, juniper, and sumac cordage by 11,000 years ago, and milkweed, flax, and cotton cordage by the LH (Figure 9).

The oldest bast fibers include two stinging nettle cords (11,930-11,410 cal BP and 11,070-10,715 cal BP) and four dogbane cords (11,690-11,255 cal BP, 11,270-11,205 cal BP, 11,080-10,715 cal BP, 11,105-10,700 cal BP). The combined eleven total dates for dogbane cordage and netting confirm its consistent use throughout the Holocene, with the youngest dogbane net dating to 625-515 cal BP. Similarly, the five dates for stinging nettle cordage confirm its use in the early and LH with the youngest stinging nettle net dating to 670-560 cal BP. All five flax fine cords were dated, and include LH dates of 1,825-1,630 cal BP, 960-835 cal BP, 685-570 cal BP, and 560±20 BP, and one middle Holocene date of 6,295-6,115 cal BP. Two of the four milkweed cords were dated, with LH dates of 2,670-2,350 cal BP and 1,410-1,345 cal BP.

Late Pleistocene fiber other than sagebrush includes juniper bark (12,440-11,815 and 11,995-11,820 cal BP) and sumac stem coarse cordage (11,970-12,310 and 11,860-12,110 cal BP) and one late period sumac cord (1,180-1,060 cal BP). The only identified cattail fiber includes a new date for twined matting dating to 6,660-6,485 cal BP. Of the seven dated cotton textiles, two returned recent dates and are considered modern intrusions. Three cotton cords returned dates of 645-540 cal BP, 460-310 cal BP, and 255-30 cal BP, the latter likely historic. Two of the plaited fabrics returned dates of 305-418 cal BP and 980-940 cal BP. This is the first identification of pre-contact era cotton from the Paisley Caves and the NGB.

Table 1. Paisley Caves Textile Radiocarbon Dates

Lab No.	**Cat. No.**	**Description**	**Plant Material**	**Conv. 14C**	**Calibrated Age BP (1 σ error)**	**Publication**
Beta-221344*	1374-PC5-2B-28-1	Cordage, modern?	*Gossypium*	FM = 139.1		
PSUAMS-11478*	1704-PC2-5D-13-1	Cordage, modern?	*Gossypium*	80±15	255-30	
UCIAMS-79679	1374-PC5-5D-30-1b	Plaited fabric	*Gossypium*	275±25	305 (362) 418	Jenkins et al. 2013
PSUAMS-10714*	1294-PC1-5A-4-1	Cordage	*Gossypium*	330±15	460-310	
PSUAMS-10720*	1704-PC5/12A-6-3	Net fragments, Szz	*Apocynum*	535±20	625-515	
PSUAMS-13787*	1896-PC1/7C-WF-1	Szz fine cordage	*Linum lewisii*	560±20		
PSUAMS-11477*	1294-PC5-7C-D-1B	Cordage	*Gossypium*	585±20	645-540	
PSUAMS-12950*	1294-PC2-3C-25-4	Net fragment, Szz fine cordage	*Urtica dioica*	670±20	670-560	
PSUAMS-13784*	1294-PC2/3C-22-1	Szz fine cordage	*Urtica dioica*	665±20	670-560	
PSUAMS-13783*	1294-PC2/3C-16-1	Szz fine cordage	cf. *Linum lewisii*	715±20	685-570	
PSUAMS-11476*	1374-PC5-5C-3-1B	Cordage	*Gossypium*	815±20	740-675	
PSUAMS-13791*	1704-PC-2/4D-8-1	Szz fine cordage	*Linum lewisii*	1015±20	960-835	
Beta-195907	1294-PC1-4C-19-1	Plaited fabric	*Gossypium*	1060±40	980-940	Jenkins et al. 2013
PSUAMS-13788*	1704-PC1/8C-7-1	Zss coarse cordage	*Rhus*	1195±20	1180-1060	
PSUAMS-13781*	1704-PC5/11B-11-9	Szz fine cordage	*Asclepias*	1510±20	1410-1345	
PSUAMS-13786*	1961-PC5/17B-CU-8	Szz fine cordage	*Linum lewisii*	1825±25	1825-1630	
D-AMS1217-407 and AA-96489	1961-PC2-7A-31-6	Weft element, s-twist	*Schoenoplectus acutus*	2107±26 and 2285±37	2041-2121 and 2341-2206	Jenkins et al. 2013
D-AMS-035354	1896-PC2-60-58-9	Twined mat fragments	*Schoenoplectus acutus*	2170±25	2290-2145	Connolly 2019
PSUAMS-10715*	1704-PC2-4a-WF-1	Net fragment, Szz fine cordage	*Apocynum*	2270±15	2345-2180	
PSUAMS-13789*	1830-PC2/6B-24-1	Szz robust cord with overhand knot	*Asclepias* with bark	2410±20	2670-2350	
PSUAMS-10719*	1830-PC2-6A-22-1	Zss coarse cordage	*Artemisia*	2430±20	2690-2355	

Table 1. Paisley Caves Textile Radiocarbon Dates, continued

Lab No.	**Cat. No.**	**Description**	**Plant Material**	**Conv. 14C**	**Calibrated Age BP (1 σ error)**	**Publication**
PSUAMS-12614*	1961-PC2-7C-17-60a	Szz fine cordage	*Apocynum*	2985±20	3230-3070	
PSUAMS-13782*	1829-PC2/6C-29-2	Szz fine cordage	*Linum lewisii*	5410±30	6295-6115	
PSUAMS-13790*	1829-PC2/6C-29-1	Twined mat, possible edge, Zss-twisted weft	*Typha*	5765±30	6660-6485	
PSUAMS-13593*	1961-PC5-17a-cu-7	Zss fine cordage	*Apocynum*	6870±30	7785-7615	
PSUAMS-13779*	1829-PC2/4A-38-1	z-spun fine cordage element	*Apocynum*	7620+35	8520-8360	
Beta-240513	1294-PC2-3A-31-1	Possible weft elements from basketry structure	*Apocynum*	7680±50	8430-8530	Jenkins et al. 2013
PSUAMS-12953*	1896-PC2-6D-48-1a	Zss fine cordage with knot node, possible net frag	*Apocynum*	9075±40	10,250-10,205	
AA-96487	1961-PC2-7A-18-36	Zss fine cordage with loops, suggesting unknotted net/bag	*Apocynum*	9080±50	10,279-10,212	Jenkins et al. 2013
PSUAMS-13780*	1896-PC2/4A-44-4	Zss cordage, thicker	*Urtica dioica* or *Apocynum*	9190±40	10,495-10,240	
PSUAMS-12952*	1961-PC2-7A-17-11	Zss fine cordage	*Urtica dioica*	9535±45	11,070-10,715	
PSUAMS-13594*	1961-PC5-17b-cu-e-1e	Zss fine cordage	*Apocynum*	9555±45	11,105-10,700	
PSUAMS-11475*	1895-PC5-16A-22-8b	Zss fine cordage	*Apocynum*	9555±30	11,080-10,715	
UCIAMS-75104	1829-PC5-11A-37-2	Cordage?	Unidentified plant	9625±20	11,120-11,170	Jenkins et al. 2013
PSUAMS-12954*	1896-PC2-6A-52-2	Szz fine cordage	*Apocynum*	9840±45	11,270-11,205	
PSUAMS-13778*	1896-PC2/4A-45-2	Szz fine cordage	*Apocynum*	9970±40	11,690-11,255	

Table 1. Paisley Caves Textile Radiocarbon Dates, continued

Lab No.	**Cat. No.**	**Description**	**Plant Material**	**Conv. 14C**	**Calibrated Age BP (1 σ error)**	**Publication**
UCIAMS-79678	1294-PC5-6A-44-1	S-spun fiber with tight loop	Unidentified plant	10,030±90	11,375-11,790	Jenkins et al. 2013
UCIAMS-87421, UCIAMS 85337, and D-AMS1217-410	1896-PC2/6B-59-13	Szz coarse cord, w/ 2nd Szz cord tied with overhand knot	*Artemisia*	10,070±30, 9995±25, and 9770±50	11,455-11,770, 11,370-11,575, and 11,186-11,232	Jenkins et al. 2013
PSUAMS-11479*	1374-PC5-5B-26-1a	Szz fine cordage	*Urtica dioica*	10,130±30	11,930-11,410	
D-AMS-035353	1830-PC5-11A-32-5	Knotted cordage (sample used up)	Purshia	10,155±50	11,965-11,640	Connolly 2019
UCIAMS-87420 and 85336	1896-PC5-16-25-5a	Szz coarse cordage, Szz, two frags dated	unidentified bark	10,290±35 and 10250±25	11,970 -12,310 and 11,860-12,110	Jenkins et al. 2013
Beta-195908	1294-PC2-3C-31	Three-strand braid	*Artemisia*	10,290±40	12,100-11,988	Jenkins et al. 2013
UCIAMS-79680 and D-AMS1217-411	1829-PC2-4D-48-1	Knot	*Artemisia*	10,365±30 and 10,365±40	12,120-12,470 and 12,101-12,466	Jenkins et al. 2013
Beta-171938	1374-PC5-5A-30 1 & 2	Five twisted fibers	Unidentified, possible grass	10,550±40	12,390 (12,520) 12,655	Jenkins et al. 2013
AA-96490	1961-PC2-7D-18-28	Three-strand braid	*Artemisia*	10,300±60	12,398-12,016	Jenkins et al. 2013
PSUAMS-12611	1961-PC2-7C-18-49	Three-strand braid, unmodified bark fiber in overhand knot at one end	*Artemisia*	10,255±35	12,430-11,815	
PSUAMS-12613 and PSUAMS-12951*	1830-PC5-12C-22-4	Szz coarse cordage	*Juniperus*	10,265±40 and 10,230±50	12,440-11,815 and 11,995-11,820	
PSUAMS-11473*	1961-PC2-7C-16-126	Three-strand braid	*Artemisia*	10,335±30	12,460-11,945	

Table 1. Paisley Caves Textile Radiocarbon Dates, continued

Lab No.	**Cat. No.**	**Description**	**Plant Material**	**Conv. 14C**	**Calibrated Age BP (1 σ error)**	**Publication**
AA-96488	1961-PC2-9B-49-12	Szz cordage	Unidentified fiber-root?	10,480±60	12,584-12,231	Jenkins et al. 2013
PSUAMS 12612*	1294-PC2-3C-29-1	Three-strand braid	*Artemisia*	10,400±40	12,585-12,045	
D-AMS 035352	1294-PC5-7C-25-1	Basket element, S-twist	*Schoenoplectus acutus*	12,270±60	14,660-14,080	Shilitto et al. 2020

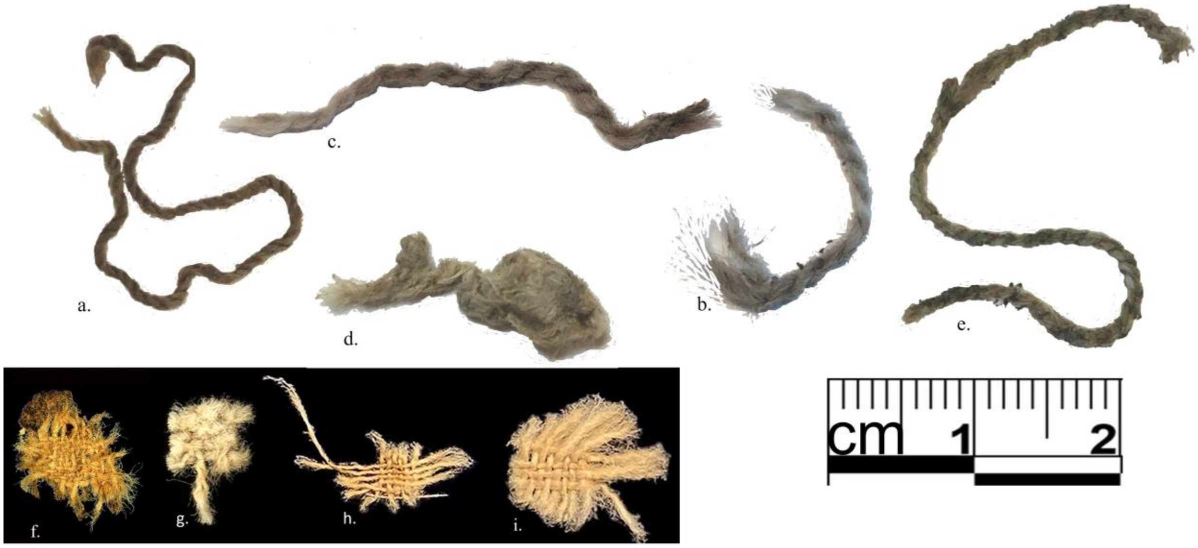

Figure 9. Cotton cordage: a. 460-310 cal BP; b. 645-540 cal BP; c. 740-675 cal BP; d and e. Cotton plaiting: f. 305-418 cal BP; g. 980-940 cal BP; h and i.

Temporal distributions of plant taxa

Textiles were grouped by artifact type, taxa, and temporal component to examine plant selection over time (Table 2). Age ranges of fibers are based on direct radiocarbon dates or associated temporal components (largely based on obsidian hydration and stratigraphy) (see also Jenkins et al. 2013). Nearly 40% of textiles are from disturbed components, which refer to krotovina disturbance and excavation pits by looters during the early 1900s. Overall, there is consistent use of a limited number of taxa since the late Pleistocene. Fine cord and netting are represented by dogbane and nettle during the late Pleistocene and throughout the Holocene, with milkweed and flax occurring much later during the LH. Coarse cordage and braids made from bark and monocot stem indicate consistent use of sagebrush since the late Pleistocene, and while juniper, sumac, and bitterbrush represent less than 2%, they also occur during the EH. Other textiles (coils, knots, bent and twisted fiber) are dominated by sagebrush knots and tule twisted and bent fiber present continuously since the late Pleistocene; bitterbrush and grass are also present during the late Pleistocene. While beyond the scope of this paper, it should be noted that bast cordage technology remains constant since the EH; twist direction is consistently Szz, and fine cord metrics (cord diameter and number of twists per cm) for knotted and unknotted cordage does not vary based on dogbane and nettle selection.

Table 2. Artifact Type by Temporal Component and Taxa

Family	**Genus, Species**	**Common Name**	**Paisley 15,700-12,800**	**Connley 12,800-11,500**	**Fort Rock 11,500-9000**	**Lunette Lake 9000-6000**	**Bergen 6000-3000**	**Boulder Vill. 3000-contact**	**Dist. Comp.**	**Total**
Fine Cordage (includes netting and cord elements)										
Apocynaceae	*Apocynum* spp.	Dogbane			8	14	13	17	31	83
Apocynaceae	*Asclepias* spp.	Milkweed						2	2	4
Urticaceae	*Urtica dioica*	Stinging Nettle		3	1	6	2	10	25	47
Linaceae	*Linum lewisii*	Blue Flax				1		4		5
Apocynaceae and Urticaceae	*Apocynum* spp. and *Urtica dioica*	Dogbane and Stinging Nettle			2	2	2	5	4	15
		Unidentified bast fiber (likely Nettle, Flax, or Milkweed		1		1	1	5	5	13
		Unidentified bast fiber							2	2
Malvaceae	*Gossypium* spp.	Cotton					1	4		5
		Unidentified plant fiber		2			2			4
Cyperaceae	*Schoenoplectus acutus*	Tule (bulrush)				2			1	3
		Unidentified bark			1					1
		Total	0	6	12	26	21	47	70	182
Coarse Cordage, Cord Element, and Braids										
Asteraceae	*Artemisia tridentata* and other species	Sagebrush		9	4	5	9	3	9	39
Rosaceae	*Purshia* spp.	Bitterbrush		1					1	2
Cupressaceae	*Juniperus occidentalis*	Western Juniper		1		1				2
Anacardiaceae	*Rhus* spp.	Sumac, Skunkbrush			1			1	1	3
Cyperaceae	*Schoenoplectus acutus*	Tule (bulrush)			4	9	7	5	26	51
Typhaceae	*Typha* spp.	Cattail leaf					1		1	2
		Unidentified Monocot				2	1		6	9
		Unidentified Bark			1		1		2	4

Table 2. Artifact Type by Temporal Component and Taxa, continued

Family	**Genus, Species**	**Common Name**	**Paisley 15,700-12,800**	**Connley 12,800-11,500**	**Fort Rock 11,500-9000**	**Lunette Lake 9000-6000**	**Bergen 6000-3000**	**Boulder Vill. 3000-contact**	**Dist. Comp.**	**Total**
		Unidentified Plant Fiber		1		1	4	2	7	15
Pocaceae	Unknown, many types	Grass							1	1
		Total	0	12	10	18	23	11	54	128

Woven Structures (basketry, matting, plaiting)

Asteraceae	*Artemisia tridentata* and other species	Sagebrush			1				1	2
Cyperaceae	*Schoenoplectus acutus*	Tule (bulrush)	1		1	1	1	4	6	14
Typhaceae	*Typha* spp.	Cattail leaf				1				1
		Cotton (plaiting)						2	2	4
		Total	1	0	2	2	1	6	9	21

Other (twisted fiber, bent fiber (possible weft or warp elements), knots, coils)

Asteraceae	*Artemisia tridentata* and other species	Sagebrush		13		4	3		8	28
Rosaceae	*Purshia* spp.	Bitterbrush		1					1	2
Cyperaceae	*Schoenoplectus acutus*	Tule (bulrush)		5	5	9	1	1	12	33
Typhaceae	*Typha* spp.	Cattail				1				1
Pocaceae	Unknown, many types	Grass		1						1
		Unidentified monocot		1	2	2			4	9
Salicaceae	*Populus* spp. or Salix spp.	Cottonwood, Black and White or willow							2	2
Chenopdiaceae	unknown	Goosefoot							2	2
		Unidentified Plant Fiber			1		1	1	2	5
		Animal hair			1	3			1	5
		Total	0	21	9	19	5	2	32	88

Plant taxa was also grouped by ecology and temporal component, excluding artifacts from disturbed components. Data is presented by number of artifacts (Figure 10); these broad ecological groupings indicate continuity overall, but with a clear pattern of increased wetland plants after 12,000 years ago. The Lunette Lake period (9,000-6,000 years ago) has the highest frequency of wetland plants, decreasing significantly during the Bergen and Boulder Village periods (after 6,000 years ago) (see discussion).

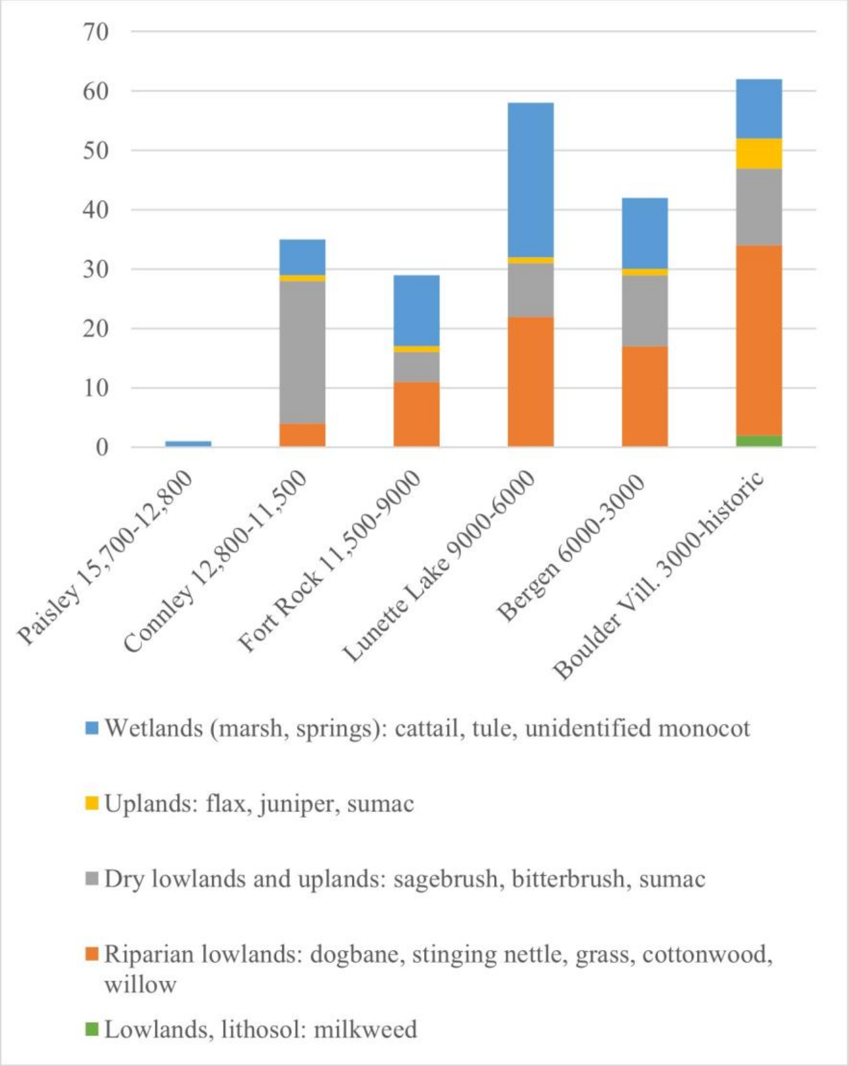

Figure 10. Taxa distribution by ecology and chronology.

Discussion

Late Pleistocene-early Holocene transition

Late Pleistocene/early Holocene fiber artifacts at Paisley Caves are limited in number but already suggest knowledge of a variety of textile fiber resources represented by sagebrush rope and three-stand braids, tule basketry weft elements, bitterbrush knotted bark, and twisted grass threads. Dogbane and stinging nettle fine cordage, and sumac stem and juniper bark coarse cordage are present between 12,000-10,000 cal BP. All three-strand braids are made from sagebrush bark (Figures 4, 5, 6). These plants continue to dominate the NGB textile record throughout the Holocene and into the nineteenth century.

During the Bolling/Allerod (>14.7-12.9 ka), deep-bodied lakes filled lowland basins, and Lake Chewaucan was at its highest levels as the earth warmed at the end of Last Glacial Maximum. Lake level high stands during the Paisley Period were followed by lake contraction during the Younger Dryas cold snap between ~12,900-11,600 years ago when the earth's climate returned temporarily to a glacial state (Goebel et al. 2011; Hudson et al. 2021). During the late Pleistocene/early Holocene transition, expanded wetlands, spring fed lakes, and seasonal ponds overall may have improved conditions considerably for animal and plant resources (Hockett et al. 2017), including fiber plants. Riparian and wetland textile fiber well suited for basketry and cordage, such as tule, cattail, rushes, dogbane, and stinging nettle likely thrived in these new landscapes. This dramatic period in ecological change coincides with the earliest evidence of humans populating the NGB by 14,500 years ago (Goebel et al. 2008; Jenkins et al. 2012; Hockett et al. 2017; Shillito et al. 2020), and Columbia Plateau by ~16,000 cal BP (Davis et al. 2022).

Earliest dates for stinging nettle and dogbane fine cordage are 11,900-11,200 years ago, with an increase in the presence of tule and other monocot artifacts after 12,000 years ago. This coincides with expanded wetlands and lowland riparian areas, ideal habitats for these plants. The decline in Lake Chewaucan lake levels (to the immediate southeast of Paisley Caves) during the Younger Dryas likely resulted in expanded wetlands (in place of deep-water lakes) to the north and south as well as around Lake Abert, with steppe shrub habitat moving upland. While an increase in the presence of wetland and riparian plant fiber artifacts could be due to preservation issues, it may also reflect an increase in or introduction of tule basketry and fine cordage manufacture. Whether this represents cultural innovations or changes in fiber-based technology due to environmental adaptations, or both, is unknown.

Research at Paisley Caves and Connley Caves suggest a broad-spectrum diet was already established by the Younger Dryas (Hockett and Jenkins 2013; Kennedy 2018; McDonough et al. 2022), including bison, pronghorn, grouse, rabbit, fish, insects, and a range of plants. The botanical lens in

Paisley Cave 2 includes pronghorn and jackrabbit cut bone, and possible fishbone and insects also deposited by humans (Hockett et al. 2017). At Paisley Cave 2, human coprolites with dates of 9,620±30 and 10,833±59 BP include edible taxa of sunflower family (Asteraceae), mustard family (Brassicaceae), carrot (Apiaceae), Great Basin wild rye (*Leymus cinereus*), wild buckwheat (*Eriogonum* sp.), and evening primrose family (Onagraceae) (Taylor et al. 2020). Uncharred stinging nettle seeds were present in the hearth features and Cave 5 earth oven (Kennedy 2018); this plant resource was used for nettle cordage during the Younger Dryas. This diverse diet was likely established in tandem with textile technology, including netting suited for rabbit hunting and fishing.

Younger Dryas macrofloral remains from a Paisley Cave 1 hearth suggest a diet of *Chenopodium*, bunch grass (Poaceae), needlegrass (*Achnatherum), Sesuvium,* borage *(Boraginaceae* sp*.)*, and saltbush (Kennedy 2018). These upland charred seed taxa reflect the seasonal use of the caves during early spring and fall when these plants were most abundant (Jenkins et al. 2016; Kennedy 2018). It is noteworthy that raw bast material is not present in the unmodified macrobotanical remains (sticks, bark, grass), as is seen at Bonneville Estates Rockshelter (Coe 2021), which includes unmodified milkweed, dogbane, and flax phloem fibers. The absence of raw bast fiber material at Paisley Caves may suggest a lack of cord-making activity at the site, which supports the interpretation that the caves were used during the spring and summer months for short periods, with requisite tools being brought to the site rather than being made on site.

Foothill shrub zones and upland areas also provided resources for coarse cordage technology including sagebrush, bitterbrush, sumac, and juniper. The presence of five cords of juniper, sumac, and bitterbrush during the Younger Dryas, while small in number, illustrate that sagebrush was not the only dryland shrub or upland resource for fiber (Figure 7). Younger Dryas pollen studies of Paisley Cave 2 coporolites include juniper, sagebrush family (Asteraceae), bitterbrush, alder (*Alnus*), pine (*Pinus*), fir (*Abies*), popular (*Populus*), hemlock (*Tsuga*), and willow (Beck et al. 2018; Blong at al. 2020; Taylor et al. 2020), evidence that these taxa were available for technological use.

Early Holocene and seasonal fiber collection

During the Fort Rock and early pre-Mazama period (11,000-7,600 years ago) populations increased, people were highly mobile, and travelled long distance based on obsidian sourcing (Connolly 1999). People also accessed a diverse range of habitats, including marshlands, dryland, step shrub zones, and high elevation forests to maintain a broad-spectrum diet. Textile fiber collection and processing was likely an important component of travel to different ecological zones for seasonal foraging and hunting activities. Winters were spent primarily at lakesides and marshes where fish and waterfowl were available year-round. Tule stem, one of the most common monocot basketry and cordage fiber in the Paisley assemblage, is gathered from marshes in the fall when the stems turn brown; stands of tule in standing water could be accessed from dugout canoes. Other wetland fiber plants such as cattail, sedge, willow, and juncus would have been collected in late summer through early fall (Downs 1966; Fowler and Fowler 1970; Stewart 1939; Wheat 1967). Travel to high elevations in summers for large game hunting of ungulates (antelope, mountain sheep, deer, and bison) included foraging for seeds, roots, and berries, and may have been an opportunity to collect juniper bark and sumac. The abundance of sagebrush and bitterbrush lowland and upland shrub zones were ideal for collecting wood fuel and bark fiber for textiles.

Dogbane and stinging nettle were well established as the primary bast fiber resources for fine cordage and netting by 11,000 years ago (Figure 5, 6), and continued to be used throughout the Holocene and into the Contact era. Fine cordage netting was likely used in fowling and fishing year-round, and possibly in fall rabbit drives as early as the late Pleistocene. In addition to late Pleistocene rabbit bone and carcasses in the Paisley botanical lens (Hockett et al. 2017), the EH site Buffalo Flats in the Fort Rock Basin is known for pit features with a sizeable number of jackrabbit and cottontail bone. These features are interpreted as processing areas following repeated hunts in which rabbits were driven into pits (Oetting 1994). Long linear nets made from dogbane and nettle, ethnographically known to be anywhere from 20-400 feet long, were used in communal hunts to catch rabbits as they were driven from brush (Adovasio et al. 2009; Connley et al. 2017; Kelly 1932; Wheat 1967).

Based on the continuity and quantity of dogbane and nettle cordage and netting from Paisley Caves, summer and fall activities likely included the essential task of gathering these bast fibers as part of larger foraging activities. Both of these plants grow adjacent to wetlands and in riparian habitats; *Apocynum cannabinum*, the wetland species of dogbane (Franklin and Dryness 1988; Rhode 2002; Gilky and Dennis 2001), was likely targeted over *A. androsaemifolium* (spreading dogbane) and *A. pumilim* (low dogbane). The tall stems of *A. cannabinum* are ideal for extracting long strands of phloem fiber, especially if stands are cut down each fall. Dogbane cordage manufacture would have required repeated visits to wetland stands in the late fall when stems die and turn brown; they could then be cut back to the ground. Their rhizome root structure allows for seasonal return to the same patches. Historically, Northern Paiute peoples collected long, dried dogbane stalks and scraped bark away or crushed and then peeled or scraped away bark. Stalks are then hammered or retted, split open, and the inner pith removed (Rhode 2002; Wheat 1967). Stinging nettle can be collected throughout the summer around the periphery of wetlands, near shady spring-fed creeks in the foothills above the basin floor, and as an understory within the Fremont National Forest and Owyhee Mountains (Gilkey and Dennis 2001; OregonFlora 2021).

Middle Holocene climatic change

During the Lunette Lake Period, vegetation records indicate drought-like conditions, with a shift toward a drier, more arid environment, with lower lake levels and increased marshlands and spring fed basins ~ 8,000-6,000 years ago. Mazama ash fall likely temporarily reduced plant diversity and contributed to overall population decrease. There was a transition from cave and rock shelter habitation sites to open-air locales closer to permanent lakes (such as Paulina Lake), seasonal springs, and vernal pools, perhaps in response to this mid-Holocene climatic change (Aikens et al. 2011; Jenkins et al. 2004; Ollivier et al. 2017). Groups were highly mobile, with ephemeral use of caves sites, and temporary camps around lakeshores.

The textile assemblage from Paisley Caves offers support for this model, with an increase in wetland plants during the Lunette Lake period, including a twisted cattail leaf, tule basketry fragment, and the only identified cattail woven structure dated to 6,660-6,485 cal BP (Figure 3, 10). While this may be due to inflated numbers from fragmentary monocot (primarily tule) and bast artifacts, the increase in wetland taxa is significant. There is also continued use of upland areas, represented by one (undated) juniper cord from a Lunette Lake component, and one flax cord dated to 6,295-6,115 cal BP. This broader range of upland, dryland, and wetland plants may represent the more transient or temporary use of Paisley Caves during this time (Jenkins et al. 2016), in which people may have brought resources from a more diverse range of habitats.

Previous research has also used textiles as a proxy for illustrating changing land use patterns during the middle Holocene. At Last Supper Cave in Nevada, the sequence of dates from Fort Rock, Spiral Weft, and Multiple Warp sandals represents a hiatus during the middle Holocene, which suggest the gap in the sequence for these sandals may represent more short-term use of caves and rockshelters (Ollivier et al. 2017). There is also a hiatus in Catlow Twined basketry likely due to the more ephemeral use of dry caves rather than a reduction in production of these fiber artifacts (Camp 2018).

During the Bergen Period, Lake Chewaucan shorelines rose slightly, close to historical levels at 1290m, as did Lake Abert after 3,900 years ago (Hudson et. al. 2021). This general trend toward a wetter and cooler climate has continued to the present (Aikens et al. 2011) with oscillating dry and wet climatic periods. At Connley Caves, plant taxa present in human coprolites dating to the Bergen period indicate seasonal use of uplands and continued reliance on wetlands, including juniper and sumac upland plants, and cattail and tule seeds (McDonough 2019). Year-round village sites, such as the Bergen Site, Big M Village, and DJ Ranch were adjacent to wetlands, ponds, springs, and lakeshores, allowing for continued access to wetland and riparian fiber and dietary resources. Catlow Cave and Roaring Springs Cave, known for their rich and diverse textile assemblage, are also situated close to lakes and springs.

There is a significant increase in fine cordage and tule cordage and basketry in the Paisley Caves assemblage during this period. However, the slight decrease in wetland fiber plants following the Lunette Lake period may indicate fewer marsh resources were brought out of lowlands to temporary cave sites; and more upland plants may have been brought to seasonal camps such as Paisley Caves, away from lowland settlements. No upland textile fibers are represented at Paisley during the Bergen phase; however, two sumac artifacts remain undated and from disturbed components, and upland plants overall (sumac, juniper, flax) represent less than 3% of the entire assemblage.

Late Holocene upland resources

Unexpected results of this study include the presence of milkweed, flax, and cotton fine cordage dating to the late Holocene. Though limited, these fibers make up 8% of all LH fine cordage (milkweed and flax just 5%). During this period people increasingly use upland areas for root gathering due to cyclical wet and dry periods, reduction in marshlands, and increases in population (Brashear 1994; Byram 1994; Jenkins 1994; Prouty 1994) centered around Warner Valley, Chewaucan Basin, and Klamath Basin. An expanded resource area during this period may relate to increased populations and dispersal in the NGB generally. The acquisition of cotton cordage and plaited fabric radiocarbon dated within the last 1000 years may reflect increased interactions with exterior groups. Dietary plants are also most diverse during this time; at LSP-1 Rockshelter (Kennedy and Smith 2015), people may have been motivated by nutritional benefits, not only caloric return based on the diversity of dietary plants including *Chenopdium* sp., saltbush and mustards, as well as marsh foods such as cattail, and upland resources including chokecherry seeds.

Flax, a high-elevation plant, was likely collected during visits to upland root-gathering areas, such as Boulder Village, the largest spring root collecting site (Byram 1994). Flax prefers drought-like conditions and mid to high-elevations in association with sagebrush, bitterbrush and pinyon-juniper habitats between 4,500-7,500 feet in elevation (Rhode 2002; OregonFlora 2021; USDA Plant database 2021). Juniper bark was also used for cordage during this time, and upland sites show significant use of juniper for structural material (Stenholm 1994). Milkweed at Paisley Caves only makes up a total of four identified cords, but like dogbane, milkweed is also gathered in late summer or fall from dry open meadows and rocky slopes or in areas with moist, sandy, loamy soils (Rhode 2002).

Conclusions

This research provides long-term data on culturally significant native plants, with continuity in plant selection spanning the last 14,000 years. During the late Pleistocene/early Holocene transition, the archaeological record suggests a cultural 'explosion' with Western-stemmed lithic technology, basketry and fine cordage, bone needles, and a broad-spectrum diet including waterfowl, rabbits, fish, artiodactyls, seeds and roots (Hockett et al. 2017; Rosencrance et al. 2019). This cultural expansion included knowledge of several key textile plants including tule, sagebrush, juniper, bitterbrush, stinging nettle, and dogbane. Expanded marshlands during the late Pleistocene/early Holocene created suitable plant communities ideal for fiber technology, specifically wetland monocots (tule, sedges) and herbaceous dicots including dogbane and stinging nettle. This technology is key to subsistence activities and craft production throughout the Holocene.

By the EH, a limited group of plants ideal for strong string fiber, rope, and basketry are well established; there is continued reliance on this select group of taxa throughout the Holocene, while the near absence of cattail, juncus, reed, and willow for fiber at Paisley is notable. Despite climatic events during the Lunette Lake period, in which people transitioned from caves to sites centered around lakeshores and wetlands (a trend exhibited in the increased number of wetland plants in the Paisley assemblage), the suite of fiber plants and their technological application remains constant. This overall continuity parallels what we know about dietary plants; much of the taxa present in the late Pleistocene diet from Paisley Caves is present in the middle Holocene diet at Connley Caves. At the Paisley Caves, dogbane, nettle, and tule fiber were used for millennia and are primary fibers in nineteenth century Klamath baskets. During the LH, bast fiber material diversified with the addition of flax and milkweed. The presence of flax in particular, a high elevation plant, may reflect the increased use of upland root collection areas as populations increased.

The Great Basin is a region rich in textiles made from plant material; this study reveals new and important aspects of people's lives that have largely been unexplored archaeologically. Textile plant identification allows a more nuanced understanding of how people engaged with diverse and changing landscapes, illustrates the importance of fiber collection as part of a larger system of settlement and subsistence practice, and compliments ongoing research in dietary studies. In the Northern Great Basin, ecological knowledge required for fiber technology was established by 14,000 years ago, and continues today, exemplified through traditional arts and technology.

Bridge

The following Chapter 4 builds on chronological and botanical data for textiles from the Paisley Caves presented in the current chapter and applies fiber identification methods described in Chapter 2. While Chapter 3 focuses on plant selection, landscape use and settlement and subsistence patterns since the terminal Pleistocene, raw material is only one key variable in textile analysis. Chapter 4 analysis explores the correlation between raw material selection and cordage metrics and other artifact attributes.

CHAPTER 4

CORDAGE AND NETTING FROM THE PAISLEY CAVES: PLANT MATERIALS, TECHNOLOGY, AND CULTURAL INDICATORS

Elizabeth Kallenbach authored this chapter independently, with editorial comments and assistance with figures from co-author Thomas J. Connolly. Connolly also cataloged the cordage assemblage and recorded technical attributes with co-author Kallenbach. Intended for publication in 2024.

Introduction

In the Northern Great Basin (NGB), thousands of cordage artifacts have been recovered from dry cave sites; the Paisley Caves alone have over 330 artifacts of cordage and cord elements that span the last 12,000 years. The Paisley Caves are known for pre-Clovis, late Pleistocene occupations based on DNA and biomarkers from coprolites and a basketry weft element dating to 14,200 years ago (Jenkins et al. 2016; Shillito et al. 2020) (Figure 1). The antiquity, preservation, and size of the cordage assemblage make it well-suited for a diachronic study of NGB cordage technology. Cordage is a primary technology employed in manufacturing clothing, netting, sewing thread, snares, and bow strings, and serves as weft elements in Great Basin basketry. Previous studies in Great Basin cordage have explored regional differences in fine cordage net technology between the NGB and Western Great Basin (Connolly et al. 2017), and the importance of netted structures to Great Basin lifeways (Adovasio et al. 2009; Jolie 2005). Cordage technology can also serve as an indicator of gender roles, ethnicity, or group identity (Coe 2021, 2023; Connolly et al. 2017; Haas 2006; Jolie 2005). Coe (2021) has examined technological-stylistic traits to explore social organization and a *chaine operatoire* approach to understanding site function. Experimental tests also compare strength and elasticity of raw fiber materials (Lawlor 2020), and quantity and production time required (Herrero-Otal et al. 2023). Textile studies, including cordage, are unique in that this artifact type can be directly dated and encompasses specific technological traits that are often associated with cultural regions and time periods. Recently, researchers used directly dated cordage to refine chronologies at sites such as Paisley Caves, Connley caves, and Cougar Mountain Cave (Jenkins et al. 2016; Kallenbach 2023; Rosencrance et al. 2019). Early Holocene fine cordage from Cougar Mountain Cave and Paisley Caves, including fragments of stitched leather contemporaneous with eyed bone needles, suggests these fibers are some of the earliest sewing threads from the NGB (Aikens et al. 2011; Davis et al. 2023; Rosencrance et al. 2019); sewn hide clothing was likely an essential adaptation to the region’s climate.

This study presents plant taxa, metrics and attributes, and chronology of the Paisley Caves cordage assemblage in order to explore the correlation between raw material and technology, and changes or continuity in raw material and technological attributes over time. Results further define cordage industries throughout the Holocene, identify materials of importance to cordage production, and further characterize regional differences in Great Basin fine cordage. Additionally, late Holocene fine cordage yields new insights into extra-regional interactions, with the presence of novel materials including cotton and milkweed.

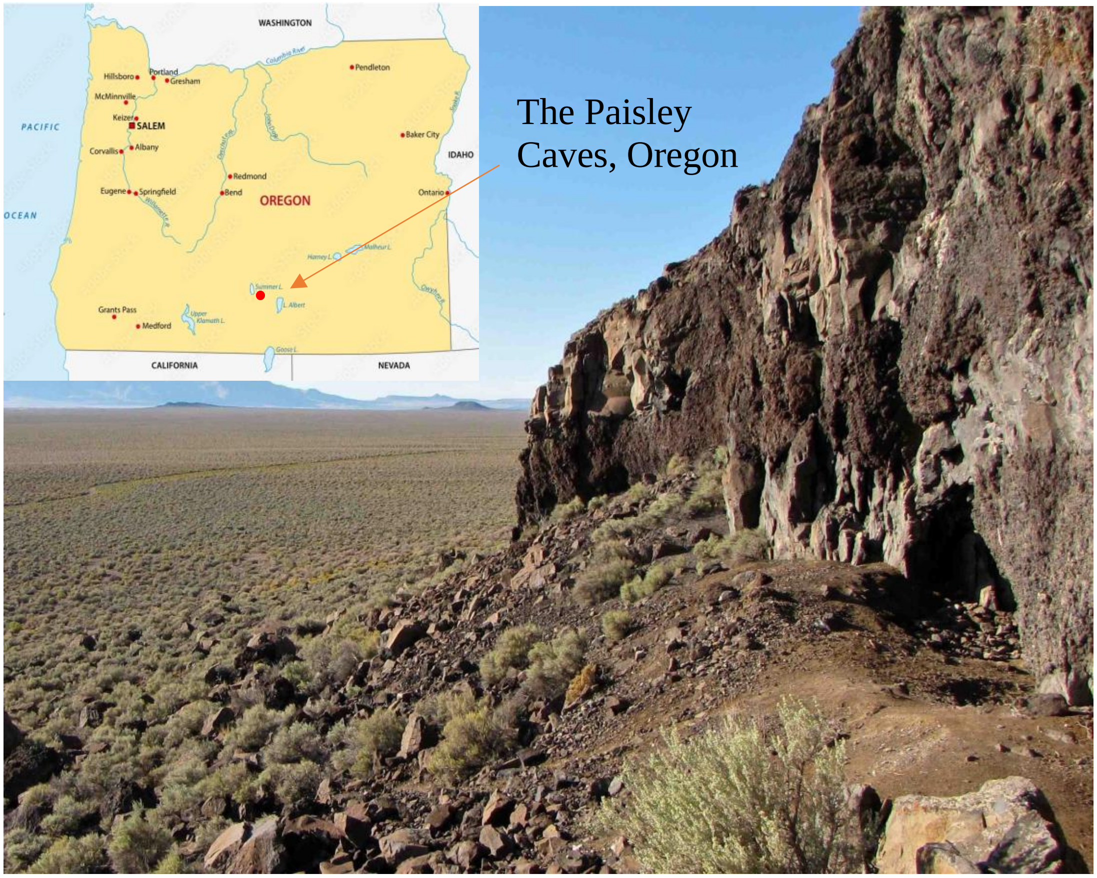

Figure 1. The Paisley Caves overlooking Summer Lake basin.

Great Basin Cordage Technology

Cordage is one of the most versatile textile forms, used in lashing, tying, net-making, sewing (e.g., rabbit skin blanket construction), snares, carrying bags, hairnets, bow strings, fish line, and as warp elements in twined basketry and matting (Fowler and Lawrence 1986; Fowler 1992). Historically, Klamath, Modoc, and Northern Paiute peoples used linear nets (upwards of 300 feet in length) to catch rabbits, fish, and waterfowl (Adovasio et al. 2009; Connolly et al. 2017; Kallenbach 2013; Oetting 1994;). Nets with very small mesh gauge and relatively thick cordage were used as either small fish nets, men's hair nets, or bags. Women primarily wore twined hats, but hair nets were worn by Washoe men and made of milkweed (D'Azevedo 1986). Klamath people were known to use triangular dip nets for fishing from dugout canoes. Small nets with an arrow were also used to catch birds (Barrett 1910). Cordage is one of the most common fiber artifacts recovered from Paisley Caves and other NGB cave sites, and many of these cords are identified as net fragments due to the presence of at least two weaver's knots forming one side of a mesh unit.

Differences between Northern, Western, and Eastern Great Basin basketry have been well established (Adovasio 1970, 1986a, 1986b; Camp 2018; Connolly and Barker 2008; Connolly 1994, 2013, 2022; Connolly et al. 2016; Fowler and Hattori 2011). Technological variations for netting have also been explored by Connolly et al. (2017). In the Western Basin, cord diameter is more uniformly small, regardless of mesh gauge, while in the north there is positive (but weak) correlation between cord diameter and mesh size. Western Great Basin net cordage is also twisted about twice as tightly (on average) than NGB net cordage. More twists can add density and strength to cordage, which may compensate for the generally finer net cordage in the Western Great Basin (Connolly et al. 2017).

Twist direction and group identity

Universally, most fine cordage is two-ply, in which individual plies are twisted in the opposite direction of the final twist; Szz refers to two z-twisted plies with a final S-twist direction, and vice-versa (Figure 2). At Paisley Caves, exceptions include three-strand braids, four-ply cordage in which a two-ply cord has been folded over and twisted again, and single ply twists of fiber that may be cord elements. Directionality of cordage twist has been associated with group identity, learned behavior, and gender roles. Petersen and Wolford (2000) examined Amazonian cordage spanning the last 3000 years and argue twist direction correlates to cultural identity. Haas's (2006) analysis of fiber industries of Basketmaker II also supports a preference for Zss cordage at Boomerang Shelter in Utah.

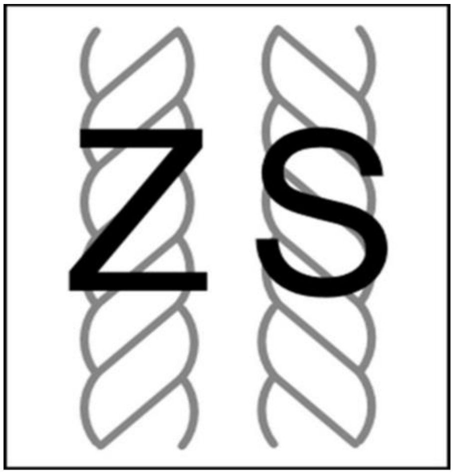

Figure 2. Two-ply cordage Z and S twist directions.

In a collaborative project between the University of Oregon Museum of Natural and Cultural History and the Nevada State Museum, net cordage from museum collections was found to be consistently S-twist (Connolly et al. 2017). This pattern differs from the predominantly Z-twist of other cord types, including the Z-twist tule cordage warp used in Catlow twined basketry. Most ethnographic net fragments described in the literature were also made from S-twist cordage. Historically, men usually made nets while women were generally basket weavers. Within the Paisley Cave textile assemblage, we also see predominantly S-twist in fine cordage and netting, Z-twist for monocot medium-sized cordage, and both S and Z-twist for coarser rope usually made from sagebrush or other bark, suggesting possible gender-based cord-making traditions (Connolly et al. 2017; Fowler 1992). It is also possible that women, or both women and men made cordage for netting, and men constructed the nets. One other possibility is that the S-twist used in fine cordage is a cultural tradition, and not gender-based, as fine S-twist cordage was also used for a variety of purposes including sewing, lashing, and tying. Fiber type was considered by Minar (2000) as one factor determining twist direction. Through interviews with weavers and experimental spinning and twisting, Minar concluded that fiber type could not be definitively linked to direction of twist.

Fiber Plants Used in Cord-Making

Strong, pliable fiber required for fine cordage and netting manufacture are generally made from the inner fibers of herbaceous dicot stems, including those in the Paisley Caves assemblage. These vascular fiber bundles (bast) are much softer and stronger than monocot stems and bark from woody shrubs, making them ideal for string, cordage and loom-woven fabric. In the Great Basin, the most common bast fibers used historically include *Apocynum cannabinum* (dogbane), *Urtica dioica* (stinging nettle), *Linum lewisii* (Rocky Mountain flax or blue flax) and *Asclepias* sp. (milkweed). *Amsonia tomentosa* (Whoolly Bluestar), a perennial small shrub with blue to white flowers is much less common, but the stem produces a strong fiber similar to dogbane and was used by the Owens Valley Paiute for twine (Rhode 2002; Steward 1933;). *Chamerion augustifolium* (fireweed) is known to be used by Northwest Coast peoples, including the Coast Salish who historically integrated fluff from fireweed seed plumes into blankets, along with stinging nettle, dogbane, woolly dog and mountain goat hair (Turner 1998, Hammond-Kaarremaa 2018). Fireweed is native to the Chewaucan Basin, but its use is not documented historically. Novel fibers not indigenous to the NGB could have been acquired through trade, such as yucca and cotton used in the American Southwest. Cotton is present in the Paisley assemblage, discussed under results.

Dogbane was most frequently used throughout much of the Great Basin and California (Barrett 1910). Anderson (2005) notes that in California, large quantities of dogbane and milkweed were required to construct nets, clothing, bags, and other items. Among the Sierra Miwok, five plant stalks were needed to make one foot of string (Anderson 2005:231). Lawlor's (2020) experimental testing of fiber processing and tensile strength showed dogbane and milkweed ranked highest in tensile strength and ability to handle great strain and were predominately used in making nets and snares in the Eastern Great Basin. Plant selection may relate to these inherent qualities of the plant but could also be due to availability.

Stinging nettle fiber, milkweed, and blue flax were also commonly used by the Klamath and some Northern Paiute bands, as well as western Shoshone (Anderson 2005; Barrett 1910; Coville 1897; Cummings 2004; Downs 1966; Fowler and Fowler 1970; Jenkins 1994; Stewart 1941; Wheat 1967). Nettle, like dogbane, is a strong, heavy-duty fiber that was used in rabbit nets, bow strings, and carrying bags (Coville 1897; Spier 1930; Rhode 2002) but was also a medicinal herb used by Kawaiisu as a poultice for soreness and headaches (Chamberlain 1911, Rhode 2002, Zigmond 1981). Klamath and Modoc used primarily nettle according to Barrett (1910) for small gill nets and dip nets used with a hoop and pole. Nettle was also used for fishing line, but, according to Barrett (1910:250) brown milkweed was used as the leader as it was said to be less visible in the water. Spier (1930) also notes that brown and grey nettle was the preferred fiber as it was very strong, though flax was used as well. Among the Klamath, flax was used for fine string in fish nets, in certain parts of baskets and mats, and for the mesh of snowshoes (Spier 1930; Coville 1897).

Dogbane, like milkweed, is gathered in the fall from lakesides and other riparian areas when most of the stalks have dried and turned brown. Long, straight stems were desired, and patches of dogbane were best managed with fire (Anderson 2005). Dogbane wetland species rather than spreading dogbane would have likely been targeted for its long stems that provide long fibers, like stinging nettle. Milkweed is also gathered in late summer or fall. Stalks could be soaked in water to loosen the bark and separate from the inner fibers (Rhode 2002). Northern Paiute collected long, dried dogbane stalks, and scraped bark away or crushed and then the bark peeled or scraped away (Rhode 2002; Wheat 1967). Dried milkweed stalks could be scraped or pounded on rocks to separate inner fibers from the outer bark, and then soaked before making cord (Rhode 2002). However, stinging nettle stem fiber can be collected spring though late summer (Downs 1966; Fowler and Fowler 1970; Stewart 1941; Wheat 1967). Nettle leaves were removed, and the stems left to dry, which were then pounded or cracked to release the inner fibers (Turner 1998). In a related study of Paisley Caves fiber-based technologies, dogbane and stinging nettle were identified as the primary fibers used in fine cordage, with few examples of milkweed and flax (Kallenbach 2023).

Coarser cordage and rope are made from several barks, shredded and plied together. Sagebrush (*Artemisia tridentata* and other species) is the most common, but western juniper (*Juniperus occidentalis*) and bitterbrush (*Purshia* spp.) were also used. Medium cordage, which can be used in the construction of basketry and matting, is commonly made from several monocots such as tule or bulrush (*Schoenoplectus acutus*), juncus rush (*Juncus textilis*), cattail (*Typha* spp.), grasses (Pocaceae), and less common, woody sticks from willow (*Salix* spp.), cottonwood (*Populus* spp.), and sumac (*Rhus* spp.).

The Paisley Caves Cordage

Cordage is well represented at Paisley Caves, and numbers approximately 330 artifacts out of a total of nearly 500 textiles and spans the late Pleistocene through the late Holocene (Figure 3). Cordage is defined as two plies twisted together, the exception being several late Pleistocene/early Holocene three-strand sagebrush braids. Other textiles include basketry, matting, knotted and folded bark fibers, twisted and coiled fibers, and single plies of twisted fiber that are likely cord elements. Coarse cordage is more rope-like, with cord diameter wider than 7mm, upwards of 13mm, and usually made from shredded bark of sagebrush, but also juniper and bitterbrush. Most monocot stems are used in making medium-sized cordage (with a mean diameter of 2.6mm) which is often more rigid than sagebrush rope. Paisley medium-sized cordage is mostly tule stem, but also sumac and cattail, and some sagebrush bark. Tule cordage, being both more rigid and Zss-twisted, suggests many are warp elements trimmed from Catlow Twined basketry. Fine cordage ranges in diameter from 0.6 to 3.3 mm, is usually between 8-14 twists per cm, and almost exclusively z-spun, S-twist. Fine cordage makes up a third of the textile assemblage (135 fragments), though fragmented segments could be elements of the same structure. This ubiquitous artifact type includes twelve net fragments with more than one weaver's knot, and 37 cords with a single weaver's knot, also likely net fragments, but may represent other structures such as hairnets or snares.

Radiocarbon dating and temporal components

The ongoing radiocarbon dating program for Great Basin perishables includes over 70 dates for fiber artifacts from the Paisley Caves (Connley et al. 2019; Jenkins et al 2013; Kallenbach 2024 in press). A total of 35 cordage artifacts from the UO field school collections were directly dated (Table 1). Samples were first sent to the University of Nevada, Reno Human Paleoecology and Archaeometry Lab for pretreatment and combustion to CO_2, overseen by Richard Rosencrance (University of Nevada, Reno), using standard protocol (McDonough et al. 2022), followed by graphitization and measurement at Penn

State Radiocarbon Lab. For this study, chronological control was based on direct radiocarbon dating of selected cordage artifacts and obsidian hydration data generated from the field school excavations (Jenkins et al. 2013). Temporal components include the following periods: Paisley (12,800-11,500 years ago), Connley (12,800-11,500), Fort Rock (11,500-9,000), Lunette Lake (9,000-6,000), Bergen (6,000-3,000), and Boulder Village (3,000-historic era).

Figure 3. Paisley Caves cordage: a. fine bast cordage; b. medium tule cordage; c. coarse sagebrush cordage.

Table 1. Paisley Caves Cordage Radiocarbon Dates

Lab No.	Cat. No.	Description	Plant Material	Conv. 14C	Calibrated Age BP (1 σ error)	Publication
UCIAMS-79679	1374-PC5-5D-30-1b	Plaited fabric	*Gossypium* sp.	275±25	305 (362) 418	Jenkins et al. 2013
PSUAMS-10714	1294-PC1-5A-4-1	Cordage	*Gossypium* sp.	330±15	460-310	Kallenbach 2024
PSUAMS-10720	1704-PC5/12A-6-3	Net fragments, Szz	*Apocynum* sp.	535±20	625-515	Kallenbach 2024
PSUAMS-13787	1896-PC1/7C-WF-1	Szz fine cordage	*Linum lewisii*	560±20		Kallenbach 2024
PSUAMS-11477	1294-PC5-7C-D-1B	Cordage	*Gossypium* sp.	585±20	645-540	Kallenbach 2024
PSUAMS-12950	1294-PC2-3C-25-4	Net fragment, Szz fine cordage	*Urtica dioica* sp.	670±20	670-560	Kallenbach 2024
PSUAMS-13784	1294-PC2/3C-22-1	Szz fine cordage	*Urtica dioica* sp.	665±20	670-560	Kallenbach 2024
PSUAMS-13783	1294-PC2/3C-16-1	Szz fine cordage	*Linum lewisii*	715±20	685-570	Kallenbach 2024
PSUAMS-11476	1374-PC5-5C-3-1B	Cordage	*Gossypium* sp.	815±20	740-675	Kallenbach 2024
PSUAMS-13791	1704-PC-2/4D-8-1	Szz fine cordage	*Linum lewisii*	1015±20	960-835	Kallenbach 2024
Beta-195907	1294-PC1-4C-19-1	Plaited fabric	*Gossypium* sp.	1060±40	980-940	Jenkins et al. 2013
PSUAMS-13788	1704-PC1/8C-7-1	Zss coarse cordage	*Rhus* sp.	1195±20	1180-1060	Kallenbach 2024
PSUAMS-13781	1704-PC5/11B-11-9	Szz fine cordage	*Asclepias* sp. (milkweed)	1510±20	1410-1345	Kallenbach 2024
PSUAMS-13786	1961-PC5/17B-CU-8	Szz fine cordage	*Linum lewisii*	1825±25	1825-1630	Kallenbach 2024
PSUAMS-10715	1704-PC2-4a-WF-1	Net fragment, Szz fine cordage	*Apocynum* sp.	2270±15	2345-2180	Kallenbach 2024
PSUAMS-13789	1830-PC2/6B-24-1	Szz robust cord with overhand knot	*Asclepias* sp. with bark	2410±20	2670-2350	Kallenbach 2024
PSUAMS-10719	1830-PC2-6A-22-1	Zss coarse cordage	*Artemisia* sp.	2430±20	2690-2355	Kallenbach 2024
PSUAMS-12614	1961-PC2-7C-17-60a	Szz fine cordage	*Apocynum* sp.	2985±20	3230-3070	Kallenbach 2024
PSUAMS-13782	1829-PC2/6C-29-2	Szz fine cordage	*Linum lewisii*	5410±30	6295-6115	Kallenbach 2024
PSUAMS-13593	1961-PC5-17a-cu-7	Zss fine cordage	*Apocynum* sp.	6870±30	7785-7615	Kallenbach 2024
PSUAMS-12953	1896-PC2-6D-48-1a	Zss fine cordage with knot node, possible net frag	*Apocynum* sp.	9075±40	10,250-10,205	Kallenbach 2024
AA-96487	1961-PC2-7A-18-36	Zss fine cordage with loops, suggesting unknotted net/bag	*Apocynum* sp.	9080±50	10,279-10,212	Jenkins et al. 2013
PSUAMS-13780	1896-PC2/4A-44-4	Zss cordage, thicker	*Urtica dioica* sp. or *Apocynum* sp.	9190±40	10,495-10,240	Kallenbach 2024
PSUAMS-12952	1961-PC2-7A-17-11	Zss fine cordage	*Urtica dioica* sp.	9535±45	11,070-10,715	Kallenbach 2024
PSUAMS-13594	1961-PC5-17b-cu-e-1e	Zss fine cordage	*Apocynum* sp.	9555±45	11,105-10,700	Kallenbach 2024
PSUAMS-11475	1895-PC5-16A-22-8b	Zss fine cordage	*Apocynum* sp.	9555±30	11,080-10,715	Kallenbach 2024
PSUAMS-12954	1896-PC2-6A-52-2	Szz fine cordage	*Apocynum* sp.	9840±45	11,270-11,205	Kallenbach 2024
PSUAMS-13778	1896-PC2/4A-45-2	Szz fine cordage	*Apocynum sp.*	9970±40	11,690-11,255	Kallenbach 2024
UCIAMS-79678	1294-PC5-6A-44-1	S-spun fiber with tight loop	Unidentified plant	10,030±90	11,375-11,790	Jenkins et al. 2013
UCIAMS-87421, UCIAMS 85337, and D-AMS1217-410	1896-PC2/6B-59-13	Szz coarse cord, w/ 2nd Szz cord tied with overhand knot	*Artemisia* sp.	10,070±30, 9995±25, and 9770±50	11,455-11,770, 11,370-11,575, and 11,186-11,232	Jenkins et al. 2013

Table 1. Paisley Caves Cordage Radiocarbon Dates, continued

Lab No.	Cat. No.	Description	Plant Material	Conv. 14C	Calibrated Age BP (1 σ error)	Publication
PSUAMS-11479	1374-PC5-5B-26-1a	Szz fine cordage	*Urtica dioica* sp.	10,130±30	11,930-11,410	Kallenbach 2024
D-AMS-035353	1830-PC5-11A-32-5	Knotted cordage (sample used up)	*Purshia* sp.	10,155±50	11,965-11,640	Connolly 2019
UCIAMS-87420 and 85336	1896-PC5-16-25-5a	Szz coarse cordage, Szz, two frags dated	Unidentified bark	10,290±35 and 10250±25	11,970-12,310 and 11,860-12,110	Jenkins et al. 2013
PSUAMS-12613 and PSUAMS-12951	1830-PC5-12C-22-4	Szz coarse cordage	*Juniperus*	10,265±40 and 10,230±50	12,440-11,815 and 11,995-11,820	Kallenbach 2024
AA-96488	1961-PC2-9B-49-12	Szz cordage	Unidentified fiber-root?	10,480±60	12,584-12,231	Jenkins et al. 2013

Fiber identification

Plant identification for fiber artifacts was conducted as part of other related studies on the Paisley Caves textiles using polarized light microscopy (PLM) and energy dispersive x-ray spectroscopy (EDS) (Kallenbach 2023). Fibers less than 0.5 cm in length were extracted from cordage using clean tweezers or razor blades and placed on glass slides and encased in Entellen New mounting medium with glass cover slips. Fibers were examined with a Leica DM polarizing light microscope at the Museum of Natural and Cultural History archaeological lab, with a subset of fibers also examined under a scanning electron microscope with EDS at the University of Oregon, Center for Advanced Materials Characterization of Oregon. Fiber identifications were made based on comparisons with reference samples obtained from herbaria and field collections, and from fiber characteristics provided in previous publications (Bergfjord and Holst 2010; Florian et al. 1990; Jakes et al. 1994; Jakes and Mitchell 1996; Suomela et al. 2018).

Results from this plant identification study show coarse cordage constructed primarily from sagebrush bark, but also bitterbrush, juniper, cattail, and unidentified bark. Medium-sized cordage (many of these may be basketry elements) is primarily made from tule stem, but also other unidentified monocots, and in a few cases, sumac stem and sagebrush bark. Fine cordage and netting are almost exclusively constructed from bast fibers including dogbane, stinging nettle, milkweed, and flax; however, cotton cordage, twisted animal hair, and modern fibers are also present. Of the 174 fragments of fine cordage, dogbane (ct=89) and nettle (ct=50) are the primary fibers employed, followed by flax (ct=5), milkweed (ct=4), mixed nettle and dogbane (ct=7), radiocarbon dated cotton (ct=4), and unidentified bast fiber (ct=18). Unidentified bast fibers are likely stinging nettle.

Methods

To explore plant selection and technological applications in cord-making over time, three sets of data were evaluated together: plant taxa, cordage attributes, and chronology. The authors recorded twist direction, knot type, and metrics using hand-held digital calipers. Measurements include cord diameter, number of twists per centimeter, and length of cord following Connolly et al. (2016), Emery (1966), Jolie (2019), and Teague (1998). For fine cordage with more than one knot, a knot-to-knot (from center of knot) distance was recorded to evaluate net gauge size. For single-ply cords, only twist direction was recorded. The textile assemblage includes many fragments of twisted and bent fibers that are not clearly cultural; these were excluded from the current study. Angle of slant was not recorded, as number of twists per cm and diameter was deemed sufficient, however, in cases where cords appear to be unraveling, measurements were not included in the analysis. Metrics were used to assign artifacts into technological categories of coarse cordage, medium cordage, and fine cordage and netting. Technology for each subcategory of cordage as described above was then evaluated in relation to plant taxa and chronology using box plot distributions, focusing on twist direction, cordage fineness, and cordage type (knotted or unknotted).

Results - Cordage Materials and Attributes

Twist direction

All but two of the 48 medium coarse cords made from monocot stem are Zss, while more robust cords made from bark (primarily sagebrush), are both Szz (ct = 20) and Zss (ct=11). The predominantly Zss tule medium cordage suggests some are likely trimmed warp ends of Catlow twined basketry. Of the two Szz-twisted split tule cords, one is from a Fort Rock component (1294-PC-2/3C-20-2b), and one from a disturbed component. Most notable is the near absence of Zss fine cordage after the early Holocene. There is a total of eight Zss cordage fragments out of an assemblage of 171 bast fiber cords (Figure 4), and six of the Zss bast cords date to the early Holocene. All but one Zss cord were radiocarbon dated; six date between 10,000-11,000 years ago, and one dates to 6870±30, 7785-7615 cal BP (Table 1). The one undated knotted cord is from a Lunette Lake component.

Twist	Bark	Monocot	Bast
Zss	11	48	8
Szz	20	2	163

Figure 4. Zss-twisted fine cordage: a. nettle, 9535±45, no. 1961-pc-2-7a-17-11; b. dogbane, 6870±30, no. 1961-pc5-17a-cu-7; c. dogbane, 9075±40, no. 1896-pc2-6d-48-1a; d. dogbane, 9555±45, no. 1961-pc5-17b-cu-e-1e; e. dogbane in two parts, 9078±52, no. 1961-pc2-7a-18-36; f. dogbane, 9555±30, no. 1895-pc5-16a-22-8b.

Knotted fine bast cordage and netting

Of the 49 knotted bast fine cords, all are Szz-twisted cordage, twelve have more than one weaver's knot, and are interpreted as net fragments. Of the cordage with a single knot, twelve are made from nettle, 33 from dogbane, and three are a mix of dogbane and nettle (based on fibers extracted from cord). All twelve net fragments are dogbane. Though this could be interpreted as a preference for dogbane over nettle in net-making, it may also just reflect the overall ratio of dogbane to nettle, with the number of dogbane cordage almost double that of nettle (50/89). A third of all knotted cords are also nettle, and some of these may be fragments of net structures.

Net gauge ranges from 0.84cm to 3cm knot to knot, with a median of 2.1. The net fragment with the smallest gauge (2345-2180 cal BP) has five knots of 0.84, 0.9, 0.9, 0.9 and 1.0 cm, however, it is loosely twisted with only eight twists per cm. The net fragment with the widest gauge of 3-5cm has some of the finest cord, with 14 twists per cm.

Bast cordage fineness

Cordage metrics are used to evaluate change or continuity in technology over time, and to further describe differences between artifacts groups such as fine and coarse cord. Plant selection is an important part of the process, as it is one of many choices made in determining the strength, elasticity, rigidity, and flexibility required in the final structure. Box plots illustrating the number of twists per centimeter and cord diameter are presented by taxa, temporal components, twist direction, and by knotted and unknotted cords. First, fineness was compared across all taxa (Figure 5); dogbane and nettle are much finer than milkweed and flax, with dogbane slightly finer on average than nettle. However, the sample size for milkweed and flax is less than ten artifacts total, so Figure 7 through 11 box plots are limited to dogbane and nettle.

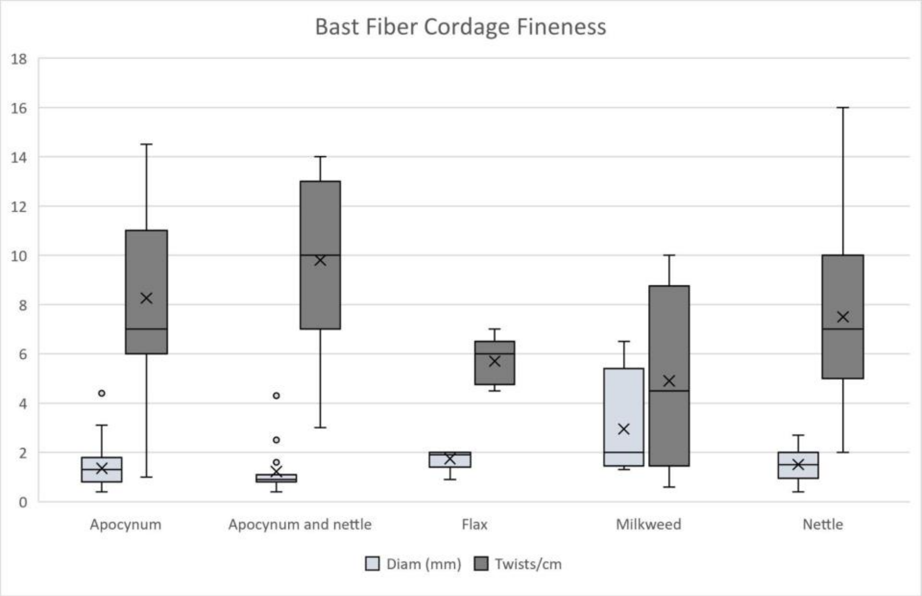

Figure 5. All bast fiber; cordage fineness illustrated by twists per cm and cord diameter.

Over the last 11,000 years, dogbane is represented about twice as often as stinging nettle in the fine cordage assemblage, but this ratio remains fairly constant (Figure 6), with both peaking during the Lunette Lake Period and again during the Boulder Village Period. Unknotted cord, cords with a single weaver's knot, and cords with more than one weaver's knot were also compared for dogbane (Figure 7) and nettle (Figure 8). Cords with more than one knot, interpreted as net fragments, have the highest median for fineness, followed by cords with one knot, and knotless cords the least fine on average. This pattern applies to both dogbane and stinging nettle.

A diachronic examination of dogbane and nettle fineness shows a clear pattern of increasing fineness over time (Figure 9), with the finest cordage on average during the Boulder Village component. However, this pattern is not as evident when evaluated within subgroups of knotted (Figure 10) and unknotted cordage (Figure 11). Cordage shows a slight increase in fineness over time for these subgroups, but also a greater range in the number of twists per cm during the late Holocene. The increase in the number of nets and knotted cordage during the Boulder Village period likely increases the overall median value for twists per cm during the late Holocene. Lastly, twist direction was compared, with Szz fine cord slightly finer on average than Zss cordage. However, Zss cord sample size is only ten artifacts, and does not include any knotted cord or netting, so this comparison is not considered viable.

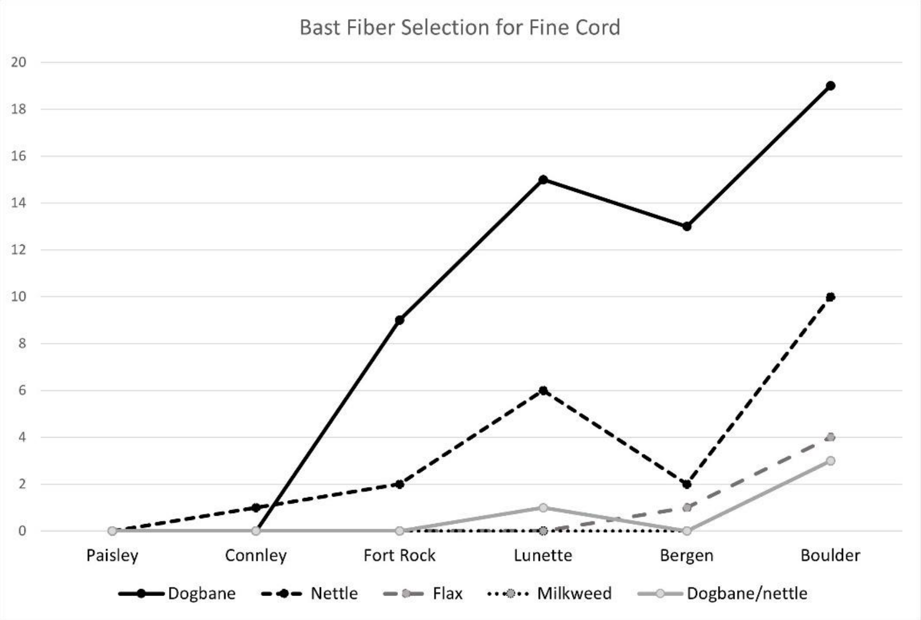

Figure 6. All bast fiber cordage artifacts over time, dogbane, stinging nettle, milkweed, and flax.

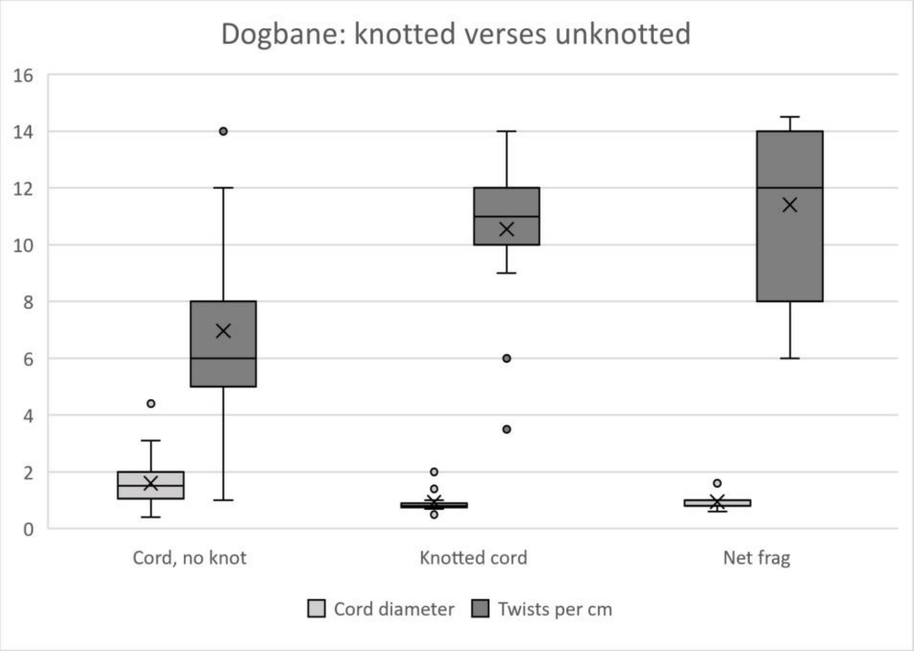

Figure 7. Dogbane knotted (single weaver's knot), unknotted cord, and netting (more than one weaver's knot), cordage fineness illustrated by twists per cm and cord diameter.

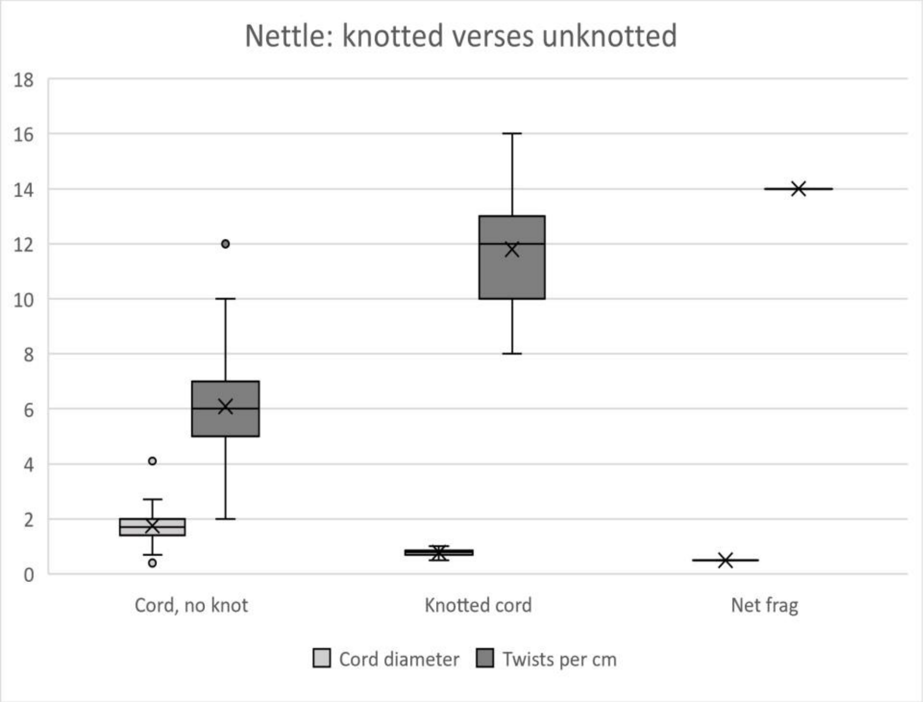

Figure 8. Stinging nettle knotted (single weaver's knot) unknotted cord, and netting (more than one weaver's knot), cordage fineness illustrated by twists per cm and cord diameter.

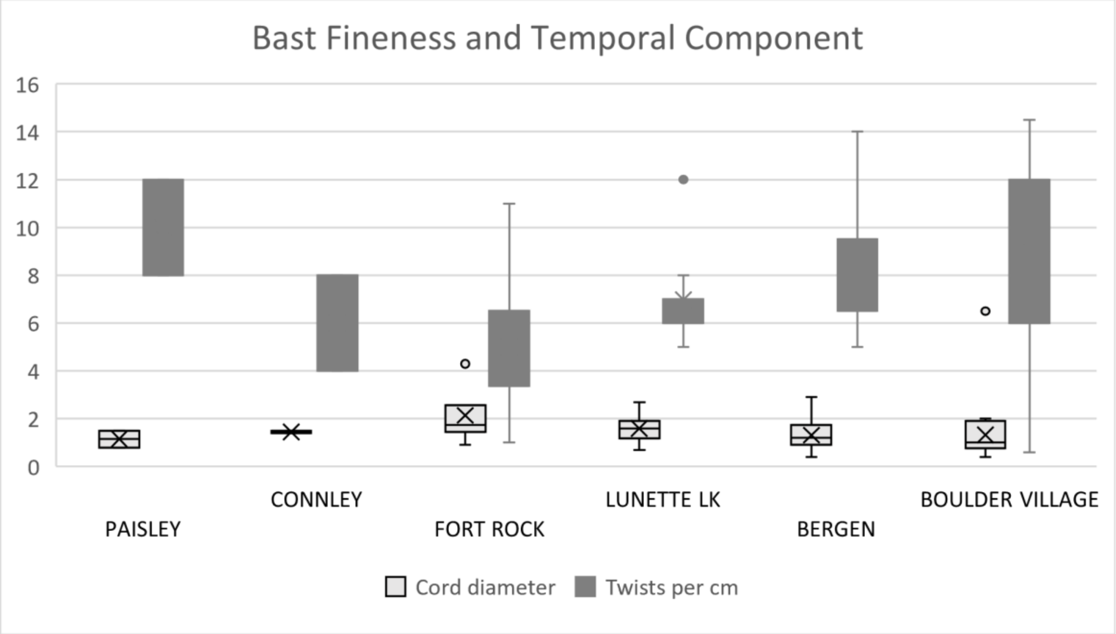

Figure 9. All dogbane and nettle cordage by temporal component; cordage fineness illustrated by twists per cm and cord diameter.

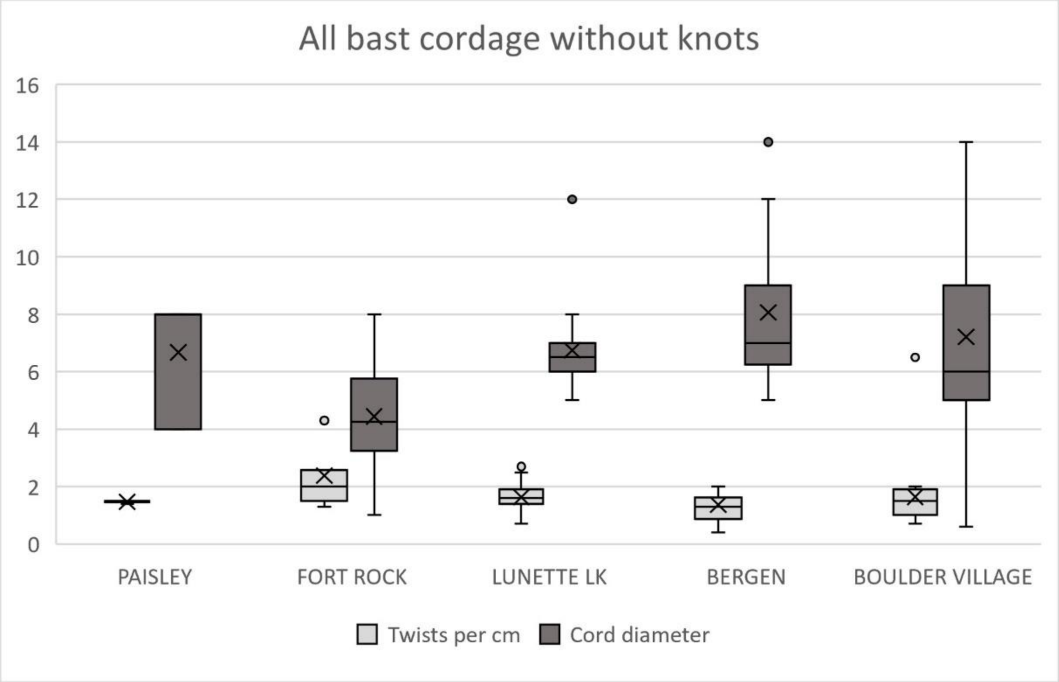

Figure 10. All dogbane and nettle cordage without knots by temporal component; cordage fineness illustrated by twists per cm and cord diameter.

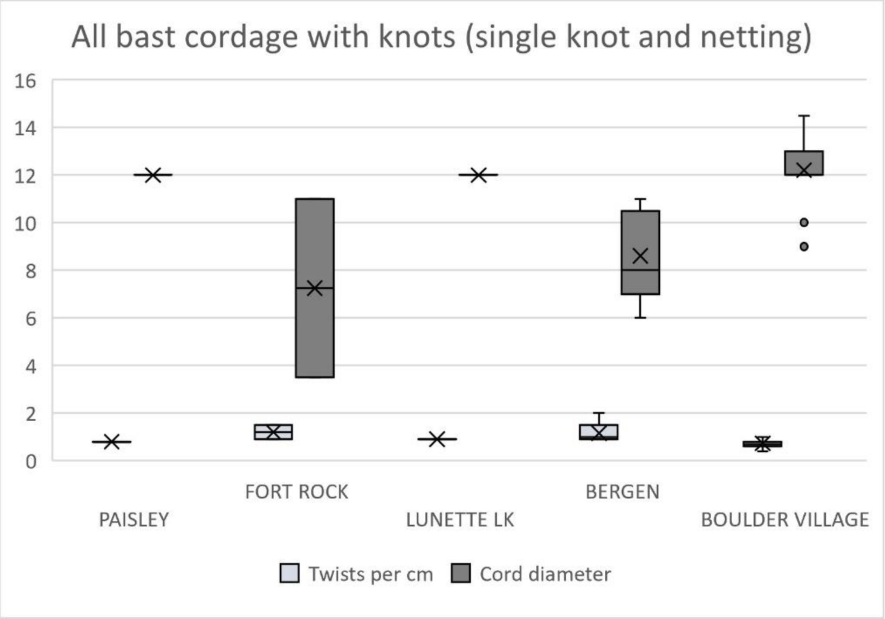

Figure 11. All dogbane and nettle cordage with one or more knots by temporal component; cordage fineness illustrated by twists per cm and cord diameter.

Coarse cordage

Cord diameter and number of twists per cm were also evaluated over time, by twist direction, and by monocot and bark sub-groupings. Monocot (primarily tule) cordage shows strong continuity in cord fineness over time, with a slight increase in cord diameter during the Boulder Village period (Figure 12). The three sumac stem cords are loosely twisted medium cords. Two are Zss-twisted; twists per cm are 1.0 and 2.5, and diameter 2.4 and 2 cm. The third sumac cord is s-spun and coiled back around the single ply. Bark cordage is more diverse in size overall, ranging from rope-like to medium sized cordage, however, Boulder Village bark cordage is notably finer (less coarse) than earlier periods (Figure 13). Juniper and bitterbrush bark, fibers present during the Connley Period and Boulder Village Period, are generally wide cords and loosely twisted, but the small sample size (ct=7) precludes making any interpretations.

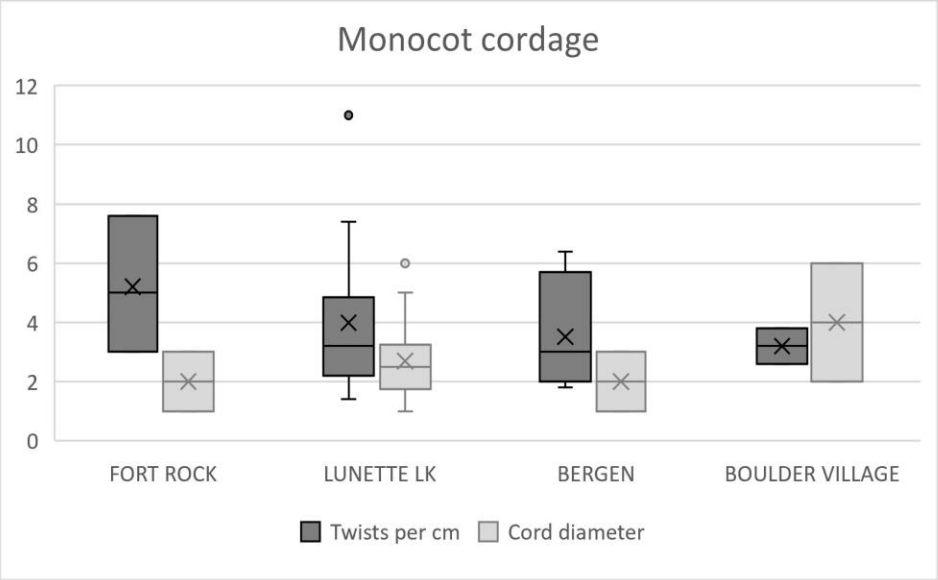

Figure 12. Monocot cordage by temporal component, fineness illustrated by twists per cm and cord diameter.

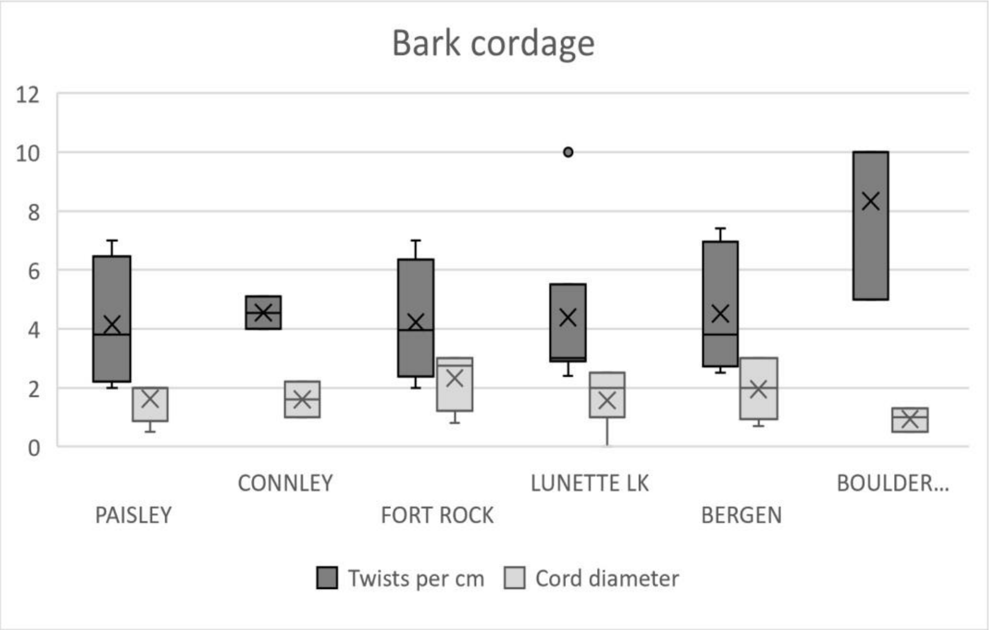

Figure 13. Bark cordage by temporal component, fineness illustrated by twists per cm and cord diameter.

Unique attributes

Artifacts that exhibit unique attributes include unusually wide bast cordage diameter, cordage with feather quill or embedded feathers, cordage with two component parts made from different plants, bast fiber overhand knots as opposed to weaver's knots, and four-plied cords (Figure 14). A weaver's knot is the primary knot type employed in knotted cordage and netting, widely used in net making across the Great Basin, however, three Szz-twisted bast cords have overhand knots, two of these are dogbane, and one is an unidentified bast fiber. One Zss-twisted looped cordage is interpreted as a knotless net structure (Figure 4). A Szz-twisted stinging nettle cord (1704-PC-2/4B-13-1) is also partly Z-Szz-Szz, to create a 4-ply cord, whether this is to create greater strength, or to store cordage for a later use, is unknown. There are examples of sagebrush four-ply cordage as well from the Paisley Caves.

One small feather quill is wrapped once with an Szz-twisted dogbane cordage, and a Szz-twisted flax cord (1961-PC-5/17B-CU-8) also contains a very small down feather embedded in the fibers, more visible under polarized light. While the function of these is unknown, Janetski (1979) describes a downy feather attached to a draw cord in a scissor snare from Painted Cave (Haury 1945), the function of the feather is unknown. A robust Szz-twisted milkweed cord (1830-PC-2/6B-24-1) with an unusual diameter of 6mm, also has bark fibers embedded or knotted into the cordage. This thicker bast cord resembles the selvage cord of linear nets, which are documented as wider and more robust bast cords that run the length of one side of the net (Connolly et al. 2017; Kallenbach 2013). One dogbane cordage is also tied with sagebrush bark (1704-PC-2/4B-18-3), the complete structure is unknown, but bast cordage was used to lash together sagebrush bark strips, or as twining elements in sagebrush and tule matting.

Mixed materials

In many cases, animal hair (many are likely rabbit and bat), feathers, pollen, and crystalline inclusions are visible using polarized light microscopy. Some fine cords also contain both dogbane and stinging nettle. For this reason, it was necessary to use clean razors or tweezers and clean glass slides for each new collection to avoid cross contamination. In 15 cordage samples, both dogbane and nettle fibers are present, and in seven of these cordage fragments, two distinct and separate fiber bundles of both dogbane and nettle are visible using PLM, including one net fragment from the Bergen Period (1704-PC-5/12A-4-2) (Figure 15).

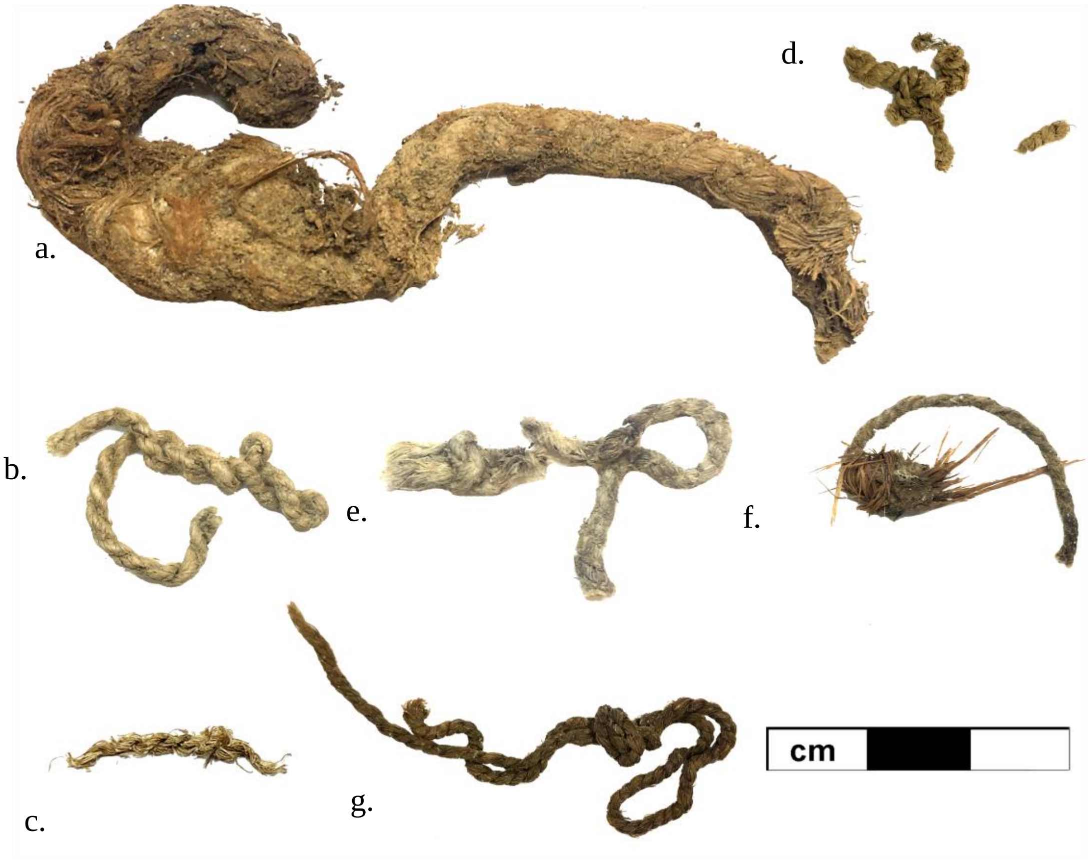

Figure 14. Unique artifacts: a. robust Szz-twisted milkweed cord (1830-PC-2/6B-24-1); b. Szz-twisted stinging nettle cord partly Z-Szz-Szz, to create a 4-ply cord (1704-PC-2/4B-13-1); c. Szz-twisted flax cord containing a small down feather embedded in the fibers (1961-PC-5/17B-CU-8); d. Szz-twisted dogbane cord with overhand knot, (1704-PC-1/9B-12-1); e. milkweed cord with overhand knot and wide diameter (1294-pc-14c-17-1); f. dogbane cordage tied with sagebrush bark (1704-PC-2/4B-18-3); g. Szz-twisted dogbane cord with overhand knot (1704-PC-1/9A-14-1).

Mixed bast fibers are likely the result of post depositional conditions, however, mixing of cordage made from different plant fibers in the construction of the same basket or bag is documented ethnographically (Mathewson, personal communication, 2018), and archaeological examples of mixed dogbane and nettle cordage include the two complete linear nets from Chewaucan Cave (Kallenbach 2013). However, these are additive cordage repairs and sections of netting to create the desired length; mixed taxa within a single ply, or two plies of different taxa twisted together is not documented for the Chewaucan nets. Coast Salish weavers also mixed materials, including mountain goat, doghair, and fireweed (Solazzo et al. 2011).

Figure 15. Mixed materials; dogbane and stinging nettle fiber cordage.

Discussion

Cultural change during the early Holocene

Cultural patterns in the NGB have long been discussed in terms of early pre-Mazama, or Fort Rock Period (12,000-9000) with cultural change occurring after 9000 years ago, largely based on assemblages from Fort Rock Cave, Connley Caves, Paisley Caves, Buffalo Flat bunny pits, and Cougar Mountain Caves (Connolly and Barker 2004; Cressman 1986; Oetting 1994). Overall drying conditions following the Younger Dryas cooling event no doubt served as a catalyst for changes in land use and adaptations to new landscapes and resources. Fort Rock period lithics are characterized by Western Stemmed, lanceolate, and foliate points, large basalt scrapers, and crescents, with lacustrine-based resources that supported a diet of small (rabbit, pike, grouse) and large mammals, waterfowl, fish, and a number of seeds and berries (Bedwell 1970; Connolly 1994; Jenkins et al 2012; 2017; Kennedy 2018; McDonough et al. 2022). Textiles of the early Holocene, pre-Mazama period are defined by undecorated, simple open and close-twined basketry, sagebrush Fort Rock style sandals, sagebrush rope and matting, fine cord netting (Connolly and Barker 2004), and more recently, fine twisted fibers, likely sewing threads, from Paisley and Cougar Mountain Cave (Davis et al. 2023; Rosencrance et al. 2019).

The presence of Zss fine cordage, primarily limited to the early Holocene at the Paisley Caves, may also be another characteristic of Fort-Rock period textiles. Zss-twisted fine cordage is much less common than Szz in the Northern and Western Great Basins generally, and this holds true with the Paisley Cave assemblage. At Paisley, there are only eight Zss fine cords out of a total of 175 fine bast cords. Of these eight, six date between 10,000-11,000 years ago (Table 1, Figure 4). Additionally, one of these represents a possible knotless net structure, with a series of loops. This type of structure is the only example from this site, as NGB netting is nearly always knotted. There are 15 fine cords total for this period, and Zss and Szz cords are contemporaneously represented. Six Zss fine cords are made from dogbane, and one from nettle, which, based on the ratio of dogbane to nettle in the rest of the fine cordage assemblage, does not indicate that plant selection is related to early Zss-twisted cords. For medium cordage, one of the two Szz-twisted tule cords is from a Fort Rock component (the other from a disturbed component); though undated, also points towards differences between Fort Rock and later periods, as Zss-twisted tule cordage and basketry is a central characteristic of NGB textiles.

A cultural shift or transition likely occurred around 9000 cal BP (Aikens et al. 2011; Bedwell 1973; Connolly and Barker 2004, 2008; Cressman 1986); with increased drying came a shift to more ephemeral use of caves evident in the sparsity of lithic flaking debris and small cave hearths. Most significant is a transition from Fort Rock sandals (not present after 8400 cal BP) to Multiple Warp and Spiral Weft (appearing around 9400 cal BP), the first appearance of Catlow twining (Connolly et al. 1998; Connolly and Barker 2004, 2008; Jenkins et al. 2013; Ollivier 2016; Plager et al. 2006) and the addition of decorative overlay and false embroidery. Connolly et al. (2016) report a 400-year temporal overlap (9450–9040 cal BP) between Fort Rock and Multiple Warp style sandals, which suggests this transition may have been abrupt (9500-9000 cal BP). Zss fine cordage, and Szz tule cordage is also seemingly discontinued after this point based on the Paisley assemblage, with the exception of the two middle Holocene Zss cords (one dated, one undated) (Table 1).

While changing climatic conditions play a large part in technological decisions and resource availability, other factors may have also contributed to this cultural shift, such as changing group territories and exchanges of information between groups (Connolly and Barker 2004). Basketry (and cord-making) is a universally conservative craft, meaning that broad changes and innovation are rare and often the outcome of major population movements, replacements, or intermarriage (Adovasio 1970; 1986; 1994; Connolly and Barker 2004; Connolly et al. 2016) The process of basketry construction (including the choice of plant material and twist direction) are always culturally determined, passed on through generations at the group/regional level. Novel basketry styles likely originate from different cultural groups and archaeologically can represent population movements or trade. In the NGB, coiled basketry perhaps serves as the best example of this, appearing late in the archaeological record, about 2500 years ago from primarily eastern sources (Connolly 2013), and represented by less than 20 specimens in contrast to the thousands of twined basketry fragments (Andrews, Adovasio, Carlisle 1986). The transition from both Zss and Szz-twisted fine bast cordage, to exclusively Szz-twisted after 10,000 years ago, with the exception of one Lunette Lake cord, supports an argument for shifting populations or group interactions and exchanges. Dogbane and stinging nettle were both employed in Szz and Zss fine cord manufactured by 12,000 years ago, indicating this change was based on cultural rather than environmental factors.

Cordage technology throughout the Holocene

Fine cordage and netting are made exclusively from bast fibers, with the exception of cotton cordage not indigenous to this region. The Paisley assemblage represents extraordinary consistency in raw material selection, fineness of cordage, and twist direction since the early Holocene, despite climatic changes and shifting land use patterns. Dogbane and stinging nettle do not appear to be selected for distinctively different applications, both are used in net-making in the Paisley assemblage, or structures requiring weaver's knots. Dogbane is represented nearly twice that of nettle, continuous across temporal components, but may be due to availability and not a preference between these two taxa in the final form. The quantity of fine cordage used in netting and snares (essential to lake and marsh-based hunting, fishing, and fowling) peaks first during the Lunette Lake period (Figure 6), with fewer twined structures and artifact diversity overall at Paisley Caves, which likely represents the more transient use of cave sites by more mobile populations adapting to increasingly arid landscapes (Jenkins 2004). Bast fiber cordage numbers drop during the Boulder Village period and peak a second time during the Bergen period. However, both dogbane and nettle use peak during the Lunette Lake and Bergen periods (Figure 6), suggesting changing land use patterns and drying periods did not affect plant selection for fine cordage technology. Dogbane and nettle cordage also share technological attributes and are indistinguishable from each other based on cord fineness (cord diameter and number of twists per cm), with cordage for both taxa notably finer for knotted cords, and highest for netting, or cords with more than one knot.

Rope-like cordage, or coarse cordage made from primarily sagebrush bark (but also juniper, bitterbrush, and sumac) are both Szz and Zss-twisted, while tule stem medium cordage, which is more rigid, is almost exclusively Zss-twisted, a pattern that characterizes other NGB cordage assemblages (Adovasio 1986; Connolly 1994; Connolly and Barker 2004; Connolly et al.2017). Monocot cord fineness is relatively consistent and uniform over time, while bark cordage is diverse, from coarse, loosely twisted rope to medium sized cordage, with the exception of finer bark cordage during the Boulder Village period. This may be due to sampling or may represent a greater number of bark cords used in twined matting and basketry.

While dogbane and stinging nettle fine cord technology was consistent throughout the Holocene, during the Boulder Village period, there is a greater diversity of textiles. The late Holocene in the NGB is characterized by changes in social organization, long-term, year-round habitation sites, population movement, trade, and oscillating dry and wet climatic periods (Aikens et al. 2011; Jenkins 2011). Textiles from both private collections and field school excavations include a basketry tray with decorative elements, an open twined possible hat with false embroidery, matting, decorative Catlow twined tule basketry, Multiple Warp style sandals (all sandals from Paisley are Multiple Warp style dating to the late Holocene), numerous fine cordage and netting (Connolly et al. expected publication 2024) and the addition of milkweed, flax, and cotton. This diversity of textiles and raw materials may point towards more long-term winter residencies at the caves and a wider range of activities. Cordage fineness was also compared for milkweed, flax, dogbane, and stinging nettle, with milkweed and flax (though less than ten artifacts) notably wider and more robust than dogbane and nettle. The presence of more robust milkweed and flax cordage, as well as cotton during the Boulder Village period, may represent access to different resources, experimentation or a need for new applications, or population dispersal and interactions with exterior groups. While dogbane and nettle thrive in more riparian environments, flax is a mid-high elevation drought-tolerant plant and milkweed prefers lithosol soils and can grow within steep, disturbed slopes.

Late Holocene extra-regional interactions

During the late Holocene, Klamath maintained cultural ties with groups in the Columbia Plateau and Central Great Basin, evident in stone tool technology (Jenkins 1994), coiled basketry in the NGB, and Catlow twining outside the NGB (Camp 2018). The presence of cotton dating between 1000-250 years ago at Paisley also suggests NGB people had connections with groups in the Eastern Great Basin with ties to the American Southwest, acquired as raw or loom-woven fabric. Cotton (*Gossypium hopi*) was introduced from Mexico and Central America, and first appeared in Arizona and New Mexico around 700 AD (Baldwin 1939; Smith and Gish 2015), where it was cultivated by Ancestral Pueblo people. Southwestern cordage material is characterized by cotton and yucca, but also dogbane, hair, and juniper bark (Haas 2006). Southwestern cotton has been recovered from several sites in Southeastern Utah (Aikens 1999; Coe 2012; Teague 1998), in the San Joaquin Valley of Southern California (Schenck and Dawson 1929), and with the exception of Paisley Caves, has been found as far west as Gypsum Cave in Nevada (Simpson 1965).

While there are no other examples of cotton traded or acquired as far north as Oregon, long distance trade has been well documented between the Great Basin and the Pacific Coast with a record of *Olivella* shell beads recovered at numerous sites. Late Holocene *Olivella* shell beads from California are documented at Fremont sites and in the NGB (Bennyhoff and Hughes 1987). Earlier exchange networks are also documented, including early Holocene *Olivella* beads from the Northern California or Southern Oregon coast found at LSP-1 Rockshelter in eastern Oregon (Smith et al. 2016), and middle Holocene *Olivella* rectangular grooved beads from the California Channel Islands found at sites in Nevada and Oregon, including DJ Ranch (Jenkins and Erlandson 1996; Raab and Howard 2000). Ceramics have also served as a marker for exchange or population movement. Late period Intermountain brownware, specifically Shoshoni pottery, has been found in southeastern Oregon and suggests NGB people had ties with groups farther east (Dean 1992; Lyons and Cummings 2002). At the Lost Dune Site in southeastern Oregon, brown ware pottery dating within the last 400 years has been sourced to the Owyhee Mountains in Idaho (Lyons and Cummings 2002). This same pottery tradition is found in southern Idaho, Nevada, Montana, and Wyoming, and was made historically by Shoshoni speakers. Madsen (2023) also argues that Fremont greyware, found ubiquitously across Utah, is found within a much broader area beyond the Fremont cultural area, as far as Idaho and Nevada, perhaps brought by Fremont foragers moving beyond their agricultural centers. Considering the fluidity and interactions between populations during this late period, it is not surprising that cotton would also make its way to the NGB from southwestern origins; cotton has likely been recovered from other more northern and western Great Basin cave sites with perishable collections, but has been erroneously identified as modern cotton, or as a bast fiber.

In the Eastern Great Basin, dogbane, milkweed, flax, and yucca and cotton to a lesser extent, are the prevalent fibers used in fine cordage (Coe 2012, 2021, Jennings 1957; Lawlor 2020). At Bonneville Estates Rockshelter and Four Siblings Rockshelter in Nevada, and Danger and Hogup Cave in Utah, fine cordage fibers and raw material are primarily dogbane and milkweed, followed by flax, while stinging nettle is rarely reported (Coe 2012; Coe 2021; Lawlor 2020). Historic accounts report Northern Paiute, Klamath, and Modoc using stinging nettle (Ebeling 1986; Janetski 1979; Turner 1998; Zigmond 1981) and Klamath people using milkweed and flax (Colville 1897), however, the predominance of nettle and dogbane cordage over milkweed and flax is noteworthy at the Paisley Caves, with milkweed and flax making up only 5% of all bast cordage (approximately ten artifacts).

Flax and milkweed cords from the Paisley Caves are less fine than dogbane and nettle based on cord diameter and twists per centimeter, including one robust milkweed cord (Figure 14). This may be due to differences in artifact function or other applications. Based on Lawlor's (2020) study of tensile strength in which stress and strain are measured, milkweed ranked similar to dogbane (which ranked the highest), this is supported by the use of dogbane and milkweed as the strongest fibers of choice in the Eastern Great Basin, and one of the most common bast fibers used in fine cordage from sites such as Hogup Cave, Cowboy Cave, Danger Cave, Bonneville Estates Rockshelter, and Etna Cave (Adovasio et al. Coe 2021; Lawlor 2020). This suggests nettle in the NGB may have been selected over milkweed during the late Holocene based on cultural preference, availability, or both, rather than fiber strength. Or milkweed, along with cotton, represents interactions with exterior groups farther east.

Future Work

The presence of cotton cordage and plaited fabric deserves further study. Loom-woven fabric is novel to this region, as is any indigenous cotton fiber. While the six dates on cotton place it within a pre-contact period, additional lines of evidence such as DNA or comparative textile analysis with samples from the Southwest would support the claim of interactions between Pueblo people and the NGB. Secondly, additional textile assemblages housed in museum collections should be revisited to identify plant fibers, primarily those used in cord and net making which are difficult to identify without PLM and EDS. Identified cordage materials used in complete structures, such as snares, nets, sewing thread, and bow strings can offer clues as to plant preference in different applications. Sampling, while destructive, requires less than 0.5cm of a single hair-like fiber, which can be removed without visibly altering the artifact. Building a database of known plant fibers in conjunction with radiocarbon dates and type of structure will allow a regional and diachronic perspective of plant selection; this may offer new clues to the decision-making process in cordage technology or point toward cultural or environmental factors.

Conclusion

Cordage is perhaps the simplest expression of textile technology, yet still embodies learned behavior, group identity, and ecological knowledge of raw materials required to create the desired structure. This study uniquely focuses on the large assemblage of cordage from the Paisley Caves, using identified raw materials and directly dated cordage to explore changes and continuity in cordage industries in the NGB since the early Holocene. While dogbane cordage numbers are nearly twice that of nettle, cordage metrics and attributes do not indicate this is based on decisions regarding the final structure, but rather resource availability. The technological application of stinging nettle and dogbane after 10,000 years ago exhibits continuity in cord fineness and twist direction for all subclasses (knotted and unknotted cord). The equal distribution of Zss and Szz fine cordage constructed from both dogbane and stinging nettle limited to 11,000-10,000 years ago, further supports the hypothesis of a cultural shift due to population movements or group interactions rather than, or in addition to, environmental causes.

Basketry cultural regions were established nearly 50 years ago (Adovasio 2021), the timing and frequency of basketry styles and technologies have since been refined, and difference in netting between Western and Northern regions has also been demonstrated (Connolly et al. 2017). To this we can also add plant selection; stinging nettle and dogbane are a distinguishing feature of NGB fine cordage technology, which differs significantly from the predominantly milkweed and dogbane cordage of the Western and Eastern Great Basins. The additions of cotton and milkweed may also be a product of extra-regional interactions.

CHAPTER 5
CONCLUSIONS

Principle Findings

The Great Basin is a region rich in textiles made from plant material; this project incorporated chronological, botanical, and technological attributes of textiles from the Paisley Caves to examine ways in which people engaged with diverse and changing landscapes since the Terminal Pleistocene. Key findings include identifying specific plants selected for textile manufacture as early as 12,000 years ago, and further defines continuity and changes in these choices throughout the Holocene. Knowledge of fiber plants and their seasonal collection is intertwined with settlement and subsistence decision-making processes, yet also bound to traditional weaving technologies that are passed down through generations.

Fiber identification

Chapter 2 demonstrates that polarized light microscopy (PLM) is an essential tool for fiber identification, in particular, for distinguishing between native and non-native plant fibers, and in the identification of dogbane (*Apocynum*) and stinging nettle (*Urtica dioica*). PLM is also used to differentiate between bitterbrush, sagebrush, and juniper, three bark fibers that can appear similar macroscopically. Energy-dispersive x-ray spectroscopy, or elemental analysis, proves to be a secondary but necessary method in distinguishing between flax (*Linum lewisii*), milkweed (*Asclepias*), and stinging nettle. Specifically, spectra from milkweed indicate low, but slightly higher amounts of surface potassium than flax which shows trace amounts. This study demonstrates the potential for incorporating raw material as a variable in textile analysis. Other perishable artifacts curated in repositories across the Great Basin offer the potential for similar analysis to further define patterns of plant use over time for specific technological applications.

Long-term perspectives on human-environmental interactions

In Chapter 3, a paleoethnobotanical approach to textile studies is uniquely positioned to address several interrelated questions, drawing from paleoecological, archaeological, and ethnographic data. A limited number of textile plants were selected for cordage and basketry construction since the Terminal Pleistocene, but continuity throughout the Holocene demonstrates extraordinary antiquity for these culturally significant native plants. During the late Pleistocene/early Holocene climatic transition, there is a significant increase in a diversity of cultural activities defined by Western Stemmed lithic technology, basketry and fine cordage, sewing equipment such as fine twisted threads and bone needles, and a broad-spectrum diet (Hockett et al. 2017; Rosencrance et al. 2019). Ecological knowledge of key textile plants such as tule, sagebrush, juniper, bitterbrush, stinging nettle, and dogbane were an essential component to this cultural expansion. Expanded marshlands during the late Pleistocene/early Holocene created new plant communities; wetland monocots (tule, sedges, grasses) and riparian herbaceous dicots, especially stinging nettle and dogbane, thrived in these new habitats, ideal resources for fiber technology. The earliest dogbane and nettle fine cord dates to 12,000 years ago; these textile traditions continue throughout the Holocene, as subsistence activities and craft production are largely derived from plant-based fiber technologies. A limited number of taxa ideal for strong rope, string, and basketry are present over the last 12,000 years, with the notable absence of cattail (with the exception of two specimens), juncus, reed, and willow.

During the drier Lunette Lake period, people positioned themselves around lakeshores and wetlands, while cave sites were visited less frequently and for shorter stints. However, there is an increase in the number of wetland plants in the Paisley assemblage, and an increase in the total number of taxa represented, including juniper bark, sumac, cattail (Figure 3) and the first occurrence of flax (one cordage fragment), a high elevation herb. This may represent a more diverse range of activities in which people accessed a wider range of resources, transporting fiber-based items from both uplands and lowland basins and wetlands. Overall, plant selection for specific technological applications remains constant. At the Paisley Caves, dogbane, nettle, and tule fiber were used for millennia and are primary fibers in 19th century Klamath baskets. This continuity throughout the Holocene parallels research in subsistence plants; the middle Holocene diet at Connley Caves is largely unchanged from the late Pleistocene diet at the Paisley and Connley Caves (Kennedy 2018; McDonough 2019; McDonough et al. 2022).

During the late Holocene, people may have chosen to occupy upland areas close to root gathering zones in conjunction with overall drying conditions and population increases. Bast fiber material diversified during this time with the addition of flax, milkweed, and cotton. The presence of flax in particular, a high elevation plant, may reflect this increased use of upland root collection areas, which supports previous research (Jenkins 1994). Milkweed, while native to this region and documented as a fiber plant ethnographically, is represented by less than five specimens in the Paisley assemblage.

Cordage technology and cultural indicators

Chapter 3 explores changes and continuity in cordage industries in the NGB since the early Holocene. Cordage is the simplest form of textile that only requires twisting two plies of fiber together, yet this technology is foundational to much of Great Basin weaving; it forms the basis for net making, sewing, lashing, and tying. Cordage also embodies learned behavior, can signify group identity, and requires ecological knowledge of raw materials. The antiquity, preservation, and size (ct=330) of the cordage assemblage from the Paisley Caves allows for observable patterns in raw materials and techniques.

Building on data from Chapters 2 and 3, cordage metrics and artifact attributes were evaluated in conjunction with raw material and temporal components (including directly dated cordage). Dogbane is the primary bast fiber used in fine cord manufacture and was used nearly twice as often as stinging nettle; however, cordage metrics and attributes strongly suggest choice of raw material was not based on the final structure or technological requirements, but resource availability. Metrics for cord fineness and twist direction for all subclasses (knotted and unknotted cord) do not show differences between nettle and dogbane. Not only were these two plant fibers used interchangeably, their technological application exhibits continuity throughout the Holocene. One significant exception is the early occurrence of Zss-twisted fine nettle and dogbane cordage, chronologically limited to 11,000 to 10,000 years ago. This further supports the hypothesis of cultural change occurring around 9000 years ago, with Fort Rock style sandals primarily dating to around 9500 years, but rare after about 9000 years ago. This is likely due to interactions between different groups or population movements, rather than, or in addition to, environmental causes. As a conservative craft, basketry and cordage traditions are passed down through generations; variations in these traditions are uncommon and are usually due to changes in group identity though intermarriage, shifting demographics, or other significant factors that can affect cultural traditions.

This study also demonstrates differences between Northern and more Western and Eastern Great Basin fine cordage traditions. Fine cord raw material from the Paisley Caves is primarily stinging nettle and dogbane; however, Western and Eastern Great Basin fine cord raw materials is predominantly milkweed and dogbane, while stinging nettle is rarely reported. The additions of cotton and milkweed cordage at the Paisley Caves during the late Holocene may also be a product of extra-regional interactions. The Paisley Caves cotton plaiting and fine cordage (dating to within the last 1000 years) is the farthest north that archaeological cotton has been documented. However, it is not necessarily unexpected, as late Holocene *Olivella* beads and Shoshoni pottery are found at several Northern Great Basin sites, demonstrating trade or interactions with groups as far as the California coast and the Eastern Great Basin, respectively.

Future Research Directions

Niche construction theory

Within historical ecology, traditional resource and environmental management (TREM) is one way to explore how people interacted with their landscape over time. This dissertation provides a foundation from which to further explore past ecosystems management through experimental plant cultivation and collection. Research questions can be structured within niche construction theory to explore mechanisms of change. Were targeted fiber plants in the Northern Great Basin during the Holocene managed or modified? Does continued coppicing of dogbane and stinging nettle affect its abundance or contribute to longer stems? Based on this dissertation and many other studies of Great Basin textiles, we know fiber industries and textile production were essential to people's everyday lives, for hunting, fishing, fowling, clothing manufacture, and food storage. This required seasonal plant collection, and in many cases likely required a significant amount of plant resources to construct larger nets, basketry, and matting (Anderson 2005). Over millennia, repeated seasonal visits to the same habitats for coppicing and stem collection may have been a catalyst for ecosystems change.

However, documenting environmental management in the archaeological and paleoecological record is difficult. The most common methods used for documenting landscape management are: 1) integrating paleoecological data on climate change and vegetation regimes with archaeological data; 2), comparing lightening verses human-lit fires; 3) using ethnobotanical studies and historical accounts about dietary plants and traditional resource and land management practices; and 4), paleoenvironmental reconstructions of vegetation during or just proceeding Euroamerican settlement (Lepofsky et al. 2001; Minnis 2004; Pyne 1998). For example, Northwest Coast peoples expanded, through landscape modifications, the narrow area of suitable tidal marsh habitat for edible geophytes such as Springbank clover, pacific silverweed, Nootka lupine, and northern rice root lily though the construction of rock and earthen walls (Deur 2005; Smith 2014). On a larger scale, anthropogenic fire regimes have altered forests and grasslands, and extended the natural habitats of some plants (Fowler and Lepofsky 2011; Lepofsky and Armstrong 2018). Anthropogenic, or prescribed burning occurred in western North America along California's coastal grasslands (Braje and Rick 2013; Evett and Cuthrell 2013; Lightfoot et al. 2013a; 2013b), in the Sierra Nevada foothills (Anderson and Rosenthal 2015; Klimaszewski-Patterson and Mensing 2016), Klamath Mountains (Crawford et al. 2015),western Oregon (Boyd 1999), and British Columbia (Hoffman et al. 2017; McCune et al. 2013; and Pellatt and Gedalof 2014). In paleoethnobotany, data that points towards the intensification of plant resources within non-agrarian, small scale societies can be an indicator of TREM (Lepofsky and Lyons 2003). Examples include intensification of wapato (*Sagittaria latifolia*), an aquatic tuber, on the Northwest Coast (Hoffmann et al. 2016) during the mid to late Holocene.

An experimental research program could evaluate the effects of traditional fiber collection methods on plant structure and abundance compared to unmodified areas. Historically, Northern Paiute people returned seasonally to stands of dogbane and nettle. Stems were cut down to the ground after they died and were collected for subsequent processing (bark removal through scraping and peeling, cracking open the stems and extracting inner fibers). The rhizome root structure of dogbane and nettle allows for the annual return of new growth each spring. Coppicing stimulates the root system and encourages new stem growth. The longer, straighter shoots were most desirable because they produced the longest fiber strands, requiring less splicing during cord-making. Historic 18th and 19th century basketry and raw ethnobotanical materials housed in museums is another resource to examine changes in plant characteristics (Anderson and Moratto 1996). Kathy Wallace, founding board member of the California Indian Basketry Association, has noticed longer, straighter redbud and willow shoots used in older baskets; this trait is not seen in contemporary plant communities due to the lack of burning or coppicing (personal communication, October 15, 2003).

Historical ecology approach to conservation planning

This project complements the rich ethnographic record and contemporary Indigenous knowledge about native plant management and use, and thus has broad appeal for contemporary weavers, ethnobotanists, and biodiversity conservation planning (Myra Johnson-Orange, Warm Springs Tribal elder and basketweaver, personal communication October 2023; Stephanie Craig, weaver and Grande Ronde Tribal member, personal communication October 2023). Weaving is a culturally significant art form for many Oregon tribal members, and ecological knowledge about native plants used in basketry is constantly evolving. Yet access to native plants and permissions to manage these habitats on public lands is challenging (Dobkins et al. 2017). This study provides a historical perspective of native plant knowledge essential to textile technology and has the potential to support future conservation efforts. Crumley’s (1994) historical ecology is also a call to action, in which we must address environmental issues such as ecological restoration, heritage management, and biodiversity conservation by drawing from different areas of study (e.g., climatology, palynology archaeology, ethnography). The flexibility and integrative nature of historical ecology makes this a practical approach for the study of landscape history and management (Crumley 2017).

Shrub-steppe communities cover the majority of the Northern Great Basin, including most of southeastern Oregon (Franklin and Dyrness 1988:234). The sagebrush (*Artemisia tridentata*) and bunch grass or wheatgrass (*Agropyron spicatum*) association is the most widespread (OregonFlora n.d), but according to the National Park Service, sagebrush steppe is currently one of the most endangered ecosystems in North America due to ranching and agriculture (Rodhouse et al. 2020). Dogbane (*Apocynum*), while one of the most important fiber plants in North America, is toxic to cattle and other animals, and is also regularly removed from range lands. Dogbane occurs in many different environmental zones across North and South America, from riparian environments to dry steppe shrub (OregonFlora n.d.; USDA Plants Database n.d.). *A. cannabinum* is found usually in wet or moist areas (Gilky and Dennis 2001:322) and is the most desirable species for cordage as it has longer stems.

Examples of applied work in Oregon include research on managed beargrass (*Xerophyllum tenax*), an important basketry plant in California and Oregon (Dobkins et al 2017), and prescribed burn programs in the Willamette Valley to encourage the regrowth and health of camas (*Camassia quamash*), tarweed (*Madia elegans*), and the restoration of oak savannah (Boyd 1999; Long et al. 2021). Archaeobotanical studies in the Channel Islands show that geophytes, specifically Brodiaea-type corms (blue dicks), were present throughout the last 10,000 years (Gill et al. 2019), providing strong evidence for their use as a dietary staple over millennia. With the removal of ranching activities, geophytes are now returning to the islands along with cacti, manzanita, and acorn.

Native plant habitat conservation planning for the purposes of enhancing or protecting culturally relevant resources should be initiated by tribal members or driven by the goals of tribal entities with their support. Public land management agencies (the Bureau of Land Management is the primary agency in eastern Oregon) are also key collaborators and possible sources of funding. Conservation planning should consider long-term landscape change and the role of humans throughout history, drawing from archaeological, historical, biological, and paleoecological data.

Collaborative work with Native weavers

This dissertation provides a foundation for future collaborative work with descendant communities and contemporary weavers. The current project included continued conversations with Myra Johnson-Orange (The Confederated Tribes of Warm Springs and Northern Paiute and Sahaptin elder and basketweaver) (see *Mukurtu* project, Introduction). NSF funding for this dissertation was made available for travel and honorarium to host Ms. Johnson-Orange at the University of Oregon (UO) Many Nations Longhouse in October of 2023, in collaboration with Jennfier O'Neal (The Confederated Tribes of Grande Ronde and UO Department of Indigenous, Race, and Ethnic Studies), UO Native Strategies, and UO Museum of Natural and Cultural History (MNCH). For this visit, Ms. Johnson-Orange generously shared her knowledge of her families' tradition of weaving, plant collection, and Northern Paiute lifeways. Baskets from the MNCH holdings were also exhibited and examined by Ms. Johnson-Orange, which prompted a larger discussion with museum staff. Following this visit, Ms. Johnson-Orange attended the Great Basin Anthropological Conference in Bend, Oregon in which she viewed my presentations on the current study. This prompted several key discussions about weaving, fiber collection, and technology. In November of 2024, Ms. Johnson-Orange, Jennifer O'Neal, Marta Lu Parazoo Clifford (The Confederated Tribes of Grand Ronde), Clara Gorman (PhD student, UO Department of Indigenous, Race, and Ethnic Studies), and myself will serve on a panel at the Pacific Northwest History Conference on tribal knowledge and data sovereignty.

Secondly, I have begun a project with basketweaver Stephanie Craig (Confederated Tribes of Grand Ronde) and Christopher Ruiz (MNCH Historic Preservationist) to explore the interconnections between Oregon's hop industry, Indigenous labor, and basketweaving during the 19th century. Similar to fiber identification methods applied to this dissertation project, Craig is also exploring plant identification techniques for her family's baskets. The results of our pilot study will be presented at the Northwest Anthropological Conference in March of 2024.

Additional data collection

This project focused on the Paisley Caves textile collections generated from the University of Oregon field schools and did not include legacy collections or recent gifts curated at MNCH. Legacy collections include sandals, basketry, coarse and fine cordage, many with radiocarbon dates (Table 3.1) acquired as part of the Great Basin Radiocarbon Dating program. Additional fiber identifications for these collections would augment the data set, particularly the late Holocene assemblage. Fiber identification, together with radiocarbon dating and artifact typologies, can be applied to other Great Basin dry cave collections, both at MNCH and other repositories. Some questions to consider are the use of cattail and willow in eastern Oregon (which are fairly absent at the Paisley Caves), and the presence and timing of flax and milkweed at late Holocene sites such as Roaring Springs Cave.

Refining fiber identification methodologies

This project developed fiber identification methods based on unprocessed reference fibers, but the cellular structure of bast fibers may be altered through different processing methods. Indigenous processing methods for bast fibers includes a variety of techniques, from scraping or peeling outer bark from stem fibers, pounding to crack open stems, or soaking to loosen and remove bark. Inner phloem fibers are subjected to further twisting and splitting. The buried environment over time is an additional way in which cellular structure can be manipulated or degraded. Jakes's foundational work in fiber identification explored some of these processing methods to see how they might alter the fiber structure (Jakes et al. 1994; Jakes 1996). This work should be repeated for Great Basin textiles and expanded to include samples from different growing seasons and collection areas.

This was the first study to examine *Linum lewisii*, the flax species native to North America, using PLM and EDS. Additional studies on flax should be conducted by more than one independent researcher using a more diverse comparative collection to document the extent of variations in fiber characteristics, if any. Additional studies comparing spectra of bast fibers would further this area of study. Phytolith analysis is yet another unexplored area in textile plant identification.

Cotton DNA

Radiocarbon dates were acquired for cotton cordage and plaiting, with dates ranging between 1000-250 years ago, which strongly suggests Northern Great Basin peoples during the late Holocene had ties to the American Southwest. However, aDNA from archaeological cotton fiber may offer additional supportive evidence. DNA from cotton has been extracted from seeds; one example is the Piñaleño cotton cache (Haury and Huckell 1993), but the single-nucleus fiber cell is usually not a viable tissue for DNA extraction, and archaeological specimens may be even further degraded. However, some labs are now exploring this option for commercial purposes, which may prove useful for archaeological applications.

Expanding the fiber reference collection

A fiber reference collection was established for this project, with a focus on taxa represented in Northern Great Basin textiles. Reference slides for each taxon with corresponding micrographs and fiber characteristics (Appendix B) were also prepared for this project, now curated at the University of Oregon Museum of Natural and Cultural History. This collection can be expanded to include taxa relevant to western Oregon, the Plateau, the western and eastern Great Basin, and the Northwest Coast more generally. Many of these plants are already represented in the reference collection, but still require analysis using microscopy to develop fiber characteristics. This would be relevant to basketry and cordage analysis (both ethnographic and archaeological) from other regions, and from other repositories. Animal fiber reference material, such as wool and hair from other mammals would also be an excellent resource for museum textile analysis.

Contributions to Archaeology

This study broadens our knowledge of North American paleoethnobotany, contributing new data to archaeobotanical and paleoenvironmental research in the Great Basin. Results offer a more nuanced look at seasonality and plant selection over time, with apparent regional differences between northern and more western and eastern Great Basin cordage industries. This project was the first to document fiber characteristics using PLM and EDS for dogbane, nettle, flax, and milkweed for reference samples, which can be applied to other Great Basin archaeological fiber assemblages. The presence of milkweed, flax, and cotton adds to the repertoire of Great Basin textile manufacturing elements and illustrates the importance of material identification that can correct previously made assumptions.

This project complements other current research in Northern Great Basin archaeology, including dietary studies (Fowler and Rhode 2011; Kennedy 2018; Rhode and Louderback 2007), basketry studies (Connolly 2013; Connolly et al. 2016; Ollivier 2016, 2017; Smith and Barker 2017), and subsistence organization and settlement patterns (Graf and Rhode 2007; Jenkins et al. 2017; Wriston and Smith 2017). In the Northern Great Basin, ecological knowledge surrounding fiber arts and technology was established as early as 14,000 years ago. While relationships with native plants are ongoing and landscapes are always changing, this research offers an archaeological perspective that emphasizes and elevates Native Oregonians’ textile traditions.

APPENDIX A

ECOLOGY OF TEXTILE PLANTS

Family	Genus and Species	Common Name	Textile type	Parts Used	PC	Coll. Season
Cyperaceae	*Schoenoplectus acutus (*formally *Scirpus acutus)*	Tule or hard-stem bulrush	Cord, twined basketry, sandals, matting	Stems (culms), roots, and basal leaves	WET	Summer-Fall
Typhaceae	*Typha latifolia* and *T. angustifolia*	Cattail	Matting, stuffing, padding	Seed hair, leaves, stems	WET	Summer-Fall
Juncaceae	*Juncus effusus*	Juncus Rush	Basketry, matting, cord	Stem	WET	Summer-Fall
Pocaceae	*Phragmites communis*	Reed or cane	Matting, cord	Stem	WET	Summer-Fall
Cyperaceae	*Carex* spp.	Sedge	Basketry, matting, cord	Stem	WET	Summer-Fall
Amarnthaceae	*Atriplex*	Saltbush	Coarse cord	Bark	LOW	
Asteraceae	*Artemisia tridentata* and other species	Sagebrush	Coarse cord, braids, sandals, matting	Bark	LOW, UP	Summer-Fall
Rosaceae	*Purshia tridentata*, and *P. mexicana* (cliffrose)	Antelope Bitterbrush, Cliffrose	Coarse cord	Bark	LOW, UP	Summer-Fall
Chenopdiaceae	unknown	Goosefoot			LOW, UP	
Anacardiaceae	*Rhus trilobata* and *R. aromatica*	Sumac, Skunkbrush	Basketry, cord	Bark, woody stem	UP, LITH	
Pocaceae	Unknown, many types	Grass	Matting, cord	Stem	LOW	Summer-Fall
Apocynaceae	*Apocynum cannabinum, A. androsaemifolium*, (spreading) and *A. pumilim* (low)	Dogbane, hemp	Fine cordage	Stem fiber	LOW, RP	Fall
Apocynaceae	*Asclepias* spp.	Milkweed	Fine cordage, stuffing	Stem fiber, seed hair	LOW, LITH	Summer-Fall
Urticaceae	*Urtica dioica*	Stinging Nettle	Fine cordage	Stem fiber	LOW, RP	Spring, Summer, Fall
Salicaceae	*Populus* spp.	Cottonwood, Black and White	Basketry, wood implement	Woody stem	LOW, RP	
Salicaceae	*Salix* spp.	Willow	Basketry, wood implement	Bark, wood	LOW, RP	Summer, Fall
Cupressaceae	*Juniperus occidentalis*	Western Juniper	Coarse cord, wood implement	Bark, wood	UP	
Linaceae	*Linum lewisii*	Western Blue Flax, Prarie Flax	Fine cordage	Stem fiber	UP, LITH	Summer
Betulaceae	*Alnus oregana*	Adler, Red and White		Bark, wood		
Malvaceae	*Corchorus olitorius* and *C. capsularis* (both non-native, commerial)	Jute	Cordage, fabric	Stem fiber	n/a	n/a
Malvaceae	*Gossypium hopi* (native)	Cotton	Fine cordage, fabric	Seed hair	n/a	n/a

Plant Community (PC): WET (wetland), LOW (lowland), UP (upland), LITH (lithosol), RP (riparian)

Franklin and Dryness 1988; Gilky and Dennis 2001; Oregonflora project; Prouty 1994; USDA Plant database n.d

APPENDIX B

FIBER REFERENCE COLLECTION

Common Name	**Family Name**	**Genus and Species**
Beargrass	Melanthiaceae	*Xerophyllum tenax*
Birch	Betulaceae	*Betula jacquemontii*
Bitterbrush/antelope brush	Rosaceae	*Purshia tridentata*
Blue Flax	Linaceae	*Linum lewisii*
Cattail	Typhacae	*Typha latifolia*
Cedar	Cupressaceae	*Thuja plicata*
Cherry	Rosaceae	*Prunus avium*
Corn husk	Poaceae	*Zea mays*
Cotton	Malvaceae	*Gossypium hopi*
Dogbane	Apocynaceae	*Apocynum cannabinum*
Dune Grass	Poaceae	*Lymus mollis*
Fireweed	Onagraceae	*Chamaenerion angustifolium*
Iris	Iridaceae	*Iris tenax*
Juncus	Juncaceae	*Junus effusus*
Juniper	Cupressaceae	*Juniperus occidentalis*
Jute	Malvaceae	*Corchorus olitorius*
Maple	Sapindaceae	*Acer macrophyllum*
Milkweed	Apocynaceae	*Asclepias* sp.
Sagebrush	Asteraceae	*Artemisia tridentata*
Seagrass	Zosteraceae	*Zostera marina*
Sisal	Asparagaceae	*agave sisalana*
Spruce	Pinaceae	*Picea sitchensis*
Stinging nettle	Urticaceae	*Urtica dioica*
Tule	Cyperaceae	*Schoenoplectus acutus*
Willow	Salicaceae	*Salix* sp.
Yucca	Agavaceae	*Yucca filamentosa*

The fiber reference collection curated at the University of Oregon Museum of Natural and Cultural History, and includes plant fibers, microscope slides, and micrographs.

REFERENCES CITED

Adams, K. R. 2004. Anthropogenic Ecology of the North American Southwest. In *People and Plants in Ancient Western North America*. Washington: Smithsonian Books, 167-204.

Adovasio, J. M. 1970. The Origin, Development and Distribution of Western Archaic Textiles. *Tebiwa* 13(2):1–40.

Adovasio, J. M. 1986a. Prehistoric Basketry. *Great Basin: Handbook of North American Indians, Vol. 11*, edited by Warren L. d'Azevedo, pp. 194–205. Smithsonian Institution, Washington, D.C.

Adovasio, J. M. 1986b. Artifacts and Ethnicity: Basketry as an Indicator of Territoriality and Population Movements in the Prehistoric Great Basin. *Anthropology of the Desert West: Essays in Honor of Jesse D. Jennings*, edited by Carol J. Condie and Don D. Fowler, pp. 43-88. University of Utah Press, Salt Lake City.

Adovasio, J. M., and D. R. Pedler. 1994. A Tisket, a Tasket: Looking at the Numic Speakers through the "Lens" of a Basket. *Across the West: Human Population Movement and the Expansion of the Numa*, edited by David B. Madsen and David Rhode, pp. 114–123. University of Utah Press, Salt Lake City.

Adovasio, J. M., R. L. Andrews and J. S. Illingworth. 2009. Netting, Net Hunting, and Human Adaptation in the Eastern Great Basin. *Past, Present and Future Issues in Great Basin Archaeology: Papers in Honor of Don D. Fowler*. Edited by B. Hockett, Bureau of Land Management, Cultural Resource Series 20.

Adovasio, J. M. 2021. Fifty years with baskets. *North American Archaeologist*, *42*(2), 119-139.

Aikens, C. M.. 1970. Hogup Cave. *University of Utah Anthropological Papers* 93. Salt Lake City: University of Utah Press, 286 pp.

Aikens, C. M., T. J. Connolly, and D. L. Jenkins. 2011. *Oregon Archaeology*. Oregon State University Press, Corvallis.

Anderson, K. 1993. Native Californians as Ancient and Contemporary Cultivators. In *Before the Wilderness: Environmental Management by Native Californians*, ed. T. Blackburn and K. Anderson, BPAP, no. 40. pp. 151-174. Menlo Park, CA: Ballena Press.

Anderson, K. 2005. *Tending the Wild: Native American Knowledge and the Management of California's Natural Resources*. University of California Press, Berkeley.

Anderson, M. K. and M. J. Moratto. 1996. Native American land-use practices and ecological impacts. Sierra Nevada Ecosystem Project: Final report to Congress, vol. II, Assessments and scientific basis for management options. Davis: University of California, Centers for Water and Wildland Resources.

Anderson, K. and J. Rosenthal. 2015. An Ethnobiological Approach to Reconstructing Indigenous Fire Regimes in the Foothill Chaparral of the Western Sierra Nevada. *Journal of Ethnobiology*, 35:4-36.

Andrews, R. L., J. M. Adovasio, and R. C. Carlisle. 1986. Perishable Industries from Dirty Shame Rockshelter, Malheur County, Oregon. *University of Oregon Anthropological Papers* 34. University of Oregon Department of Anthropology, Eugene.

Baldwin, G. C. 1939. Prehistoric Textiles in the Southwest, *Kiva,* vol 4, No. 4, pp. 15-18.

Bedwell, S. F. 1970. *Prehistory and Environment of the Pluvial Fort Rock Lake Area of South Central Oregon*. University of Oregon Press, Eugene, Oregon.

Bedwell, S. F. 1973. *Fort Rock Basin: Prehistory and Environment*. University of Oregon Press, Eugene, Oregon.

Balée, W. 1994. *Footprints of the Forest : Ka'apor Ethnobotany-- the Historical Ecology of Plant Utilization by an Amazonian People*, New York: Columbia University Press.

Balée, W. 1998. Historical Ecology: Premises and Postulates. In *Advances in Historical Ecology*, ed. W.

Balée, W., and C. L. Erickson, eds. 2006. Preface. In *Time and Complexity in Historical Ecology: Studies in the Neotropical Lowlands*. The Historical Ecology Series. New York: Columbia University Press.

Bennyhoff, J. A. and R. E. Hughes. 1987. *Shell Bead and Ornament Exchange Networks between California and the Western Great Basin*. American Museum of Natural History, 1987.

Barrett, S. A. 1910. The Material Culture of the Klamath Lake and Modoc Indians of Northeastern California and Southern Oregon. *University of California Publications in American Archaeology and Ethnology 5(4): 239-292.*

Beck, C. and G. T. Jones. 2010. Clovis and Western Stemmed: Population Migration and the Meeting of Two Technologies in the Intermountain West. *American Antiquity* 75(1):81-116.

Beck, C. W., V. M. Bryant, and D. L. Jenkins. 2018. Analysis of Younger Dryas–early Holocene Pollen in Sediments of Paisley Cave 2, South-central Oregon. *Palynology* 42(2):1-12.

Bergfjord, C. and B. Holst. 2010. A Procedure for Identifying Textile Bast Fibres Using Microscopy: Flax, Nettle/Ramie, Hemp and Jute. *Ultramicroscopy* 110 (9): 1192–97.

Bergfjord, C., S. Karg, A. Rast-Eicher, M.-L. Nosch, U. Mannering, R. G. Allaby, B. M. Murphy, and B. Holst. 2010. Comment on “30,000-Year-Old Wild Flax Fibers.” *Science* 328, 1634-1634.

Bergfjord, C., U. Mannering, K.M. Frei, M. Gleba, A.B. Scharff, I. Skals, J. Heinemeier, M. -L Nosch, and B. Holst. 2012. Nettle as a Distinct Bronze Age Textile Plant. *Scientific Reports* 2, 664.

Blong, J., M. Adams, G. Sanchez, D. L. Jenkins, I. Bull, and L. Shillito. 2020. Younger Dryas and Early Holocene Subsistence in the Northern Great Basin: Multiproxy Analysis of Coprolites from the Paisley Caves, Oregon, USA. *Archaeological Anthropology Sci* 12, 224.

Boivin, N., M. Zeder, D. Fuller, A. Crowther, G. Larson, J. M. Erlandson, T. Denham, and M. Petraglia. 2016. Ecological Consequences of Human Niche Construction: Examining Long-term Anthropogenic Shaping of Global Species Distributions. 113(23):6388-6396.

Boyd, R. 1999. Strategies of Indian Burning in the Willamette Valley. In *Indians, Fire, and the Land in the Pacific Northwest*, ed. R. Boyd. Oregon State University Press, Corvallis.

Braje, T. J. and T. C. Rick. 2013. From Forest Fires to Fisheries Management: Anthropology, Conservation Biology, and Historical Ecology. *Evolutionary Anthropology: Issues, News, and Reviews*, 22(6), pp.303–311.

Braje, T. J., T. C. Rick, P. Szpak, S.D. Newsome, J.M. McCain, E.A. Elliott Smith, M. Glassow, and S.L. Hamilton. 2017. Historical Ecology and the Conservation of Large, Hermaphroditic Fishes in Pacific Coast Kelp Forest Ecosystems. *Science Advances* 3, no. 2.

Brashear, A. 1994. Assemblage Variation, Site Types, and Subsistence Activities in the Boulder Village Uplands, Fort Rock Basin, Oregon. *Archaeological Researches in the Northern Great Basin: Fort Rock Archaeology Since Cressman*. University of Oregon Anthropological Papers 50, Department of Anthropology and State Museum of Anthropology, University of Oregon, Eugene.

Bronk, R. C. 2009. Bayesian Analysis of Radiocarbon Dates. *Radiocarbon* 51(1):337–360.

Byram, S. 1994. Holocene Settlement Change in the Boulder Village Uplands. *Archaeological Researches in the Northern Great Basin: Fort Rock Archaeology Since Cressman*. University of Oregon Anthropological Papers 50, Department of Anthropology and State Museum of Anthropology, University of Oregon, Eugene.

Camp, A. 2018. Catlow Twine Basketry in the Western Great Basin: Use and Reuse in the Archaeological Record. *Quaternary International, 466,* 318-323.

Catling, D. and J. Grayson. 1998. Identification of Vegetable Fibers. Archtype Publications.

Chamberlain, R. 1911. The Ethno-botany of the Gosiute Indians. *Proceedings of the Academy of Natural Sciences of Philadelphia*, 63 (1):24-99.

Coe, M. 2012. A Materials Analysis of the Non-wood Perishable Artifacts from Four Siblings Rockshelter, Nevada, Masters Thesis, Texas A&M University, Department of Anthropology.

Coe, M. 2021. Basketry, Cordage, and Perishable Artifact Manufacture at Bonneville Estates Rockshelter: Diachronic Technological Variation. *Journal of Anthropological Archaeology* 64.

Coe, M. 2023. Gendered Crafts in the Great Salt Lake Desert: A Comparative Analysis of Late Holocene Cordage and Coiled Basketry. *American Antiquity*, 88(3), 302-325.

Connolly, T. J. 1999. Newberry Crater: A Ten-thousand-year Record of Human Occupation and Environmental Change in the Basin-plateau Borderlands, Anthropological Papers No. 121, University of Utah Press, Salt Lake City.

Connolly, Thomas. J. 2013. Implications of New Radiocarbon Ages on Coiled Basketry from the Northern Great Basin. *American Antiquity* 78(2):373-384.

Connolly, T. J. 2022. A New Sandal Type from the Northern Great Basin. *Journal of California & Great Basin Anthropology*, Vol. 42 Issue 2, p184-191.

Connolly, T. J., C. S. Fowler, and W. J. Cannon.1998. Radiocarbon Evidence Relating to Northern Great Basin Basketry Chronology. *Journal of California and Great Basin Anthropology* 20(1):88-100.

Connolly, T. J. and P. Barker. 2004. Basketry Chronology of the Early Holocene in the Northern Great Basin. *Early and Middle Holocene Archaeology of the Northern Great Basin*, edited by D. L. Jenkins, T. J. Connolly, and C. M. Aikens, pp. 241- 250. University of Oregon Anthropological Papers 62, Eugene.

Connolly, T. J. and P. Barker. 2008. Great Basin Sandals. *The Great Basin: People and Place Ancient Times*, edited by Catherine S. Fowler and Don D. Fowler, pp. 68-73. School for Advanced Research Press, Santa Fe.

Connolly, T. J., P. Barker, C. S. Fowler, E. M. Hattori, D. L. Jenkins, and W. J. Cannon. 2016. Getting Beyond the Point: Textiles of the Terminal Pleistocene/Early Holocene in the Northwestern Great Basin. *American Antiquity* 81(3), 490-514.

Connolly, T. J., P. Barker, E. Kallenbach, and S. J. McCabe. 2017. Netting in the Northern and Western Great Basin. *Journal of California and Great Basin Anthropology* 37(2):143-167.

Coville, F. 1897. *Notes on the Plants Used by the Klamath Indians of Oregon*. Washington, Govt. Print. Off.

Crawford, J. N., S. A. Mensing, F. K. Lake, and S. R. H. Zimmerman. 2015. Late Holocene Fire and Vegetation Reconstruction from the Western Klamath Mountains, California, USA: A Multi-disciplinary Approach for Examining Potential Human Land-use Impacts. *The Holocene* 25, no. 8: 1341-357.

Cressman, L. S. 1942. *Archaeological Researches in the Northern Great Basin*. Carnegie Institution of Washington Publication, 538. Washington, D.C.

Cressman, L. 1986. Prehistory of the Northern Area. *Handbook of North American Indians*, Vol. 11: Great Basin, pp. 120 –126. Washington, D.C.: Smithsonian Institution.

Crumley, C., ed. 1994. *Historical Ecology: Cultural Knowledge and Changing Landscapes*. 1st ed. School of American Research Advanced Seminar Series. Santa Fe, N.M. : [Seattle]: School of American Research Press ; Distributed by the University of Washington Press.

Crumley, C. 2017. Historical Ecology and the study of landscape. *Landscape Research, 42*(S1), S65-S73.

Cummings, L. S. 2004. Great Basin Paleoethnobotany. *People and Plants in Ancient Western North America*, edited by Paul Minnis, Smithsonian Books, Washington, D.C.

Darby, M. 2005. 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 Northwest Coast of North America*, ed. D. Deur and Nancy J. Turner, 194–217. Seattle : Vancouver: University of Washington Press ; UBC Press.

Davis, L., D. Madsen, D. Sisson, L. Becerra-Valdivia, T. Higham, D. Stueber, D. Bean et al. 2022. Dating of a Large Tool Assemblage at the Cooper's Ferry Site (Idaho, USA) to ~15,785 Cal yr B.P. Extends the Age of Stemmed Points in the Americas. *Science Advances* 8,1248.

Davis, M. A., B. J. Culleton, R. L. Rosencrance, and C. S. Jazwa. 2023. Experimental Observations on Processing Leather, Skin, and Parchment for Radiocarbon Dating. *Radiocarbon*: 1-23.

D'Azevedo, W. L. 1986. Washoe. *Great Basin: Handbook of North American Indians*, Vol. 11, edited by Warren L. D'Azevedo, pp. 466-498, Smithsonian Institution, Washington D.C.

Dean, P. A. 1992. Prehistoric Pottery in the Northeastern Great Basin: Problems in the Classification and Archaeological Interpretation of Undecorated Fremont and Shoshoni Wares. Ph.D. Dissertation, University of Oregon.

Deur, D. 2005. Tending the Garden, Making the Soil: Northwest Coast Estuarine Gardens as Engineered Environments. In *Keeping It Living: Traditions of Plant Use and Cultivation on the Northwest Coast of North America*, ed. D. Deur and N. J. Turner, pp. 296-327. Seattle : Vancouver: University of Washington Press ; UBC Press.

Deur, D, and N. J. Turner, eds. 2005. *Keeping It Living: Traditions of Plant Use and Cultivation on the Northwest Coast of North America*. Seattle : Vancouver: University of Washington Press ; UBC Press.

Downs, J. F. 1966. *The Two Worlds of the Washo, An Indian Tribe of California and Nevada.* Holt, Rinehart & Winston, New York.

Dunbar M, and T.M. Murphy. 2009. DNA analysis of natural fiber rope. *Journal of Forensic Science*, Jan 54(1):108-13.

Ebeling, W. 1986. *Handbook of Indian Foods and Fibers of Arid America*. University of California Press, Berkeley.

Emery, I. 1966. *The Primary Structure of Fabrics, an Illustrated Classification*. The Textile Museum, Washington, D.C.

Evett, R., and R. Q. Cuthrell. 2013. Phytolith Evidence for a Grass-Dominated Prairie Landscape at Quiroste Valley on the Central Coast of California. *California Archaeology* 5, no. 2: 319-35.

Fitzpatrick, S. M., and W. Keegan. 2007. Human Impacts and Adaptations in the Caribbean Islands: An Historical Ecology Approach. In *Earth and Environmental Science Transactions of the Royal Society of Edinburgh*, 98(1), 29-45.

Fitzpatrick, S. M, and J. M. Erlandson. 2019. Archaeology, Historical Ecology, and Marginality: Global Implications of the California Islands for Island Settlement and Sustainability. In *An Archaeology of Abundance: Re-evaluating the Marginality of California's Islands*, ed. K. Gill, M. Fauvelle, and J. M. Erlandson, Gainesville: University Press of Florida, pp. 273-294.

Florian, M. E., D. P. Kronkright, and R. E. Norton. 1990. *The Conservation of Artifacts Made from Plant Materials*. Getty Conservation Institute, Marian del Rey, California.

Fowler, C. 1992. *In the Shadow of Fox Peak: An Ethnography of the Cattail-Eater Northern Paiute People of Stillwater Marsh*. U. S. Fish and Wildlife Service Cultural Resource Series 5. Washington D.C., Government Printing Office.

Fowler, C., and D. Lepofsky. 2011. Traditional Resource and Environmental Management. In *Ethnobiology*, ed. by E. N. Anderson, D. Pearsall, E. Hunn, and N. Turner, 285–304. Oxford: Wiley-Blackwell.

Fowler, D. D. and C. S. Fowler. 1970. Stephen Powers' The Life and Culture of the Washo and Paiutes. *Ethnohistory* 17: 117–149.

Fowler, C. S. and D. Lawrence. 1986. Ethnographic Basketry. *Great Basin: Handbook of North American Indians, Vol. 11*, edited by Warren L. d'Azevedo, pp. 705-37. Smithsonian Institution, Washington, D.C.

Fowler, D. D., and C. S. Fowler. 2008. The Great Basin: People And Place in Ancient Times, edited by Catherine S. Fowler And Don D. Fowler. School For Advanced Research Press.

Fowler, C. S. and D. Rhode. 2011. Plant Foods and Foodways Among the Great Basin's Indigenous Peoples. *The Subsistence Economies of Indigenous North American Societies: A Handbook*, ed. B. D. Smith, 233-269. Washington, D.C.: Lanham, Md: Smithsonian Institution Scholarly Press.

Fowler, C. S., and E. M. Hattori. 2011. Exploring Prehistoric Trade in Western Great Basin Textiles. In *Perspectives on Prehistoric Trade and Exchange in California and the Great Basin*, edited by Richard E. Hughes, pp. 201–220. University of Utah Press, Salt Lake City.

Franklin, J. F. and C.T. Dyrness. 1988. Natural Vegetation of Oregon and Washington, Oregon State University Press.

Gahr, A. T. 2006. Paisley Caves Analysis Notes. Unpublished manuscript, on file at the University of Oregon Museum of Natural and Cultural History.

Gilbert, T., D. L. Jenkins, A. Götherstrom, N. Naveran, J. Sanchez, M. Hofreiter, P. Thomsen et al. 2008. DNA from Pre-Clovis Human Coprolites in Oregon, North America. *Science*, New York, 320. 786-9.

Gilky, H. and L. R. Dennis. 2001. Handbook of Northwestern Plants. Oregon State University Press.

Gill, K. M., M. Fauvelle, and J. M. Erlandson, eds. 2019. *An Archaeology of Abundance: Re-evaluating the Marginality of California's Islands*. Gainesville: University Press of Florida.

Goebel, T., M. R. Waters, and D. H. O'Rourke. 2008. The Late Pleistocene Dispersal of Modern Humans in the Americas. *Science* 319(5869), 1497-1502.

Goebel, T., B. Hockett, K. Adams, D. Rhode, K. Graf. 2011. Climate, Environment, and Humans in North America's Great Basin During the Younger Dryas, 12,900–11,600 Calendar Years Ago. *Quat. Int.* 242, 479–501.

Goodway, M. 1987. Fiber Identification in Practice. *Journal of the American Institute for Conservation*, 26:1, 27-44.

Groesbeck, A. S., K. Rowell, D. Lepofsky, and A. K. Salomon. 2014. Ancient Clam Gardens Increased Shellfish Production: Adaptive Strategies from the Past Can Inform Food Security Today. *PloS One* 9, no. 3: E91235.

Haas, W. R. 2006. The Social Implications of Basketmaker II Cordage Design Distribution. *Kiva 71*(3): 275-298.

Hammond-Kaarremaa, L. 2018. Threads, Twist and Fibre: Looking at Coast Salish Textiles. Textile Society of America Symposium Proceedings. 1090.

Hanazaki, N., D. F. Herbst, M. S. Marques, and I. Vandebroek. 2013. Evidence of the Shifting Baseline Syndrome in Ethnobotanical Research. *Journal of Ethnobiology and Ethnomedicine* 9, no. 1: 75.

Haugan, E., and Bodil Holst. 2013. Determining the Fibrillar Orientation of Bast Fibres with Polarized Light Microscopy: the Modified Herzog Test (Red Plate Test) Explained. *Journal of Microscopy,* Vol. 252, Issue 2, pp. 159–168.

Haugan, E., and B. Holst. 2014. Flax Look-Alikes: Pitfalls of Ancient Plant Fibre Identification. *Archaeometry* 56 (6): 951–60

Haury, E. W. 1945. Painted Cave, Northeastern Arizona. Dragoon, Arizona: The Amerind Foundation, Inc., Publication No. 3.

Haury, E. W. and Lisa W. Huckell. 1993. A Prehistoric Cotton Cache from the Pinaleño Mountains, Arizona, KIVA, 59:2, 95-145.

Herrero-Otal, M., S. Romero-Brugués, R. Huerta, A, Homs, M. de Diego, and A, Palomo. 2023. Describing the neolithic cord production process: Raw materials, techniques and experimental archaeology in La Draga (Girona, Spain; 5207–4862 cal BC). *Journal of Archaeological Science: Reports*. 50. 104092.

Hock, C. W. 1942. Microscopic Structure of Flax and Related Bast Fibers. *Journal of Research of the National Bureau of Standards* 29, no.1 41.

Hockett, B. and D. L. Jenkins. 2013. Identifying Stone Tool Cutmarks and the Preclovis Occupation of the Paisley Caves. *American Antiquity* 78, 762–788.

Hockett, B., M. E. Adams, P. M. Lubinski, V. L. Butler, and D. L. Jenkins

2017. Late Pleistocene Subsistence in the Great Basin: Younger Dryas-aged Faunal Remains from the Botanical Lens, Paisley Cave 2, Oregon. *Journal of Archaeological Science: Reports*. 13. 565-576.

Hoffmann, T., N. Lyons, D. Miller, A. Diaz, A. Homan, S. Huddlestan, and R. Leon. 2016. Engineered Feature Used to Enhance Gardening at a 3800-year-old Site on the Pacific Northwest Coast. *Science Advances* 2, no. 12.

Hoffman, K. M., K. P. Lertzman, and B.M. Starzomski. 2017. Ecological Legacies of Anthropogenic Burning in a British Columbia Coastal Temperate Rain Forest. *Journal of Biogeography*, 44(12), pp.2903–2915.

Hudson, A. M., M. M. Emery-Wetherell, P. Lubinski, V. L. Butler, and D. L. Jenkins. 2021. Reconstructing Paleohydrology in the Northwest Great Basin Since the Last Deglaciation Using Paisley Caves Fish Remains (Oregon, U.S.A.). *Quaternary Science Reviews*, 262.

International Organization for Standardization. 2019. Textiles - Qualitative and quantitative analysis of some bast fibres (flax, hemp, ramie) and their blends - Part 1: Fibre identification using microscopy methods. ISO Standard No. 20706-1:2019.

Jakes, K. A., L. R. Sibley, and R. Yerkes. 1994. A Comparative Collection for the Study of Fibres Used in Prehistoric Textiles from Eastern North America. *Journal of Archaeological Science* 21 (5): 641–50.

Jakes, K. A. and J. Mitchell. 1996. Cold Plasma Ashing Preparation of Plant Phytoliths and Their Examination with Scanning Electron Microscopy and Energy Dispersive Analysis of X-rays. *Journal of Archaeological Science* 23: 149-156.

Jakes, K. A. 1996. Clues to the Past: Further Development of the Comparative Plant Fiber Collection. *Archaeological Chemistry*, A. M. Pollard and C. Heron, eds., pp. 202-222. University of Bradford, Royal Society of Chemistry, Cambridge.

Jakes, K. A., A. J. Thompson, and C. M. Baldia. 2010. Revealing Clues from Textile Particulate through Microscopy, Infrared Spectroscopy, and X-Ray Microanalysis. *Textile: the Journal of Cloth and Culture* 8.3: 322–340.

Jakes, K. A. 2023. FRIL, the Fiber Reference Image Library, CAMEO, Conservation & Art Materials Encyclopedia Online, https://cameo.mfa.org/wiki/Fiber Reference Image Library, accessed August 23, 2023.

Janetski, J. C. 1979. Implications of Snare Bundles in the Great Basin and Southwest. Journal of California and Great Basin Anthropology 1(2):306–321.

Jenkins, D. L. 1994. Archaeological Survey and Excavations in the Duncan Creek Research Area: Changing Human Use of Uplands Environments West of Silver Lake. *Archaeological Researches in the Northern Great Basin: Fort Rock Archaeology Since Cressman*. University of Oregon Anthropological Papers 50, Department of Anthropology and State Museum of Anthropology, University of Oregon, Eugene.

Jenkins, D. L. and Jon Erlandson. 1996. Olivella Grooved Rectangle Beads from a Middle Holocene Site in the Fort Rock Valley, Northern Great Basin, *Journal of California and Great Basin Anthropology*, 18(2), pp. 296-302.

Jenkins, D. L., Thomas J. Connolly, and C. Mel Aikens. 2004. Early and Middle Holocene Archaeology in the Northern Great Basin: Dynamic Natural and Cultural Ecologies. *Early and Middle Holocene Archaeology of the Northern Great Basin,* edited by D. L. Jenkins, T. J. Connolly, and C. M. Aikens, pp. 1-20. Univ. of Oregon Anthropological Papers 62, Eugene.

Jenkins, D. L., L. G. Davis, T. W. Stafford Jr., P. F. Campos, B. Hockett, G. T. Jones, L. S. Cummings, C. Yost, T. J. Connolly, R. M. Yohe II, S. C. Gibbons, M, Raghavan, M. Rasmussen, J. L.A. Paijmans, M. Hofreiter, B. Kemp, J. L. Barta, C. Monroe, M, T. P. Gilbert, and E. Willerslev. 2012. Clovis Age Western Stemmed Projectile Points and Human Coprolites at the Paisley Caves. *Science* 337(6091):223-228.

Jenkins, D. L., L. Davis, T. Stafford, P. Campos, T. J. Connolly, L. S. Cummings, M. Hofreiter et al. 2013. Geochronology, Archaeological Context, and DNA at the Paisley Caves. *Paleoamerican Odyssey*, Graf, K.E., Ketron, C.V., Waters, M.R. (Eds.). Center for the Study of First Americans, College Station, Texas, pp. 485–510.

Jenkins, D. L., J. A. Holcomb, and K. N. McDonough. 2017. Current Research at the Connley Caves (35LK50): Late Pleistocene/Early Holocene Western Stemmed Tradition Occupations in the Fort Rock Basin, Oregon. *PaleoAmerica* 3(2):188-192.

Jenkins, D. L., L. G. Davis, T. W. Stafford Jr., T. J. Connolly, G. T. Jones, M. Rondeau, L. S. Cummings, B. Hockett, K. McDonough, P. W. O’Grady, K. J. Reinhard, M. E. Swisher, F. White, R. M. Yohe II, C. Yost, and E. Willerslev. 2016. Younger Dryas Archaeology and Human Experience at the Paisley Caves in the Northern Great Basin. *Stones, Bones, and Profiles: Exploring Archaeological Context, Early American Hunter-Gatherers, and Bison*. Boulder: University Press of Colorado, p. 127.

Jennings, J. D. 1957. Danger Cave. Society for American Archaeology Memoir No. 14. University of Utah Anthropological Papers No. 27. University of Utah Press, Salt Lake City.

Jolie, R. B. 2005. Netted Structures in the Prehistoric Great Basin. Paper presented at Unraveling the Boundary: Perishable Technologies Across and Between the Prehistoric Great Basin and Southwest, annual meeting of the Society for American Archaeology, Salt Lake City, Utah.

Jolie, E. A. 2019. Analysis of Perishables. *Archaeological Laboratory Methods: An Introduction*, 7th ed., edited by Mark Q. Sutton and Brook S. Arkush, pp. 127–144. Kendall/Hunt, Dubuque, Iowa

Kallenbach, E. 2013. The Chewaucan Cave Cache: A Specialized Tool Kit from Eastern Oregon, *Journal of California and Great Basin Anthropology* 33(1):72-87.

Kallenbach, E. 2023. Testing the Feasibility of Fiber Identification for Fine Cordage Artifacts from the Paisley Caves. *Journal of Archaeological Science: 158. 105855.*

Kallenbach, E. In press. Fiber Artifacts from the Paisley Caves; 14,000 Years of Plant Selection in the Northern Great Basin, *American Antiquity.*

Kelly, I. 1932. Ethnography of the Surprise Valley Paiute. University of California Publications in American Archaeology and Ethnology 31:67–210.

Kelly, I. and C. Fowler. 1986. Southern Paiute. *Great Basin,* edited by W.L. d'Azevedo, pp.368-397. Handbook of North American Indians, Vol.11, William C. Sturtevant, general editor, Smithsonian Institution, Washington, D.C.

Kennedy, J. and G. Smith. 2015. Paleoethnobotany at the LSP-1 Rockshelter, South Central Oregon: Assessing the Nutritional Diversity of Plant Foods in Holocene Diet. *Journal of Archaeological Science: Reports* 5.

Kennedy, J. 2018. A Paleoethnobotanical Approach to 14,000 Years of Great Basin Prehistory: Assessing Human-environmental Interactions through the Analysis of Archaeological Plant Data at Two Oregon Rockshelters. Ph.D. dissertation, Department of Anthropology, University of Oregon.

Kirch, P. 1997. Introduction: The Environmental History of Oceanic Islands. In *Historical Ecology in the Pacific Islands: Prehistoric Environmental and Landscape Change*, ed. P. Kirch, T. L. Hunt, and Pacific Science Congress, New Haven: Yale University Press.

Kirch, P. 2004. Oceanic Islands: Microcosms of "Global Change" In *The Archaeology of Global Change : The Impact of Humans on Their Environment*, ed. P. V. Kirch Washington: Smithsonian, pp. 13-27.

Klimaszewski-Patterson, A., and S. A. Mensing. 2016. Multi-Disciplinary Approach to Identifying Native American Impacts on Late Holocene Forest Dynamics in the Southern Sierra Nevada Range, California, USA. *Anthropocene* 15 (September): 37–48.

Laland, K., B. Matthews, and M. W. Feldman. 2016. An introduction to Niche Construction Theory. *Evolutionary Ecology;* 30: 191–202.

Lawlor, A. 2020. Plant Fiber and Foraging Tools in the Eastern Great Basin. Ph.D. dissertation, Department of Anthropology, University of Utah.

Lepofsky, D., N. F. Smith, N. Cardinal, J. Harper, M. Morris, R. Gitla, D.I. D. Bouchard, A.K. Kennedy, M. Salomon, K. Puckett, D. Rowell, and Nf. Gitla. 2015. Ancient Shellfish Mariculture on the Northwest Coast of North America. *American Antiquity* 80, no. 2: 236-259.

Lepofsky, D., C. Armstrong, S. Greening, J. Jackley, J. Carpenter, B. Guernsey, N. Turner. 2017. Historical Ecology of Cultural Keystone Places of the Northwest Coast. *American Anthropologist*, *119*(3), 448-463.

Szabó, P. 2015. Historical Ecology: Past, Present and Future. *Biological Reviews* 90 (4): 997–1014.

Lepofsky, D. and C. Gerala Armstrong. 2018. Foraging New Ground: Documenting Ancient Resource and Environmental Management in Canadian Archaeology. *Canadian Journal of Archaeology* 42:57-73.

Lepofsky, D., M. L. Moss, and N. Lyons. 2001. The Unrealized Potential of Paleoethnobotany in the Archaeology of Northwestern North America: Perspectives from Cape Addington, Alaska. *Arctic Anthropology*, 38(1), pp.48–59.

Lepofsky, D., and N. Lyons. 2003. Modeling Ancient Plant Use on the Northwest Coast: Towards an Understanding of Mobility and Sedentism. *Journal of Archaeological Science* 30 (11): 1357–71.

Lightfoot, K. G., R. Q. Cuthrell, Chuck J. Striplen, and Mark G. Hylkema. 2013a. Rethinking the Study of Landscape Management Practices Among Hunter-Gatherers in North America. *American Antiquity* 78, no. 2: 285-301.

Lightfoot, K. G., R. Q. Cuthrell, C. M. Boone, R. Byrne, A. S. Chavez, L. Collins, A. Cowart, R. R. Evett, P. V. A. Fine, D. Gifford-Gonzalez, M. G. Hylkema, V. Lopez, T. M. Misiewicz, and R. E. B. Reid, 2013b. Anthropogenic Burning on the Central California Coast in Late Holocene and Early Historical Times: Findings, Implications, and Future Directions. *California Archaeology* 5, no. 2: 371-90.

Lindahl, T. 1993. Instability and decay of the primary structure of DNA. *Nature* 362, 709–715 (1993).

Long, J. W., F. K. Lake, R. W. Goode. 2021. The importance of Indigenous cultural burning in forested regions of the Pacific West, USA, Forest Ecology and Management, Volume 500.

Lukešová, H, H. Andersen, M. Kolínová, and B. Holst. 2018. Is It Hop? Identifying Hop Fibres in a European Historical Context. *Archaeometry*. 61.

Lukešová , H. and B. Holst. 2021. Is Cross Section Shape a Distinct Feature in Plant Fibre Identification? *Archaeometry* 63 (1): 216-226.

Lyons, W. and M. Cummings. 2002. Sources of Sandstone Artifacts and Pottery from Lost Dune, a Late Prehistoric Site in Harney County, Southeastern Oregon, U.S.A. *Geoarchaeology.* 17. 717 - 748.

Madsen, D. 2023. Fremont Farmer-Foragers on the Margins of Agriculture Plenary Session: Beyond Boundaries. Paper presented at the 38th Great Basin Anthropological Conference, Bend, Oregon.

Markova, I. 2019. *Textile Fiber Microscopy: A Practical Approach*. First ed. Hoboken, NJ: Wiley.

Mccune, J. L., M. G. Pellatt, and M. Vellend. 2013. Multidisciplinary Synthesis of Long-Term Human–Ecosystem Interactions: A Perspective From the Garry Oak Ecosystem of British Columbia. *Biological Conservation*, 166(C), pp.293–300.

McDonough, K. 2019. Middle Holocene Menus: Dietary Reconstruction from Coprolites at the Connley Caves, Oregon, USA. *Archaeological and Anthropological Sciences* 11: 5963-5982.

McDonough, K., J. Kennedy, R. Rosencrance, J. Holcomb, D. L. Jenkins, K. Puseman. 2022. Expanding Paleoindian Diet Breadth: Paleoethnobotany of Connley Cave 5, Oregon, USA. *American Antiquity*, 87(2), 303-332.

Menzies, C. R., and C. Butler. 2006. Understanding Ecological Knowledge. In *Traditional Ecological Knowledge and Natural Resource Management*, ed. C. R. Menzies, 1–20. Lincoln: University of Nebraska Press.

Minar, J. 2000. Spinning and Plying: Anthropological Directions. *Beyond Cloth and Cordage, Archaeological Textile Research in the Americas,* edited by Penelope Ballard Drooker and Laurie D. Webster, pp. 119-139. University of Utah Press: Salt Lake City.

Minnis, P. E., ed. 2004. *People and Plants in Ancient Western North America*. Washington: Smithsonian Books.

Nazarea, V. D. 1998. *Cultural Memory and Biodiversity*. Tucson: University of Arizona Press.

Oetting, A. 1989. Villages and Wetlands: Adaptations in the Northern Great Basin: Chronology and Land Use in the Lake Abert-Chewaucan Marsh Basin-Lake County, Oregon. University of Oregon Anthropological Papers 41. Eugene: University of Oregon.

Oetting, A. 1994. Early Holocene Rabbit Drives and Prehistoric Land Use Patterns on Buffalo Flat, Christmas Lake Valley, Oregon. *Archaeological Researches in the Northern Great Basin: Fort Rock Archaeology Since Cressman*, C. Melvin Aikens and Dennis L. Jenkins, eds., pp. 155-169. University of Oregon Anthropological Papers No 50, Eugene.

Ollivier, A. P., Geoffrey M. Smith, and Pat Barker. 2017. A Collection of Fiber Sandals from Last Supper Cave, Nevada, and Its Implications for Cave and Rockshelter Abandonment during the Middle Holocene. *American Antiquity* 82(2): 325-340.

OregonFlora. 2021. Department of Botany and Plant Pathology, Oregon State University. https://oregonflora.org/. Accessed July, 2023.

Paterson, R. A., B. J. Lowe, C. A. Smith, J. M. Lord, and R. Ngarimu-Cameron. 2017. Polarized Light Microscopy: An Old Technique Casts New Light on Māori Textile Plants. *Archaeometry* 59(5): 965-979.

Pauly, D. 1995. Anecdotes and the Shifting Baseline Syndrome of Fisheries. *Trends in Ecology & Evolution*, 10(10), p. 430.

Pellatt, M. G., and Z. Gedalof. 2014. Environmental Change in Garry Oak (Quercus Garryana) Ecosystems: The Evolution of an Eco-Cultural Landscape. *Biodiversity and Conservation* 23 (8): 2053–67.

Peña-Ahumada B, Saldarriaga-Córdoba M, Kardailsky O, Moncada X, Moraga M, Matisoo-Smith E, Seelenfreund D, Seelenfreund A. 2020. A tale of textiles: Genetic characterization of historical paper mulberry barkcloth from Oceania. *PloS One*. May 18;15(5)

Petersen, J. B., and J. A. Wolford. 2000. Spin and Twist as Cultural Markers: A New England Perspective on Native Fiber Industries. *Beyond Cloth and Cordage, Archaeological Textile Research In the Americas,* edited by Penelope Ballard Drooker and Laurie D. Webster, pp. 119-139. University of Utah Press: Salt Lake City.

Piperno, D. R. 1985. Phytolith Analysis and Tropical Paleo-Ecology: Production and Taxonomic Significance of Siliceous Forms in New World Plant Domesticates and Wild Species. *Review of Palaeobotany and Palynology* 45.3: 185–228.

Plager, S., M. G. Plew, and C. A. Willson. 2006. The Archaeology of Antelope Creek Overhang. Monographs in Archeology, Volume No. 2.

Prouty, G. 1994. Root Crop Exploitation and the Development of Upland Habitation Sites: A Prospectus for Paleoethnobotanical and Archaeological Research into the Distribution and Use of Economic Plants in the Fort Rock Basin. *Archaeological Researches in the Northern Great Basin: Fort Rock Archaeology Since Cressman*. University of Oregon Anthropological Papers 50, Department of Anthropology and State Museum of Anthropology, University of Oregon, Eugene.

Puseman, K. and L. S. Cummings. 2003. Identification of Botanic Specimens from Paisley Cave #5 Site 35LK3400 Oregon. Paleo Research Institute, Golden, Colorado, technical report 03-19.

Pyne, S. 1998. Forged in Fire: History, Land, and Anthropogenic Fire. In *Advances in Historical Ecology*, ed. W. L. Balée, 64-103. The Historical Ecology Series. New York: Columbia University Press.

Raab, M. L. and W. J. Howard. 2000. Modeling Cultural Connections Between the Southern Channel Islands and Western United States: The Middle Holocene Distribution of Olivella Grooved Rectangle. In Proceedings of the fifth California Islands Symposium, Pages 590–597. D. R. Browne, K. L. Mitchell, and H. W. Chaney, editors, Minerals Management Service, Camarillo, CA.

Redman, C. L., S. R. James, P. R. Fish, J. D. Rogers. 2004. Introduction: Human Impacts on Past Environments. In *The Archaeology of Global Change: The Impact of Humans on Their Environment*. Washington: Smithsonian, pp. 1-8.

Rhode, D. 2002. *Native Plants of Southern Nevada: An Ethnobotany*. University of Utah Press.

Rodhouse T. J, K. M. Irvine, L. Bowersock. 2020. Post-fire Vegetation Response in A Repeatedly Burned Low-Elevation Sagebrush Steppe Protected Area Provides Insights About Resilience and Invasion Resistance. *Frontiers in Ecology and Evolution*. 8:584726.

Rosencrance, R., G. Smith, D. L. Jenkins, T. J. Connolly, and T. Layton. 2019. Reinvestigating Cougar Mountain Cave: New Perspectives on Stratigraphy, Chronology, and a Younger Dryas Occupation in the Northern Great Basin. *American Antiquity* 84(3): 559-573.

Schaffer, E. 1981. Fiber Identification in Ethnological Textile Artifacts. *Studies in Conservation,* 26(3):119-129.

Schenck, E. and E. Dawson. 1929. Archaeology of the Northern San Joaquin Valley, University of California Publication in American Archaeology and Ethnology, Volume 25, No. 4, pp. 289-413.

Schlick, M. D. 1994. *Columbia River Basketry: Gift of the Ancestors, Gift of the Earth*. Seattle, Washington.

Shillito, L., H. L. Whelton, J. C. Blong, D. L. Jenkins, T. J. Connolly, and Ian D. Bull. 2020. Pre-Clovis Occupation of the Americas Identified by Human Fecal Biomarkers in Coprolites from Paisley Caves, Oregon. *Sciences Advances* 6(29):eaba6404.

Simpson, R. 1965. Mark Harrington, Father of Nevada Archaeology in Nevada Historical Society Quarterly, Fall-Winter Vol VIII, 3-4.

Skoglund, G., M. Nockert, and B. Holst. 2013. Viking and Early Middle Ages Northern Scandinavian Textiles Proven to be made with Hemp. *Scientific Reports* 3, 2686.

Smith, B. D. 2011a. General Patterns of Niche Construction and the Management of 'Wild' Plant and Animal Resources by Small-Scale Pre-Industrial Societies. *Philosophical Transactions of the Royal Society B: Biological Sciences* 366 (1566): 836–48.

Smith, B. D. 2011b. Shaping the Natural World: Patterns of Niche Construction by Small-Scale Societies in North America. In *The Subsistence Economies of Indigenous North American Societies: A Handbook,* ed. B. D. Smith, 593-609. Washington, D.C.: Lanham, Md: Smithsonian Institution Scholarly Press.

Smith, B. D. 2014. Documenting Human Niche Construction in the Archaeological Record. In *Method and Theory in Paleoethnobotany*, eds. J. M. Marston, J. D. Guedes, and C. Warinner, University of Colorado Press, Boulder, Colorado, pp. 355-370.

Smith, G., M., A. Ollivier, P. Barker, A. Camp, D. Harvey, and H. Jones. 2016. A Collection of Fiber Artifacts from Southcentral Oregon. *Journal of California and Great Basin Anthropology*, 36(1).

Smith, S. J. and J. W. Gish. 2015. Archaeopalynology of PHX Sky Train Features. *Hohokam Irrigation and Agriculture on the Western Margin of Pueblo Grande: Archaeology for the PHX Sky Train Project*, edited by T. Kathleen Henderson, pp 157-172. Anthropological Paper No. 41, Archaeology Southwest, Tucson, Arizona.

Solazzo, C., S. Heald, M. Ballard, D. Ashford, P. DePriest, R. Koestler, and M. Collins. 2011. Proteomics and Coast Salish Blankets: A Tale of Shaggy Dogs? *American Antiquity* 85(330): 1418-1432.

Song, C. A., K. A. Jakes, and R. W. Yerkes. 1996. Seip Hopewell Textile Analysis and Cultural Implications. *Midcontinental Journal of Archaeology* 21.2: 247–265.

Spier, L.1930. *Klamath Ethnography*. Smithsonian Libraries, Washington D.C.

Stenholm, N. 1994. Paleoethnobotanical Analysis of Archaeological Samples Recovered in the Fort Rock Basin. *Archaeological Research in the Northern Great Basin: Fort Rock Archaeology Since Cressman*, ed. M. Aikens and D. Jenkins, 531–60. University of Oregon Anthropological Papers 50. Eugene.

Stewart, O. C. 1939. The Northern Paiute Bands. *University of California Anthropological Records* 2(3): 127-149.

Steward, J. H. 1938. Basin-plateau aboriginal sociopolitical groups. *Bureau of American Ethnology Bulletin*. 120:1–346.

Stuvier, M. and H. A. Polach. 1977. Reporting of 14C Data. In *Radiocarbon* 19(3):355-363.

Suomela, J. A., K. Vajanto, and R. Räisänen. 2018. Seeking Nettle Textiles – Utilizing a Combination of Microscopic Methods for Fibre Identification. *Studies in Conservation* 63(7): 412–422.

Suomela, J. A., Suhonen, H., Räisänen, R., and K. Wright. 2022. Identifying Late Iron Age textile plant fibre materials with microscopy and X-ray methods — a study on finds from Ravattula Ristimäki (Kaarina, Finland). *Archaeological and Anthropolological Sciences* 14, 40.

Taylor, A., J. Hutson, V. Bryant, and D. L. Jenkins. 2020. Dietary Items in Early to Late Holocene Human Coprolites from Paisley Caves, Oregon, USA. *Palynology* 44(1): 12-23.

Teague, L. 1998. *Textiles in Southwestern Prehistory*. Albuquerque: University of New Mexico Print.

Thompson, V. D. and J. C. Waggoner. 2013. *The Archaeology and Historical Ecology of Small Scale Economies*, Gainesville: University Press of Florida.

Tuohy, D. R. and Eugene M. Hattori. 1996. Lovelock Wickerware in the Lower Truckee River Basin. *Journal of California and Great Basin Anthropology* 18:284–296.

Turner, N. J. 1971. The Ethnobotany of the Coast Salish Indians of Vancouver Island. *Economic Botany*, Vol. 25, No. 3, pp. 335-339.

Turner, N. J. 1998. *Plant Technology of First Peoples in British Columbia*. Vancouver: UBC Press, 1998. Print.

Turner, N. J. 1999. 'Time to Burn', Traditional Use of Fire to Enhance Resource Production by Aboriginal Peoples of British Columbia. In *Indians, Fire, and the Land in the Pacific Northwest*, ed. R. Boyd. Oregon State University Press, Corvallis.

Turner, N. J., and D. Deur. 2005. Introduction: Reassessing Indigenous Resource Management, Reassessing the History of an Idea. In *Keeping It Living: Traditions of Plant Use and Cultivation on the Northwest Coast of North America*, ed. D. Deur and N. J. Turner, 3–34. Seattle : Vancouver: University of Washington Press ; UBC Press.

Turner, N. J., and S. Peacock. 2005. Solving the Perennial Paradox: Ethnobotanical Evidence for Plant Resource Management on the Northwest Coast. In *Keeping It Living: Traditions of Plant Use and Cultivation on the Northwest Coast of North America*, ed. D. Deur and N. J. Turner, 101–50. Seattle : Vancouver: University of Washington Press ; UBC Press.

Tütüncü S. T., N. Öztürk. And F. Dane. 2014. Occurrence, Types and Distribution of Calcium Oxalate Crystals in Leaves and Stems of Some Species of Poisonous Plants. *Botanical Studies* 55, 32.

USDA Plants Database. 2021. United States Department of Agriculture. https://plants.usda.gov/home. Accessed July 2021.

Viljanen, M., J. A. Suomela, and K. Svedström. 2022. Wide-Angle X-Ray Scattering Studies on Contemporary and Ancient Bast Fibres Used in Textiles – Ultrastructural Studies on Stinging Nettle. *Cellulose (London)* 29.4: 2645–2661

Walker, M. J. C., M. Berkelhammer, S. Björck, L. C. Cwynar, D. A. Fisher, A. J. Long, J. J. Lowe, R. M. Newnham, S. O. Rasmussen, H. Weiss. 2012. Formal Subdivision of the Holocene Series/Epoch: A Discussion Paper by a Working Group of INTIMATE (Integration of ice-core, marine and terrestrial records) and the Subcommission on Quaternary Stratigraphy (International Commission on Stratigraphy). *Journal of Quaternary Science*, Volume 27:7.

Wheat, M. 1967. *Survival Arts of the Primitive Paiutes*. University of Nevada Press, Reno.

Willoughby, C. C. 1938. Textile Fabrics from the Burial Mounds of the Great Earthwork Builders of Ohio. Ohio. *Archaeological and Historical Quarterly* 47:273-287.

Wriston, T. and G. Smith. 2017. Late Pleistocene to Holocene History of Lake Warner and its Prehistoric Occupations, Warner Valley, Oregon (USA). *Quaternary Research* 88(3): 491-513.

Zeder, M. A. 2012. The Broad Spectrum Revolution at 40: Resource Diversity, Intensification, and an Alternative to Optimal Foraging Explanations. *Journal of Anthropological Archaeology* 31, no. 3: 241-64.

Zhang, L., and H. Huang. 2014. Calciphytoliths (calcium oxalate crystals) analysis for the identification of decayed tea plants (Camellia sinensis L.). *Sci Rep*. 2014 Oct 24;4.

Zigmond, M. L. 1998. *Kawaiisu Ethnobotany*. Salt Lake City: University of Utah Press.