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Long-term Interactions of Climate, Vegetation, Humans, and Fire in Eastern Washington

Elizabeth Ann Scharf

A dissertation submitted in partial fulfillment of the
requirements for the degree of

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Abstract

Long-term Interactions of Climate, Vegetation, Humans, and Fire in Eastern Washington

Elizabeth Ann Scharf

Chair of the Supervisory Committee:
Professor Donald K. Grayson
Department of Anthropology

Modern ecological studies are unable to examine long-term processes operating on the order of hundreds of years. Because of the limited length of modern and historic records, questions about long-term interactions between people and the environment can only be answered using paleoecological and archaeological information. This dissertation uses prehistoric records spanning the past millennium to examine issues of human paleoecology on the Columbia Plateau of Washington State. Unlike many previous studies, this study (1) quantifies past human population (2) compares relative inputs of humans, climate, fire, and vegetation using multivariate statistics (3) examines relationships between variables when leads and lags of different lengths are introduced (4) identifies multicolinearity, allowing variables of no explanatory value to be eliminated.

For this analysis, lake sediments provided pollen, charcoal, and oxygen-isotopes that served as proxies for past vegetation, fire, and climate, respectively. These data were compared to a previously published paleodemographic reconstruction. Results showed that simple bivariate analyses were misleading. For example, human population was significantly correlated with charcoal when charcoal was lagged by 0, 50, 100, or 150 years, indicating that human action led to future increases in fire. When past all variables were all entered simultaneously in a multivariate analysis, however, population was shown to have no effect on fire after 50 years. Vegetation (pine woodlands) was shown to have a significant short-term influence on fire, and climate was shown to be the only long-run predictor of fire. Similar analyses were run to determine which factors (if any) were patterning future values of vegetation, human population, and climate. Results showed that the history of the system had an important influence on ecological outcomes. The analysis showed that the different factors in the ecosystem were intricately interrelated to one another, with feedbacks occurring between the variables over several different time scales. This study indicates that research on human impacts that focuses on bivariate patterns, such as simple comparisons of coeval human population and fire, can suffer from the problem of equifinality. The protocol employed in this work can avoid this problem, and has the potential to be used in any area.

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Acknowledgments

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Chapter 1. Introduction

> *"...it is foolhardy to make any ecological interpretation of modern landscapes or environments or to formulate policy in conservation or natural resource management without an historical context that extends back decades, at least, but preferably centuries or millennia." (Foster 2000:27)*

This dissertation seeks to add to our knowledge of long-term ecological processes by examining the greater historical context of one particular location -- Okanogan and Douglas counties in the state of Washington. To achieve this goal, a protocol is developed for the collection and analysis of appropriate proxy data on vegetation, landscape, fire, climate, and human activity over the past millennium. The results provide information on the significance and extent of interaction between different factors in the ecological system. In this way, historical influences, complex feedback systems, and independent causal factors can be identified and explored to better understand the past, present, and future of the environment in Eastern Washington. Both the protocol developed and the study-specific results gained from this research contribute to the larger goals of documenting and understanding long-term landscape processes around the globe.

The analysis presented in this dissertation shows that simplistic comparisons of two contemporaneous variables was often misleading. For example, when examined in isolation, human population sizes were significantly correlated with the outbreak of fire, indicating that human population could be driving the fire history in the area. A multivariate analysis was able to address the issue of equifinality, revealing if competing factors could explain the observed pattern in the outbreak of fires and whether population was itself a function of another variable. Indeed, when human population, fire, climate and vegetation were all examined together, it turned out that climate was a better predictor of fire in the long term than human population. Multivariate analysis also showed that human population was part of a feedback system with fire; human populations influenced fire frequency over the short term, but population was, in turn, determined by past fire history. Examinations of the cause of human population change and vegetation change show the same type of pattern, confirming that interactions between humans, vegetation, fire, and climate are complex, with feedbacks, operating simultaneously on different time scales.

Interest in Modern Environment-Human Interactions

How people and the environment interact is an object of continued concern and interest, worldwide. One need only to access the web, pick up a newspaper, or turn on a radio or television to encounter headline news about such issues as global warming, the destruction of wetlands, deforestation, extinction, El Niño, and La Niña. Human-environment interaction is of great interest to us for two reasons. First, as humans, we are innately interested in the legacy that we will leave behind in the form of our impact on the landscape and ecology of the planet. We want to understand how we affect the environment and how to be more knowledgeable stewards of our resources (Black 1970, Goudie 2000). Underlying this is the second and more important reason for our interest – we are concerned that changes in the climate, flora, or fauna may have a harmful impact on our future as individuals and as a species. Fear has our attention riveted on these issues because our very survival may be at stake.

Why Prehistory Matters

Obviously, all of us share an interest in how current events are shaping our ecological futures. The problem is that we know that many climatological and ecological responses take longer than a few years, or even a human lifetime, to manifest themselves. Vegetation responses to present-day disturbances, for example, could take many decades to recognize. Plant succession takes a hundred years or more to reach a state of "climax," so the result of present perturbations will take over a hundred years to be fully realized (Birks 1981, Horn 1975). Unfortunately, most ecologists "study organisms on a time scale of less than 100 years (and are usually limited to the time span of a field season, grant or dissertation)"(Schoonmaker and Foster 1991:205).

To better understand the full ramifications of slowly operating processes, we need a longer time-frame than modern ecology can deliver. Greater time-depth is exactly what the disciplines of paleoecology and archaeology have to offer. As many have observed (to the point of it becoming cliché): knowledge of the past is the key to understanding both the present and the future. In recognition of this, many researchers have used paleorecords to put ecological questions into a larger context.

Research Goals

The project presented here seeks to add to this growing body of knowledge using a Holocene dataset to understand long-term processes and outcomes. What I propose to do in this dissertation research is to explicate the interactions between humans, climate, and the landscape over the past millennium using paleoecological, paleoclimatological and archaeological records. Specific questions I will examine along the way include: How do humans affect fire frequency and how does that, in turn, affect humans? How does climate affect fire frequency? How does fire frequency affect vegetation? How does vegetation affect humans? How does fire frequency affect humans? How does climate affect humans? What kind of constraints does the history of a system impose? And how do all these factors interact with one another in more complex ways?

Environment-Human Interactions in Prehistory

Questions about environment-human interactions, such as those posed above, are not new. Studies of environment-human interactions abound, whether these are based on contemporary observations, written and oral histories, or reconstructions of prehistoric processes. Of these, truly long-term (decadal, centennial or millennial-scale) processes in many parts of the world can only be examined using prehistoric databases that predate the advent of written records. Indeed, prehistoric records have been used address a wide variety of issues, including the influence of agricultural land clearance on vegetation and soil erosion, the influence of human colonization on fire regimes, the effect of human hunting on wild animals, and the effect of human-introduced grazing animals on vegetation.

How do such studies identify human impact? How are the effects of humans recognized, since prehistoric human action cannot be directly observed but must be indirectly inferred from records of past environmental conditions?

Assessments of human impact on a given biota primarily rely on changes in the type, number, and relative abundances of plant and animal taxa in the past. Human impacts on the faunas of such geographically distant regions as Western North America (Broughton 1994, 1997; Grayson and Cannon 1999) and New Zealand (Nagaoka 2001), for example, have been studied employing the diet breadth model provided by foraging theory. Decreasing relative abundances of high-ranking (typically large-bodied) prey in archaeofaunas over time are attributed to human impact (Grayson and Cannon 1999).

Arguments have also been made for human impacts in cases of extinction, in which researchers argue that decreasing numbers of animal taxa following human colonization of new areas are evidence of human impact (Redman 1999). These studies range from the relatively secure documentation of anthropogenic extinction of birds on small Polynesian islands (Steadman 1995, Steadman and Kirch 1990) following human colonization, to the more highly debated extinction of Pleistocene and megafauna attributed to the human settlement of areas like North and South America (Grayson 2001; Martin 1967, 1972 1984; Martin and Steadman 1999).

Assessments of human impact on past vegetation, likewise, focuses on taxonomic representation in the prehistoric record. Assessments of anthropogenic change in vegetation is often based on evidence from pollen diagrams. One clear indicator of anthropogenic change, recognized worldwide, is the sudden appearance of exotic plant taxa in new geographic areas (Cole and Liu 1994, Delcourt and Delcourt 1987b). The introduction of weeds, such as common plantain (*Plantago major*) and dandelion (*Taraxacum officionale*) in North American sediments after European Contact, is an example of one of these exotic "markers" of human action (McAndrews 1976, 1988). The appearance of cultigens and domesticated plant taxa into new areas is used as an indicator of human impact as well. The deposition of maize (*Zea mays*) pollen in North America (Delcourt and Delcourt 1987a, 1987b), the spread of cassava (*Manihot esculenta*) pollen into new parts of the Amazon Basin in South America (Behling and Costa 1999), the introduction of domesticated cereals (*Cerealea*) into Europe (Iverson 1956) and rises in buckwheat (*Fagopyrum* -- Tsukada et al. 1986) are just a few examples of such indicators.

Another universally recognized sign of human impact is land clearance episodes. Human disturbance in these cases is seen to favor taxa that are typical of early-successional communities over those that are characteristic of late-successional communities. This is commonly expressed on the landscape by the conversion of woodlands into more open vegetation, typically grasslands. This is documented in pollen records by the overall increase in herbaceous taxa at the expense of arboreal taxa in pollen spectra over time. When such disturbance is temporally correlated with human behavior, in the absences of other potential causal mechanisms (such as climate change), the resulting vegetation changes are identified as anthropogenic.

Clearance episodes have been documented around the world. New Zealand, for instance, was heavily forested until the arrival of the Maori. Following the Polynesian settlement of New Zealand, arboreal taxa (e.g. podocarps) decreased radically while disturbance taxa (e.g. grasses and ferns) increased in relative abundance on the landscape (McGlone 1983, McGlone and Wilmshurst 1999). Like New Zealand, Easter Island and the Hawaiian islands also suffered from deforestation following Polynesian settlement. In the case of Easter Island, settlement of the island around A.D. 400* was followed by decreases in palm trees and increases in grasses, a trend that continued to the local extinction of the palms around A.D. 1400 (Flenley et al. 1991, Flenley and King 1984). Similar processes operated on Hawaii, which was also settled around A.D. 400. Settlement in the Hawaiian islands launched a similar trend. As the abundance of palm trees decreased sharply over time, disturbance taxa such as grasses and ferns increased (Athens and Ward 1993).

Human disturbance patterns like those documented during Polynesian settlement of the Pacific are typical of prehistoric human impact seen across the globe. Large-scale disturbance has been documented for a wide range of locations and cultures, from the deforestation of the classic Maya period in the Yucatan Peninsula (Abrams and Rue 1988), the Neolithic clearance of lands in the British Isles (Brown 1997, 1999; Greig 1992; Macklin, et al. 2000, Skinner

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*See Appendix A for all abbreviations, symbols, and conventions used throughout this manuscript.

and Brown 1999) and Euro-American clearance in Western Washington (Sugita and Tsukada 1982) to the drastic reduction of woodlands in the Anyang Dynasty in China (Redman 1999).

Human disturbance is often associated with increases in both fire frequency and soil erosion, and these usually coincide with decreases in late-seral taxa. In the case of the Maya, deforestation was accompanied by both fires and massive erosion, as evidenced by the increased deposition of both charcoal and inorganic sediments into area lakes (Binford and Leyden 1987, Rice 1996, Rice and Rice 1984, Rice et al. 1985). Likewise, human clearance of palms in Hawaii was correlated with an increase in anthropogenic fire and erosion (Kirch 1982, 1997; Kirch and Hunt 1997). Deforestation on Easter Island (Flenley and King 1984, Flenley et al. 1991) and China (Redman 1999) both resulted in soil loss, and the loss of forest cover following the settlement of New Zealand was accomplished through human-set fires (McGlone 1989, McGlone and Wilmshurst 1999, Ogden et al. 1998).

As with the case of anthropogenic vegetation disturbance, human influence on fire is recognized by first identifying an increase in charcoal deposition that is not correlated with known changes in the climate or other external environmental factors. If this otherwise unexplained increase in fire can be shown to be correlated in time with a significant archaeological event such as initial settlement of an area, adoption of agriculture, or intensified land-use from rising population densities, then the rise in charcoal is deemed evidence of anthropogenic fire.

This method of identifying episodes of anthropogenic firing has been used to identify prehistoric human impacts in such far-flung areas as New Zealand (McGlone 1989, McGlone and Wilmshurst 1999), the Falkland Islands (Buckland and Edwards 1998), the Amazon Basin (Behling and Costa 1999), Australia (D'Costa et al. 1993; Head 1989; Pyne 1991, 1997; Singh 1980), Hawaii (Kirch 1982), the Faroe Islands (Hannon and Bradshaw 2000), Chile (Moreno 2000), Madagascar (Burney 1993), the Yucatan (Rice 1996, Rice and Rice 1984), the temperate zone of Eastern North America (Clarke and Royall 1995a), and South India (Morrison 1994).

Requirements for a study of prehistoric human impact

Examining these existing studies of anthropogenic impacts helps identify the requirements that must be met when designing a new research project. (1) Proxies must be available for the past biota, human behavior, fire, and climate. (2) These proxies must be constructed on a temporal and spatial scale compatible with the scale of human action. (3) There has to be adequate temporal control for the surrogates, enabling them to be meaningfully compared. (4) There has to be a change in state of at least one of the variables. (5) The records being used must have enough time-depth to address the questions being asked.

Additionally, another criterion must be met for this study. Although past studies have identified human impact, this study seeks to examine and quantify these interrelationships on a finer scale than most. Relationships between contemporaneous variables will be investigated by calculating correlation coefficients (Pearson's *r*). Correlations will also be run with lags introduced between variables to identify which variables are leading (likely to be causal) and which are lagging. Further, time series and Granger causality will be used to simultaneously evaluate the relative contribution of all factors (human action, climate, fire, vegetation), both contemporaneous and leading, to changes in the system. In this way, Granger causality will be used to identify which factors (human action, climate, fire, vegetation), if any, are driving the system. It will allow feedbacks, dependencies, and external factors to be explored quantitatively. Because of this, problems of equifinality can be addressed in a manner that was unavailable in prior research on prehistoric human. Accordingly, for this study, surrogates should be expressed numerically so the nature and strength of the relationships between them can be examined statistically. This study contrasts with earlier studies of human impact, in that it quantifies human input into the system and uses multivariate statistics to simultaneously evaluate multiple competing explanatory variables relative to one another on multiple time scales.

Meeting the requirements

The research presented in this dissertation was designed to meet all of the above criteria. First, a study area (the area immediately surrounding Rufus Woods Lake in Eastern Washington) of an appropriate size was chosen that already had an excellent existing population proxy. The human paleodemographic record for this area extends back over a millennium, is sampled at evenly-spaced and well dated 50-year intervals, and exists in a highly useful quantitative form.

Since no comparable surrogates for vegetation, fire, or climate could be found in the literature for this particular study area, new records for these variables had to be specially created for the current study. Information on past plant communities was drawn from fossil pollen, a common paleovegetation proxy. Since permanently wet lakes preserve continuous palynological records in excellent condition, lake sediments were used to provide the data source for reconstructing paleovegetation. Fortuitously, the same lake sediments could be used to provide information on fire and climate as well. Climatic information was obtained from the isotopic composition of lake carbonates, and charcoal influx was used to track past vegetation fires. Finally, chronological control was provided by a series of AMS radiocarbon dates.

The selection of an appropriate study area and details of the research design are presented in greater depth in the following chapters (2-4). Results of the AMS dating, isotope assays, pollen analyses, and charcoal counts are given in Chapters 5-8. The final two chapters (9 and 10) present the statistical analyses, a synthesis of results, and the conclusions drawn from the study.

Chapter 2. Selection of a Region for Study

Archaeological Requirements

Dependable, systematic data regarding past human behavior are critical to the proposed research. To be successful, a study of human-environment interaction must include an estimation of the number of people living in a given area. For times that predate written records, this information can only be obtained indirectly, through a proxy demographic record. Although some researchers have relied on guesses or extrapolations from historical records to estimate past human population sizes, it has been argued that good proxy demographic records can only be produced with archaeological data as surrogates (Campbell 1989; Cook 1976; Dobyns 1963, 1983; Dunnell 1991, Ramenofsky 1987).

Prehistoric human populations have been reconstructed using many lines of information obtainable from the archaeological record. Past population estimates have been based on measurable archaeological phenomena such as burial counts, archaeological site abundance, house counts, hearth or storage-pit tallies, the number of radiocarbon dates, wear on grinding stones, volume of pottery vessels, wear on floor tiles, m^2 floor area inside buildings, room totals, or the amount of accumulated shell and bone midden (e.g. Campbell 1989; Cook and Treganza 1950; Plog 1974; Ramenofsky 1987; Schacht 1981; Schwartz 1956; Shawcross 1967,1972; Turner and Lofgren 1974). All of these suggested measures rely on the assumption that the amplitude of human impact on the archaeological record is proportional to the number of people on the landscape, with greater numbers of people producing greater amounts of food waste, more wear on tools, or constructing more living space for themselves. Creating a secure, reliable and fine-grained human population reconstruction using these kinds of data is an undertaking that requires the excavation, laboratory analysis, and radiocarbon-dating of tens to hundreds of site components in a small geographic area. Such projects usually require years of effort to complete, and become the subject of books or dissertations by themselves. To construct a new record for an area would be prohibitively costly in terms of time, labor and money. Such a large archaeological undertaking could also involve destructive analysis, making the use of existing data sets that much more desirable, both logistically and ethically. That is why, for this study, I sought an area where a systematic prehistoric population proxy already exists.

For optimal utility, a paleodemographic record should be one constructed on a spatial and temporal scale consistent with human behaviors (Stein 1993). The scale of the population surrogate must be large enough to encompass a group of people over several generations, yet fine-grained enough to be relevant to the life and actions of a single person. The population record must match the scale of human disturbance in the paleoecological record. An appropriate temporal and spatial scale for such an investigation is what authors alternatively refer to as mesoscale (Delcourt et al. 1983; Delcourt and Delcourt 1988; Schoonmaker and Foster 1991) or extralocal (Jacobson and Bradshaw 1980). This scale encompasses areas from approximately tens to a thousand square kilometers, but tending to be on the order of 100 square kilometers. Mesoscales also span time periods of several decades to a few millennia. In determining the duration of time that needs to be covered, the temporal scale also determines the necessary resolution of the proxy. The resolution, or time-span between data points, must be decadal in order for a meaningful centennial to millennial-scale proxy to be used. Areas with good existing proxy demographic records covering a millennium are quite rare. This makes the proxy demographic record the limiting and essential factor in selecting a research area and key to successfully evaluating the effects of prehistoric populations on the landscape.

There are a handful of regions in North America for which such population reconstructions have been produced (e.g. Ames 2000; Campbell 1989; Chatters 1995a, 1995b; Leavell and Chatters 1996; Ramenofsky 1987). These include such areas as upstate New York (Ramenofsky 1987), the Caddo region (Perttula 1992), the Middle Missouri River Valley (Ramenofsky 1987), the Lower Mississippi River Valley (Ramenofsky 1987), and the Southern Plateau (Ames 2000, Campbell 1989, Chatters 1995).

Of these areas, the Southern Plateau was selected for study. One advantage of the Southern Plateau was that it had the potential to provide a record with tighter chronological control than other regions. The Southern Plateau has frequently been covered by volcanic ashes of known composition and known ages, providing secure and abundant time markers throughout the Holocene record. In contrast, there is no similar series of well-dated stratigraphic events that could provide chronological control over the entire Caddo region, Lower Mississippi River Valley, upstate New York, or Middle Missouri River

Valley. A second advantage of the Plateau is that it provides an opportunity to investigate prehistoric North American hunter-gatherer impacts on the pollen record, which is something that has gotten little treatment in the literature and deserves more attention. Previous palynological attempts to document prehistoric impacts in North America have primarily focused on horticulturalists (e.g. Delcourt 1987).

The Southern Plateau Region

The Plateau is a relatively low-lying interior area east of the Cascade Mountains in the Pacific Northwest, and is geographically defined as that part of North America drained by the Columbia and Fraser Rivers (Figure 2.1; Walker 1998). The Southern Plateau is the part of the Plateau that lies south of the highest elevation in the Okanogan highlands, and can be defined as that portion of the Plateau that is drained by the Columbia River. The Southern Plateau, also called the Columbia Plateau, is considered to be a coherent geographic subdivision of the Plateau, both in terms of its environment and culture (Ames 2000).

Prehistoric Population

Population reconstructions for this entire region have been published by Ames (2000) and Chatters (1995, and in Ames 2000). Figures 2.2 and 2.3 show these demographic surrogates, which estimate based on the number of radiocarbon dates reported from archaeological sites of different ages. In both cases, complex mathematical transformations were used to correct raw data for decay of organic materials, since older materials are more likely to have been destroyed and therefore unavailable for radiocarbon dating. This method assumes that the number of radiocarbon dates analyzed is related to the amount of charred material produced per time period and related to the number of people producing charred material in each time period (Ames 2000, Chatters 1995). This, of course, assumes that archaeologists are discovering, sampling, and dating materials in an unbiased manner.

Unfortunately, these surrogates are drawn from a very large area, some 100,000 square kilometers in diameter, well beyond the optimal spatial scale suggested for investigating human impacts (Delcourt and Delcourt 1988). Thankfully, a smaller-scale proxy demographic reconstruction exists from a portion of the Plateau. The Rufus Woods Lake area of eastern Washington (Figure 2.4) was the focus of a population study by Campbell (1989), and produced a demographic proxy of the appropriate temporal and spatial scale.

Native American use of fire

Historic records, oral histories and ethnographies from the Southern Plateau and neighboring regions indicate that people may have used fire to influence the nature of vegetation. Indeed, evidence of native firing is seen throughout western North America. Many researchers believe that hunter-gatherer fires on this continent have determined the spatial distribution of the flora -- creating and maintaining a mosaic of patches at different successional stages, increasing floral diversity, and encouraging the growth of economically important taxa (e.g Day 1953, Domey and Dorney 1989, Hammet 1992, Pyne 1982).

On the Great Plains, for example, routine native burning determined the areal extent of prairieland and both the size and spatial distribution of bison herds; when routine firing of the grasslands ceased in historic times, grasses were soon overgrown by trees, converting the land to forest and decreasing bison forage (Goudsblom 1992, Lewis 1982). Historic eyewitness accounts of ethnographic burning on the Plains and the Rockies abound, back to the accounts of Lewis and Clark (Barrett and Arno 1999, DeVoto 1969, Pyne 1982, Hough 1844, Krech 1999). Likewise, Native Americans in northern Alberta set fires that helped maintain grasslands and a patchwork of microhabitats that encouraged the growth of economically important plant and animal resources, including berries, rabbits, moose, and geese (Lewis 1982).

Contact and postcontact burning is also documented for California and Oregon groups. Photographic records from Yosemite show that after native groups abandoned the area in 1854, the cessation of regular burning led to an increase in brush and deciduous trees at the expense of meadows and open grassy clearings (Aschmann 1977). Scattered historic reports from missionaries and travelers indicate that indigenous peoples burned the California chaparral, keeping grassy areas open between stands of shrubs (Bean and Lawton 1992; Lewis 1982, 1993; Pyne 1982). Native Californians also set fires to kill mistletoe (Loranthaceae family) that infested mesquite (*Prosopis* spp.) and economically important stands of oak (*Quercus* spp.)(Lewis 1993, Pyne 1982).

More complete ethnographic and historic records, combined with fire-scar histories of standing trees from forested areas in the Sierra Nevada and the

Coast Range of California, indicate that native burning kept down undergrowth, dead wood, and forest-floor litter (Aschmann 1977). This, in turn, kept the coniferous forests open and prevented the kind of disastrous wildfires that destroy living stands (Lewis 1982, 1993). Throughout California and Oregon, grassland firing resulted in an artificially-induced late-fall sprouting of new grasses. This second growing season, in turn, provided winter forage that attracted deer and migratory birds (Bean and Lawton 1992, Lewis 1982, Pyne 1982, Timbrook et al. 1982). The evidence for anthropogenic environmental change in California is so abundant and so clearly documented that it has led some researchers to claim that "the vertical structure, spatial extent, and species composition of the various plant communities that early European visitors to California found so remarkably fecund were largely maintained and regenerated over time as a result of constant, purposive human intervention" (Blackburn and Anderson 1993).

It is no surprise, then, that native peoples in the Northwest also used fire as a management tool (Hunn 1990; Ignace 1998; Lewis 1973, 1977; Pyne 1982). Fire was used in the lowlands west of the Cascades by groups from Southern Oregon to British Columbia (Boyd 1999, Turner 1999). Low elevation burning was used to drive game and to promote the growth of plants that were important to the diet of indigenous peoples. Ignition of vegetation promoted the growth of bracken fern (*Pteridium aquilinum*), acorns (*Quercus* spp.), blackberries (*Rubus ursinus*), hazelnuts (*Corylus cornuta*), salmonberries (*Rubus spectabilis*), and other economically important resources (Boyd 1999, Deur 1999, Kruckeberg

1999, Turner 1999, White 1999). At the time of European contact and settlement, many areas of Puget Sound and the Willamette Valley were open prairies or mosaics of woodlands and prairie openings that were anthropogenic in origin (Cox 1999, Kruckeberg 1991). After the imposition of historic fire suppression, late-successional vegetation has taken over these areas, with Douglas fir and conifers invading areas that were formerly kept open by Native American fires (Boyd 1999, Cox 1999, Kruckeberg 1991, Leopold and Boyd 1999).

Accounts from oral histories and ethnographies show that Native American groups were using fire to manage resources at higher elevations in the Cascade Mountains as well. Sahaptian firing in what is now the Gifford Pinchot National Forest continued in the Cascades until the recent imposition of fire suppression, and Indian burning is still remembered by living members of local communities (Hunn 1990). Vegetation burning by Sahaptin peoples in the Cascades was used primarily to enhance economically useful herbs and shrubs and to discourage trees (Hunn 1990, 1999). In this way, people encouraged the growth of berries (e.g. blueberry, grouseberry, and huckleberry) that were part of the human diet as well as the growth of vegetation that could feed deer and elk (which in turn could be incorporated into the human diet)(Hunn 1990, 1999). Photographic evidence from the Gifford Pinchot National Forest shows that past burning in this area kept meadows open and promoted the growth of early-seral taxa. Meadows that had been open and treeless in photos taken around A.D. 1900 were invaded during later decades of fire suppression, with young lodgepole pines (*Pinus contorta*) invading the edges and spreading to the center of the clearings (Hunn 1990, Jerman and Mason 1976). Molala groups of the Cascades in Oregon were known to do likewise; these native groups also set fire to vegetation at higher elevations in order to increase both huckleberries and browse for elk and deer (Zenk and Rigsby 1998).

Fire was an equally important tool for the inhabitants of the intermontane areas east of the Cascades, the region under study in this dissertation. Ethnographic and historic accounts of native firing are common began with the records from the Lewis and Clark expedition (Robbins 1999). Plateau peoples purposively used fires for the same ends as the Cascade and coastal peoples of the Northwest. The Kallispell, Nez Perce, Coeur d'Alene, and other Plateau peoples used fire to drive game (Boyd 1999, Lahren 1998, Robbins 1999), for improving browse for game (Marshall 1999, Palmer 1998), for improving berry crops (Marshall 1999), and for increasing camas and other root plants important to the Native American diet (Boyd 1999, Marshall 1999). Firing in lowland valleys and sage-grass steppe was used to promote the sprouting and growth of grasses at the expense of sagebrush. In the higher forested areas, fire was used to decrease lichen and mistletoe, increase grasses, and keep the ponderosa pine (*Pinus ponderosa*) stands free of firs and other invading tree species.

Fire history

It is likely that fire in the selected study area has been influenced by both natural and cultural factors. Currently, humans are a source of both accidental and intentionally set "prescribed" fires (Pyne 1982). Modern human behavior, as well as the ethnographic and historic evidence reviewed above, indicates that humans likely have a long history of promoting fires in this region. Written records indicate that climate is another major contributor to modern fires. In this area, lightening presently starts 21 to 40 fires per million acres per year (Martin et al. 1977). Climate change can affect this source of ignition via an increase in storminess with a concomitant increase in lightening strikes, or via a decrease in effective moisture, since dry fuel is more flammable (Bergeron and Archambault 1993; Birks and Gordon 1985; Clarke 1988a; Pyne 1982, 1991; Swain 1973).

Long-term fire histories exist for parts of the Plateau and surrounding areas. At Smeads Bench Bog, in northwest Montana, Chatters and Leavell (1994) used lake sediments to provide microscopic pollen and charcoal. The authors demonstrated that fires in the surrounding hemlock forest occurred at an average 200-year interval over the past thousand years. They observed two different fire regimes, the first one spanning the thirteenth to sixteenth centuries A.D., showing a mean interval of 135 years. The second regime, spanning the sixteenth century A.D. to present, had a much longer return period of 283 years.

Microscopic charcoal studies from lake sediments in the ponderosa pine forests of Yellowstone Park demonstrate a more variable periodicity in fire. This study found that woodlands had prehistoric fire intervals that varied widely from 40 to 280 years at each of several local sites (Millspaugh and Whitlock 1995). In a regional overview of the Plateau (but using mostly data from the eastern Rockies), Chatters (1998) notes that reconstructed Holocene fire records tend to show that fires were most frequent and least severe in the period from 1,000 to 2,000 B.P. (Chatters 1998, Hemphill 1983, Mehringer et al. 1977b, Smith 1983). Chatters interprets the period of higher fire frequency to be an anthropogenic "effort to maintain the early-seral (early-successional) vegetation and promote production of game and fruits"(Chatters 1998).

Modern climate

The modern climate in this region is primarily controlled by the configuration of two air masses -- the Pacific subtropical high and Aleutian low. Changes in these air masses, mediated by the physiography of Western North America, determines local weather conditions in the study area. The most frequent prevailing modern pattern is one in which the Aleutian low extends far south, increasing storminess and pushing moist maritime air masses to the Pacific Northwest on an eastward track. These cool, moist air masses do not deliver much precipitation to the Northern Columbia Plateau because they first encounter the coastal ranges of the Olympic and Cascade Mountains as they make landfall (Ames 2000, Chatters 1998). Adiabatic cooling of air masses that try to ascend these coastal mountain ranges causes the moisture to fall as precipitation on the west side of the mountains, and results in a rain shadow on the east side of the mountains (Figure 2.5).

Even when the configuration of air masses changes, and the Aleutian low assumes a more northerly position, eastern Washington remains relatively arid. Under such conditions, the retraction of the Aleutian low allows arctic air masses to enter the Plateau region, bringing only dry continental air. Predictably, the study area and surrounding region is considered "semi-arid" with annual precipitation tending to average about 32 cm (Forbes 1987, Leeds et al. 1985).

Although precipitation is low on average, the variability of temperature and precipitation here varies seasonally and annually. The area typically experiences hot and relatively dry summers and cold, moister winters (Chatters 1998, Forbes 1987, Leeds et al. 1985). Instrument records illustrate this seasonal swing in temperatures with mean January temperature averaging -4.0 ^{o}C, while the mean July temperature averages 22.5 ^{o}C (U.S. Dept of Commerce, Weather Bureau in Forbes 1987).

Historic and instrumental records also attest to the degree of variability from year to year. Although annual precipitation averages 32 $\pm$ 7 cm a year, the moisture delivered to this area can change quickly and unpredictably. One wet year of over 44 cm of recorded precipitation, for example, was followed immediately by a year of less than 18 cm of precipitation (Leeds et al. 1985).

Since the storm tracks determine the amount of precipitation entering the area, this variability in precipitation is determined by year-to-year changes in the extent and duration of the southern penetration of air masses such as the Aleutian Low and the Pacific Subtropical High. These weather systems, in turn, are controlled by the pattern and timing of ENSO (El Niño and La Niña) events (Taylor 1998, NOAA 2001). The result of this high interannual variability is that conditions can change radically over a short period of time, and since the flora of semi-arid areas is inherently sensitive to moisture fluctuations, the growing conditions, productivity, composition, and presence of botanical communities will fluctuate drastically from year to year (Leeds et al. 1985).

Past climate

Global climate reconstructions for the late Holocene (the period under consideration in this study) show several broad trends over this time period. The late Holocene, on the whole, is considered to be a relatively cool, moist period, preceded by a warm dry mid-Holocene trend (the Altithermal) that lasted from about 8,000 to 4,000 or 5,000 B.P. (Chatters 1998, Dalan 1985a, Sabin and Pisias 1996, Wright et al. 1993). The global trend beginning 4,000 or 5,000 B.P. is one of general cooling (the Neoglaciation), with several smaller-scale events imposed on the larger trend (Heusser et al. 1985, Sabin and Pisias 1996). Around 1,500 B.P. there was a small scale reversal in global climate resulting in a short-term relative warming (Heusser et al. 1980). Global precipitation trends are less commonly reconstructed, but precipitation seems to have remained more or less constant from 4,000 or 5,000 until 1,000 B.P., when a world-wide trend towards wetter conditions began (Heusser et al. 1980).

Imposed upon these general global late-Holocene trends described above are three even smaller events that were low in both amplitude and frequency. One is a short-term reversal to warm conditions which supposedly took place between A.D. 900 and A.D. 1350, which is referred to as the "Medieval Warm Period" (MWP), the "Little Climatic Optimum," or the "Medieval Optimum" (Crowley and Lowery 2000, Grove and Switsur 1994, Hughes and Diaz 1994, Jones et al. 1999, Luckman 1994, Millspaugh and Whitlock 1995, Meese et al.

1994). More recently, the overall late Holocene global cooling trend culminated in a period of greatest relative cold. This period of cooling is commonly referred to as the "Little Ice Age" or LIA, and was reached between 500 and 200 years ago (Bradley and Jones 1993, Graumlich and Brubaker 1986, Meese et al. 1994, Smith and Laroque 1996). It should be cautioned that the existence, nature, local expression, impact and utility of both the MWP and LIA are currently under debate in the literature (Hughes and Diaz 1994, Jones et al. 1999, Meese et al. 1994). A third and unnamed event has occurred in the past 100 to 200 years with yet another short-term reversal towards warmer conditions imposed on the general late Holocene cooling trend (Bradley and Jones 1993, Heusser et al. 1985). This recent warming trend is more widely acknowledged than the MWP and LIA as a truly global climatic trend.

Regional-scale climatic reconstructions presented for the Plateau over the late Holocene follow the generalized trends as described for the globe as a whole. Mountain glaciers in the Cascades on the western boundary of the Plateau retreated around 2,500 B.P., and re-advanced only around 900 to 1,000 B.P. (Ames 2000). Evidence from other sources such as cave spalling, erosion in alluvial fans, and freshwater mussel growth patterns agree with this evidence, pointing to a relatively warm and arid period in parts of the Plateau from around 2,500 to 1,000 B.P. (Chatters 1998).

Vegetation

Modern vegetation on the Southern Plateau is controlled by available moisture, and exhibits marked elevational zonation. Low elevations tend to be shrub steppe or mixed grass-shrub steppe with open forests restricted to higher elevations (Daubenmire and Daubenmire 1968, Daubenmire 1970).

Chatters (1998) has recently used palynological sources to produce a vegetation history for the Plateau region. At the end of the Pleistocene, vegetation characteristic of open woodland (Zone I in Figure 2.6, below) first established itself during the cool moist conditions directly following deglaciation. Around 10,000 B.P., a trend to warmer and drier conditions began. In response to this warming trend, vegetation converted first to a grassland (zone II in Figure 2.6) and then to open shrubland (zone III, Figure 2.6).

Around the time of the Mazama ash, the driest conditions in the record prevail (top of zone III), with vegetation characterized by sagebrush (*Artemesia*). By about 4,000 B.P., conditions become cooler and moister again (Nickmann and Leopold 1985). This mesic trend results in an increase in arboreal species (zone IV in Figure 2.7). Palynologists with a millennial-scale perspective interpret this transition to a mixture of grass-shrub steppe and pine-dominated forest vegetation at about 4,000 B.P. as the establishment of the basic modern vegetation pattern in the area (Dalan 1985a, 1985b; Mack et al. 1979; Whitlock and Bartlein 1997).

Others examine the regional vegetation history at finer temporal scale and note that the vegetation at 4,000 B.P. was only roughly equivalent to present patterns, since subalpine forest limits were actually lower. Forests were generally less open and more spatially extensive than today, indicating to many that the climate may have been moister and cooler than today (Chatters 1998, Mack et al. 1977, Mack et al. 1978, Mehringer 1985).

Around 2,000 B.P. conditions and spatial patterns changed with subalpine forests margins moving upslope, and other forests thinning, contracting and being invaded with grasses (Chatters, Mack et al. 1979, Mack et al. 1983). It could be said that 4,000 B.P. the general modern vegetation patterns were established, with 2,000 B.P. marking the establishment of the exact zones and spatial patterns seen in historic times (Chatters 1998). Many researchers also note a very recent brief high-frequency trend in the regional vegetation in which Chenopodiaceae increases in density and ubiquity at the expense of pine and grass, and this has been linked to the introduction of domestic herds and range grazing since the 1800s (Dalan 1985b, Davis et al. 1977). Additional information on vegetation history, along with the climate and fire histories, gives a regional context for understanding the archaeology of the study area. This information will be presented in the following chapters.

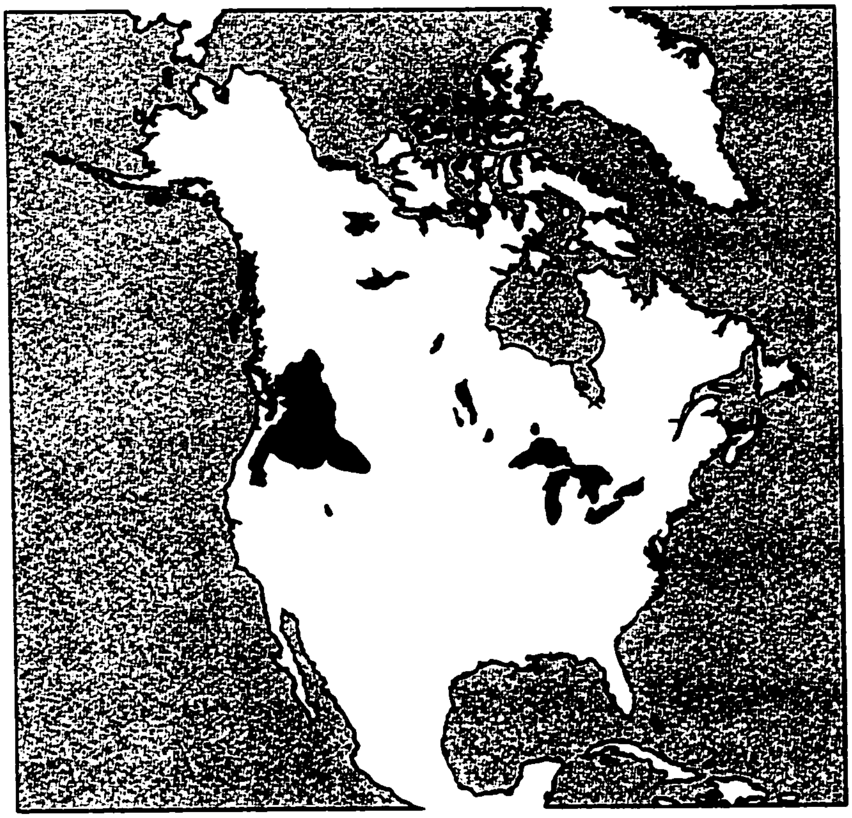


Figure 2.1. Location of the Plateau Culture Area
(Indicated By Black-Shaded Area) in North America
(from Walker 1998:iii)

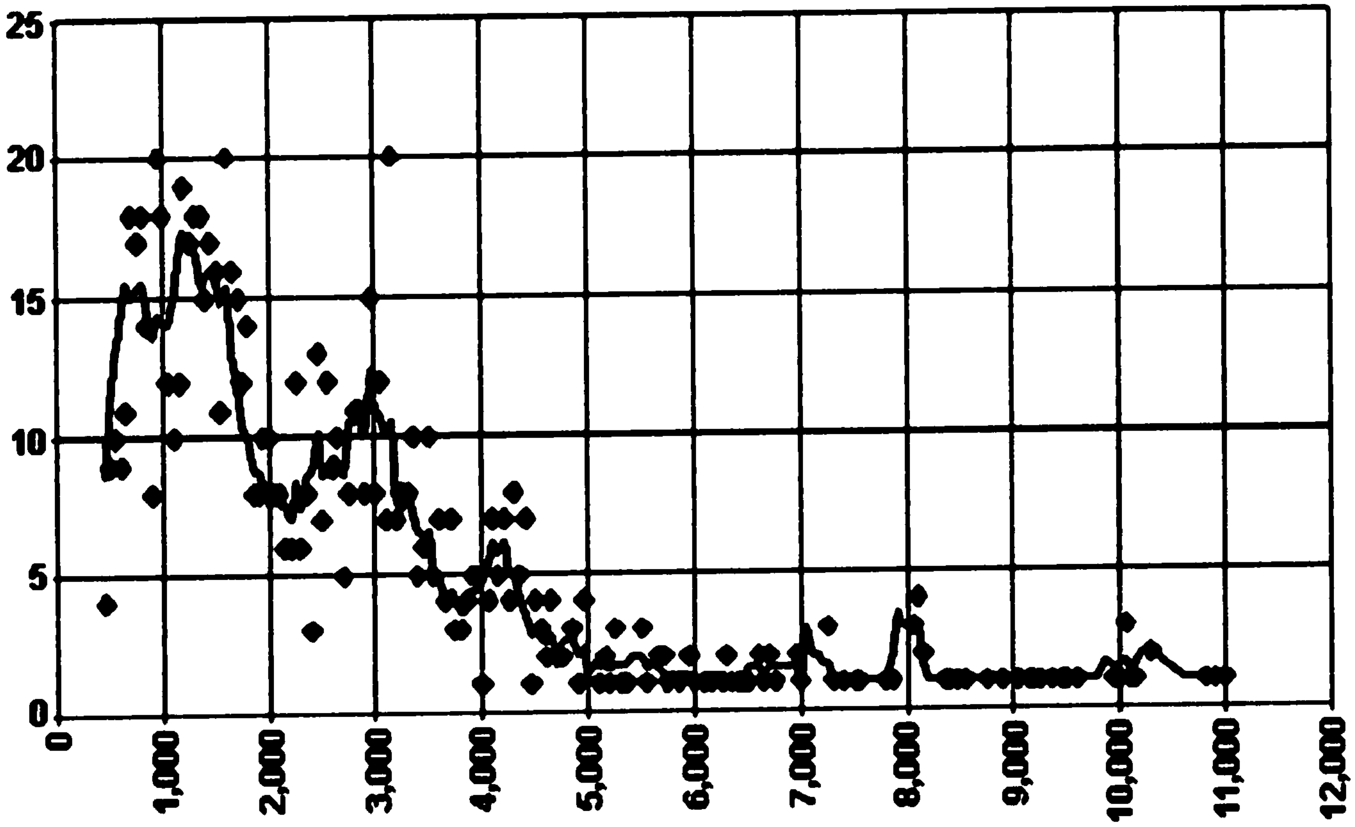


Figure 2.2. Ames' (2000:Figure 13) Plot of Abundance of Radiocarbon Samples Over Time*

*using a 50-year sampling interval

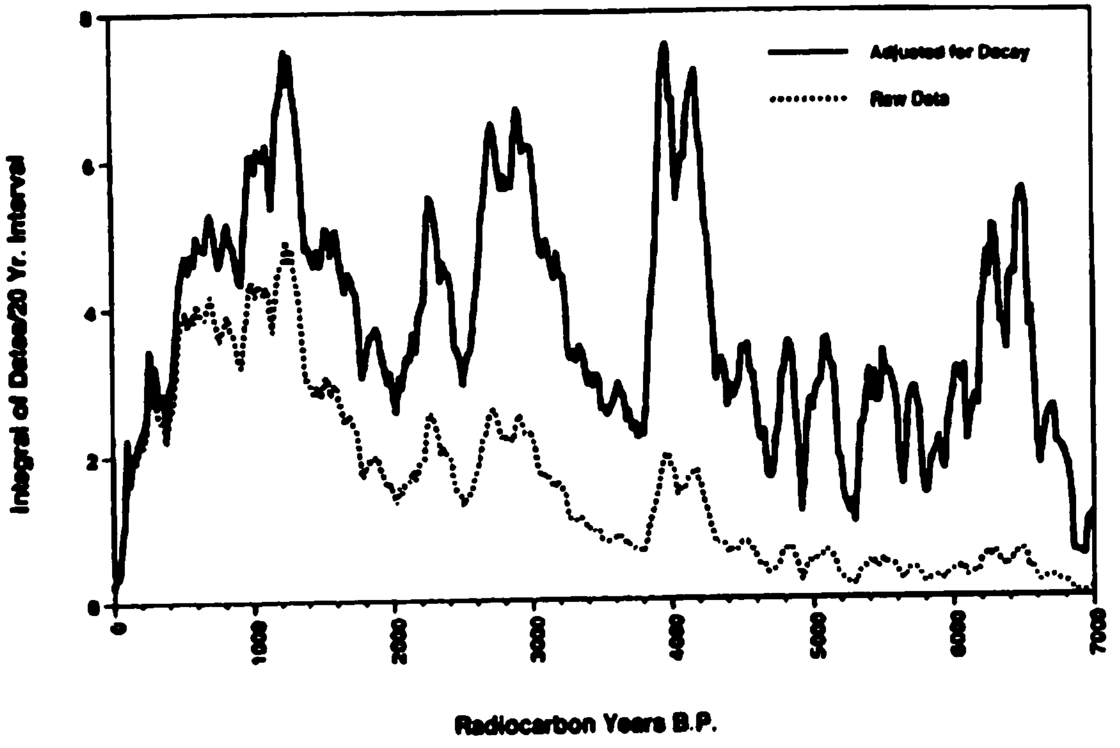


Figure 2.3. Chatter's (1995) Plot of Radiocarbon Samples Over Time for the Plateau*

*using a 20-year sampling interval. Dotted line represents Chatters' original counts of radiocarbon dates. Solid line is a reconstruction of the number of samples estimated to have originally existed (based on a complex mathematical algorithm detailed in Chatters 1995).

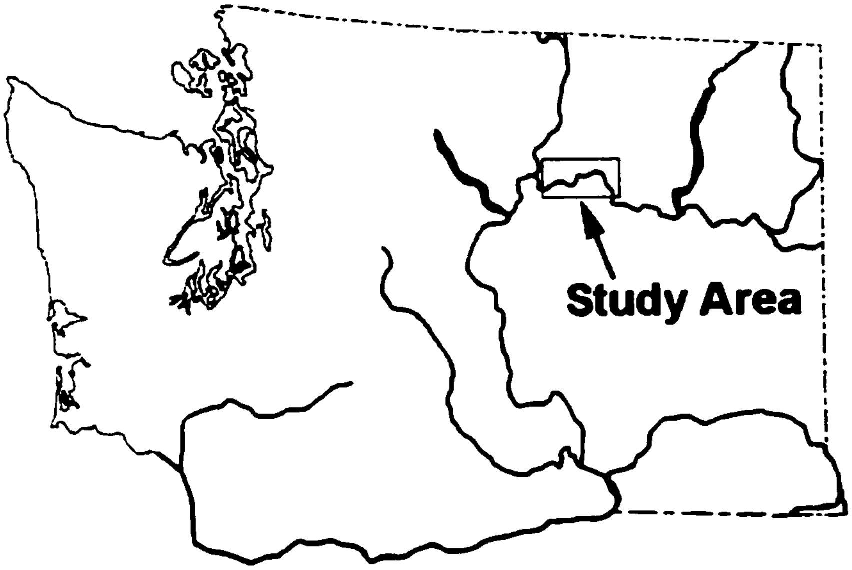


Figure 2.4. Location of Study Area
(Rufus Woods Lake Area, Washington State)

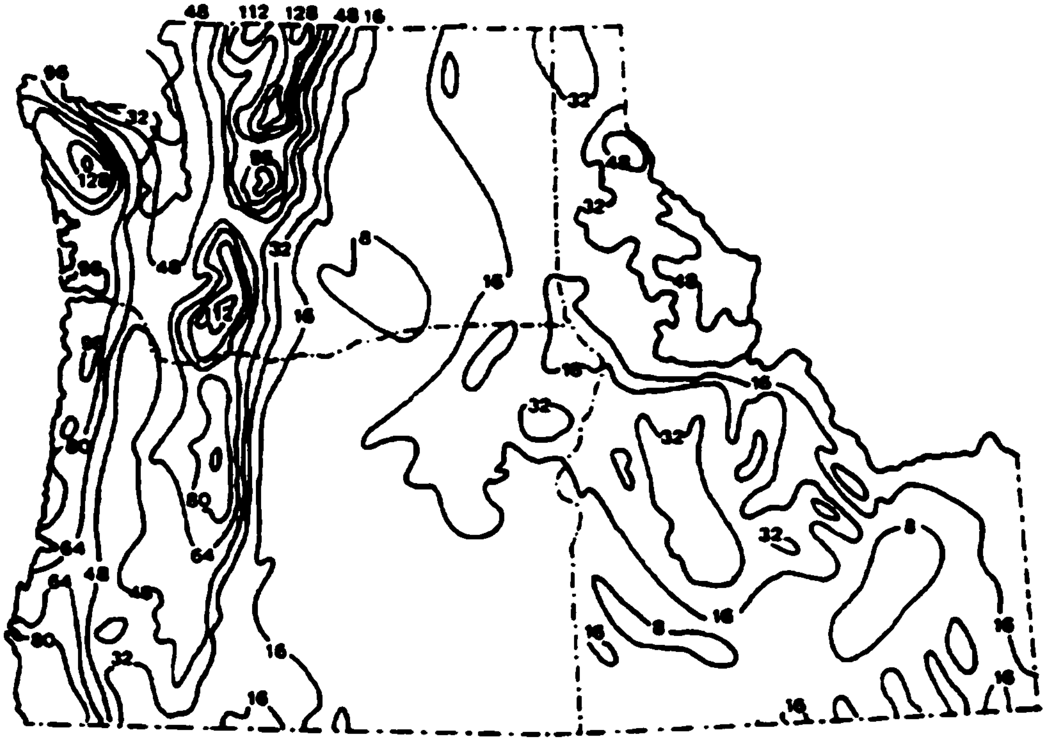


Figure 2.5. Precipitation* pattern in the Northwest (Ames 2000:Figure 3)

*in inches per year

Figure 2.6. Post-Pleistocene Pollen Diagram from Goose Lake, in the Study Area (adapted from Dalan 1985:117, 118).

* Dates from Nickmann and Leopold 1985

Chapter 3. Study Area

The Southern Plateau provides an appropriate place within which the potential impacts of hunter-gatherer groups on the landscape can be addressed. Additionally, the Southern Plateau has an existing demographic record that extends back seven thousand years at a 20- to 50-year resolution (Ames 2000, Chatters 1995). In terms of scale, however, the Plateau is too vast to securely reflect human action (Delcourt and Delcourt 1988). Within the Plateau, however, a much smaller area immediately surrounding the Rufus Woods Lake provides a more suitable record. Besides having a pre-existing fine-scale demographic record, archaeological data for this area were collected under a single large-scale CRM project, producing "what is probably the region's best, large modern [archaeological] data set" (Ames 2000).

Prehistoric Human Population Record

Campbell (1989) produced a population proxy for a relatively small area within the Southern Plateau, based on archaeological phenomena that were compiled on the necessary mesoscale (extralocal scale). Campbell's study area covers a roughly 5 kilometer-wide corridor along the Middle Columbia River of Washington State, from the Chief Joseph to Grand Coulee Dam (Figure 2.4). Since the construction of the Chief Joseph dam, the upstream portion of the river was converted to the reservoir referred to as Rufus Woods Lake or the Chief Joseph Reservoir (Campbell 1985, Ames et al. 1998). Rufus Woods Lake is located along the northern edge of the Columbia Basin, which is a relatively low-lying interior area of the Plateau, underlain by granitic batholiths and covered by a set of extensive basalt flows (Alt and Hyndman 1995). This general location is also referred to as the northern Columbia Plateau or the South-Central portion of the Plateau (Walker 1998).

Campbell (1989) produced a human demographic record which is decadal in scale. She used archaeological data from 77 site components (with 84 radiocarbon dates) in the study area to trace demographic changes that spanned the late prehistoric to early historic period along the corridor of the Columbia River from Chief Joseph Dam to Grand Coulee Dam. She used a series of several different proxy data sets to reconstruct prehistoric populations at 50-year intervals throughout the A.D. 950-1900 time period (Campbell 1989).

Many different phenomena in the archaeological record are related to population size. Archaeologists commonly use the number of sites or the area (m^2) of habitation as proxies for past population size (Campbell 1989, Ramenofsky 1987). In her study, Campbell (1989) used traditional measures of the number and area of occupations, but also included measures of the production of food waste and the production of features in her analysis. Examples of her proxy measure plots are given in Figures 3.1 and 3.2, which show the number of features and amount of animal bone wastes produced. These proxies, like those used by other archaeologists, are basically a measure of population size through quantification of human impact on the archaeological record itself; the higher the rate of production of archaeological phenomena, other things being equal, the greater the assumed associated population size.

Table 3.1 lists Campbell's (1989) data for six variables that she considered important: the number of components, the habitation area, the average #/m^2/yr of bone debris, the g/m^2/yr of bone debris, the g/m^2/yr of shell debris, and the number of features for each of her 50-year time intervals. These data were gleaned from site records for all recorded sites inhabited from A.D. 950 to 1900. These sites were documented primarily during reclamation projects relating to the construction of dams or draw-downs of reservoirs in the area. Because of this, there is a bias towards archaeological sites near the river, which tended to be winter village sites. Although the more ephemeral upland sites (such hunting camps, quarries, berry and root gathering camps) were not given as much attention during the reservoir projects, a large number of them are known and documented from the Rufus Woods Lake area. In fact, the areas away from the river in this area are better known archaeologically than the uplands in the rest of the Southern Plateau (Ames 1989).

Temporal control for Campbell's population surrogates was derived mainly from radiocarbon dating, with support from artifact seriations and the occasional presence of historic trade goods of known age. Campbell calibrated all radiocarbon dates, and found that this established a chronology that, even with the inherent uncertaintly of radiocarbon dating, produced a population proxy with a 50-year resolution.

Figure 3.1 and shows the occurrence of pit, hearth and oven features, while Figure 3.2 plots the production of bone (food) debris, as calculated by Campbell (1989). These graphs show relatively high population values early in the record, a drop around A.D. 1400, a slight increase in the 1800s and a final drop by A.D. 1900.

Confidence in Campbell's surrogate variables comes from her demonstration that the proxy indicators she used are in agreement with each other, and thus are measuring a single underlying variable – presumably population density via land use intensity. Table 3.2 lists the correlations between the six population surrogates used by Campbell (1989). These proxies, in general, were highly correlated with each other and with the composite population proxy constructed for this study. All measures except the production of shell debris were significantly (at the 0.05 level) and highly positively (*r* ranging from +0.489 to +0.909) correlated with the composite population index. Obviously, these variables are all measuring the same basic underlying phenomenon.

Additional support for Campbell's surrogates can be found in their agreement with other independent measures of population. Campbell's proxies compare favorably with the prehistoric population reconstructions given for the Plateau as a whole. The demographic reconstruction by Chatters (Figure 2.3; Chatters 1995 in Ames 2000) exhibits the same timing and variance as Campbell's data. Looking at just the past thousand years of Chatter's proxy, values start off high and decrease rapidly between 300 and 500 B.P. Populations partially recover, and drop again some 100 B.P. This is the same pattern seen in Campbell's plots. Ames' reconstruction (Figure 2.2) also documents the precipitous decline around 500 B.P., but his plot cannot be compared further because it ends by 300 or 400 B.P. (Ames 2000).

Further confirmation of the reliability of Campbell's paleodemographic work comes from its comparison to a shorter record of Plateau populations, derived from historic and ethnohistoric sources. Boyd (1985, 1990; Campbell 1989) documented two of the same events as seen in the Rufus Woods area. Boyd observed a partial population recovery in the early historic era, followed by a recent decline around A.D. 1850-1900. Because of the agreement between various measures of past population, Campbell's surrogates can be considered quantitative measures of prehistoric population, providing a solid base-line for interpreting the climate, vegetation, and fire-frequency records to be generated in the current study.

For the current study, information from all of Campbell's surrogates was combined to form a single composite index of prehistoric population. Each of the six proxies was normalized into a z-score in order to remove bias and make the measurements comparable to each other. The variables were averaged together for each 50-year period once each observation was normalized.

To standardize a particular variable, the mean value and standard deviation were first computed (Table 3.1). For example, the average number of components for all 50-year periods was 19.05, with a standard deviation of 5.68. For each interval, the average was subtracted from the actual observed number of components, and the result was divided by the standard deviation, as shown by the computations in Table 3.3. For the A.D. 1875-1925 interval, for example, 8 components were observed. This was converted to a normal score by computing (8-19.05)/5.68, producing a normalized value of -1.95. Later, all normalized scores from A.D. 1875-1925, one from each proxy variable, were averaged together and this was used as composite index (Table 3.4). This was done for each 50-year interval, in turn (Table 3.4, Appendix B).

The resulting composite population proxy is plotted in Figure 3.3. The composite population index shows a high density of people early in the record (A.D. 950-1400), a precipitous drop sometime after A.D. 1400, a partial population recovery, and then a final decline during historic times. This composite index shows the same trends as the individual proxies (Figures 3.1 and 3.2), and also upholds Campbell's conclusions that a drastic population around the time of Contact.

Campbell (1989) went further to conclue that the population decline that she documented was due to external factors, specifically introduced diseases. Statistical analysis of the composite index does demonstrate that human population values are not historically constrained, that they are not being controlled by intrinsic factors. This can be shown by correlating population size, at any given time, to the size of the population 50, 100, 150, or 200 years in the past. Table 3.5 lists the correlations between population size and past populations, with lags of one to ten intervals (50 to 500 years) introduced into the correlation model. When examined for autocorrelations (Table 3.5), the population index shows a strong dependence on values of itself one time interval (50 years) in the past. Population over this time span in the Rufus Woods Area, however, is not highly correlated with itself over longer time intervals. This indicates that population sizes are not highly constrained by demographic events in the distant past, and some external factor is influencing the system. Whether this external factor is disease, as hypothesized by Campbell (1989), cannot be addressed by the current analysis.

Paleoeconomic Information

Although the size of the population in this area over the past thousand years is a critical variable, the resource procurement activities of those people are important as well. Some information can be gained on lifeways and economies from ethnographic and historic records. Written records for this area are of limited utility, however, since the historical records do not extend far back in time; the first face-to-face contact between Native American groups and European-Americans in this area in occurred during the Lewis and Clark expedition of 1805. The number of European-Americans (and written records) in this area remained low until the late 1850s, and it was not until after 1900 that the first ethnographic work began.

The seminal ethnographic account of Plateau peoples is that done by Ray in 1932, supplemented later by work published by Spier in 1939. These ethnographies indicate that the study area was occupied by Interior or "Middle-Columbia-River" Salishan speakers practicing a central-based "intensive" subsistence system, relying on the collection of plant foods and game with a focus on anadromous fish (salmon). These people spent the winter months in permanent semi-subterranean dwellings in villages located in the floodplain of the river. During summer months, groups would fission and move around the landscape after plant and game resources, using more mobile mat lodges as shelter.

Prehistoric data from this area is mainly derived from cultural resource management projects that have been carried out as part of the hydroelectric and irrigation projects along this part of the Columbia River Basin, mainly between the 1940s and 1980s (Ames 2000, Campbell 1989). These projects and their data have resulted in the following narrative, which is a consensus overview of this area's human land use.

Throughout the prehistoric era, the area that now lies along the Columbia River between the Chief Joseph and Grand Coulee dams was populated by people practicing a hunting and gathering way of life. In the early and middle Holocene (approximately 8,000 to 2,000 B.P.) the people inhabiting this area practiced an "extensive", "wandering" form of hunter-gatherer life (Leeds et al. 1985). That is, in the warm dry Altithermal period directly preceding the focus of this study, the people in the study area were involved in a generalized strategy in which a wide variety of low-, medium-, and high-ranked resources such as small game, roots, shellfish, and seeds were collected as groups of foragers moved often across the landscape. Culture-historical units that correspond to or fall into this period include the Kartar, Hudnut, Vantage and Quilomene Bar Phases (although these have different phase names in other local areas of the Plateau, as well as having been given new "synthetic" names in recently published overviews of Plateau prehistory)(Leeds et al. 1985; Chatters 1989, 1995; Ames

2000; Ames et al. 1989). The consensus opinion among archaeologists is that this span of time represents a period of very low population density in the Columbia Basin as a whole (Ames 2000, Chatters 1995, Leeds et al. 1985).

During this period, 8,000 to 2,000 B.P., groups were very mobile. People did not stay long in any one place, nor did they return year after year to the same locations. There are few capital investments made in archaeological sites during this time. Storage pits, hopper mortars, substantial habitation structures and large aggregations of families does not occur in this area until later.

Human use of the area shifts focus at around 2,000 B.P. to being a centrally-based system in which people occupied villages near the Columbia River for part of the year, and spent the rest of the time moving across the landscape. Again, as during the previous six thousand years, people used a wide variety of low-, medium-, and high-ranked resources. Although taking the same range of resources, the people of this period were more numerous and hence put more pressure on the resources being taken. Also, congregations of populations in one area (winter villages) resulted in a more focused exploitation of firewood in one place over one particular season. These patterns are associated with the Early and Middle Cayuse Phases.

This period of time is assumed to have higher human population density than the period before it (Leeds et al. 1985). Semi-subterranean pit house structures are constructed and maintained, to be revisited year after year. Storage pits, hopper mortars and other permanent features become common as foods are harvested in bulk and preserved for later use (Chatters 1995). The later part of this time period witnesses an average increase in the size of structures, many of them presumed to house multiple families (Ames et al. 1989). It is also during this period that the bow and arrow are introduced into the region.

From 350 to 150 years ago, corresponding in time to what is referred to as the Late Cayuse Phase, subsistence and land use differed from these earlier patterns. Starting about 350 years ago, native peoples began to restrict the range of resources they were taking. Instead of focusing on a wide range of low-, medium-, and high-ranked resources, people of this time period focused primarily on a single high-ranked resource -- salmon.

A few intrusive land use behaviors began during this period, with new resources and practices introduced through direct and indirect contact with non-native peoples. Although the impact of European-American behaviors was not great, by A.D. 1730, domestic horses were introduced by native peoples, beginning the practice of keeping grazing animals (Campbell 1989, Davis et al. 1977). The early 1800s (approximately A.D. 1811 to 1850) brought a brief period of trapping for the fur trade.

Land use changed again around 150 years ago with the introduction of European-American land use practices and European-American populations. By the 1850s and 1860s the area was inundated with both White Settlers and with many of their land use behaviors such as mining, logging, and the introduction of large numbers of sheep and cattle.

Modern Vegetation

As with the greater region, vegetation in the study area is controlled by available moisture, which is determined by the climatic balance between precipitation and evaporation. Within the study area, available moisture and the resulting plant communities are largely mediated by elevation (Chatters 1998, Leeds et al. 1985). Large areas in the lower elevations are covered by shrub steppe composed primarily of big sagebrush (*Artemesia tridentata*) and cheat grass (*Bromus tectorum*), an introduced species (Leeds et al. 1985). This is an extremely recent plant association, and replaced the similar established historically recorded shrub steppe communities composed of sagebrush (*Artemisia* spp.) and a variety of native bunch-grass species (mostly *Festuca idahoensis* or *Agrophyron spicatum*, with some *Stipa comata*, *Stipa thurberiana*, *Poa cusickii* or *Sitanion hystrix*)(Leeds et al. 1985).

Areas of shrub steppe cover the slopes leading down to the Columbia River from the north and south (river right and river left), as well as the flat lying areas directly above the slopes of the river valley (Zones I, IIR, IIL and IIIL in Figure 3.4, below)(Dalan 1985a, Daubenmire 1970, Daubenmire and Daubenmire 1968, Chatters 1998, Franklin and Dyrness 1973, Leeds et al. 1985).

Although this grass-sage community accounts for most of the acreage in the areas close to the Columbia River, smaller areas containing slightly different plant associations exist within this broader vegetation zone, allowing for plants like bitterbrush (*Purshia*), and rabbit brush (*Chyrsothamnus)* to become locally dominant in patches. Small freshwater lakes dispersed throughout the grass-shrub steppe, for example, support a small community of fringing aquatic vegetation (such as *Typha*, *Juncus*, and *Carex*) and some of them support a few arboreal individuals (such as *Salix* and *Betula*).

The shrub steppe zone is also transected by streams running through narrow canyons that support a mixture of mesic trees and shrubs such as alder (*Alnus* spp.), birch (*Betula* spp.), and poplar (*Populus* spp.). The exact nature of the shrub steppe is also modified the nature of the substrate, with the steeply sloping basaltic lithosols directly south of the river (in Zone IIL) supporting relatively more economically important root crops such as balsamroot (*Balsamorhiza saggitata*), bitter-root (*Lewisia rediviva*) and lomation (*Lomatium* spp.) than the slope on the north side of the Columbia River.

North of the Columbia River, yet still within the study area, lies a higher elevation area known as the "Okanogan highlands" that supports a more enclosed type of vegetation -- an open coniferous forest, dominated by ponderosa pine (*Pinus ponderosa*) with an understory similar to the shrub steppe, and dotted with a scatter of small patches of hardwoods/deciduous trees (Zone IIIR in figure 2.4), changing to a mixed Douglas fir (*Pseudotsuga menzeseii*) and grand fir (*Abies grandis*) forest at the highest elevations along the boundaries of the study area (Zone IV in Figure 3.4).

Vegetation History

There are two published pollen diagrams from this area, given in Figures 2.6, 3.6, and 3.7. These are from Goose and Rex Grange Lakes, both in

Douglas County, WA (Figure 3.5 is an area map showing the location of these lakes and Appendix C has further location information). The pollen diagram from Goose Lake (Figure 2.6) covers the entire Holocene, and has radiocarbon and tephrochronlogic temporal controls (Nickmann and Leopold 1985). The second lake diagram from Rex Grange Lake (split into Figures 3.6 and 3.7), focuses on recent times and is undated (Dalan 1985b).

These two studies show that the vegetation change during the Holocene in the study area followed the same major path of vegetation change in the intermontane region as a whole (presented in Chapter 2). The transition from the Pleistocene to the Holocene (from Zones III to IV in Figure 2.6) is marked by a sharp decrease in pine and birch, with a sharp increase in grass, probably indicating the onset of warmer, drier conditions. From 7,800 to 6,700 B.P., (Zone V in Figure 2.6) grasses decrease while sagebrush and haploxylon pines increase; this has been interpreted as possible evidence of increased available moisture in the area (Nickmann and Leopold 1985). The post-Mazama period is treated as a single zone. Within the post-Mazama period, sagebrush increases dramatically directly after the deposition of the Mazama ash. Later, grasses and chenopods increase at the expense of the sagebrush. Dalan (1985a) examines the upper zone in more detail (Figures 3.6 and 3.7), and gives a more detailed stratigraphic record of changes in grass, sagebrush, and chenopods in the upper 19 cm of this core.

The detailed record of the upper 19 cm of sediment from Goose Lake by Dalan (1985a) suffers because it has no associated radiocarbon dates or other chronological control and so cannot be used in the current study. The longer pollen record from Goose Lake (Dalan 1985a, Nickmann and Leopold 1985), is also inadequate for the purposes of this dissertation because it allows vegetation to be viewed on a millennial, or at best centennial time-scale. In the existing published sequence, the post-Mazama record consists of a series of 18 samples. The average amount of time represented by the interval between samples is 372 years. Considering the resolution, the Goose Lake pollen record cannot be meaningfully compared to the paleodemographic or other records used in the current research (see Dalan 1993, Linse 1993, and Stein 1993 for similar scale problems). To remedy this situation, I created a new pollen record, matched to the desired scale and period of interest. This new pollen diagram is presented and discussed in Chapter 7.

Climate History

Although the review of pollen data, above, indicates some major climatic changes in the study area, these cannot be used as a proxy for climate for two reasons. First, as detailed above, the record is insufficient in temporal resolution. Second, the use of pollen-derived climate estimates for this study would be inherently circular (). If pollen is used as a proxy for vegetation, and the resulting vegetation history is used in turn as a proxy climate record, then it is necessarily the case that the vegetation and climate records created in this manner will be based on the same underlying dataset. It would not be mathematically or logically valid to use a pollen-derived climate estimation to explain a change in vegetation that is derived from the same pollen dataset; a truly independent line of climatic evidence is required.

Previous work, however, includes a master's thesis on a climate proxy from two of the area lakes. In this work, Forbes (1987) presents an oxygen isotope record from carbonates of Goose and Duley lakes. The resulting isotope diagrams are given in Figures 3.8 and 3.9. Forbes determined that isotope records from these lakes were tracking increases and decreases in available moisture, and were sensitive to climate changes on a mesoscale. Unfortunately, Forbes' records span the entire post-Pleistocene era and are sampled at approximately 140-200 year intervals making his results inappropriate for comparison to the established paleodemographic record as well. Because of this, a new set of oxygen isotope assays were run and a new climate proxy for the study area is presented in Chapter 6.

Fire History

There are no existing prehistoric fire history records in the study area itself, although there are some limited sources of historic information. In historic times (approximately A.D. 1890 to 1970), fires were suppressed (Dell 1976). This caused deadwood and similar fuels to build up on the landscape, allowing for large, intense and destructive fires to potentially occur. Before fire suppression, it seems that fires in the arid inland Northwest were relatively common. Studies of fire scars in standing forests and stumps show that ponderosa pine forests in eastern Oregon and Washington had a natural fire frequency of between 6 (Soeriaatmadja 1966) and 47 (Weaver 1959, 1961,

1967) years, depending on elevation. Fire seems to have been a frequent, naturally recurring disturbance that kept vegetation in the region in dynamic equilibrium.

The importance of fire in this area was re-discovered in the late 1960s and early 1970s, and the study area, in particular, was a focus for research and a new plan for using prescribed burns to better manage the area (Martin et al. 1977). Research affirmed that fire is an important factor determining the composition and areal extent of vegetation types, especially in a semi-arid area such as this. Although climate and elevation are major determinants of the spatial boundaries and composition of vegetation zones found in the study area, the size and frequency of fires also control the extent and openness of wooded versus grassy acreage.

Small fires have differential effects on the plant species in the study area. Small fires tend to promote the growth of ponderosa pine, a climax species, at the expense of less fire tolerant species such spruce, firs, hemlock, and sagebrush, which attempt to invade the understory of the ponderosa pine woodlands (Martin et al. 1977, Rauw 1980). Fire tends to open the shrub steppe by killing woody species like sagebrush and promoting the resprouting of native bunchgrasses, providing a greater volume and quality of grazing materials for domestic and wild animals (Daubenmire 1970, Martin et al. 1977). Fire also causes nearly-dormant shrubs to resprout, so that more forage is available to herbivores after a fire. Berry crop production is promoted by the increased amount of available nitrogen in the soil (Dell 1976). Burning also serves to kill plant parasites (like dwarf mistletoe)(Martin et al. 1977) and reduce the fuel load on the landscape, which results in lower danger of truly large intensely destructive fires (Cairns 1980, Pyne 1982). In this area, then, fire has many uses and impacts on both the vegetation and the animals that rely on this vegetation. Important to this study is the impact that fire and fire frequency can have on human economies.

Area-specific Predictions

Based on knowledge of long-term processes that have been documented elsewhere around the globe (Chapter 1) and the information presented for the study area and surrounding region in this chapter, specific expectations for past events can be generated for the Rufus Woods area.

Native peoples were ethnographically known to burn the vegetation, resulting in the increase of grasses, decrease of sagebrush, and maintenance of open ponderosa pine forests (suppressing growth of invading, moisture-loving, arboreal species such as fir and hemlock). In other parts of the world, prehistoric anthropogenic fire is identified from increased deposition of charcoal into area lakes, with concomitant increases in early-successional plant pollen. Such disturbance signals are strongest when human population is dense or when people abruptly increase in number during episodes of colonization. In eastern Washington, one would expect there to be evidence of prehistoric burning by native people until the historic suppression of fire about 100 years ago. The charcoal record, then, should show high influxes of charcoal from 1,000 to 100 years ago, followed by a decrease at the end of the record. Since fluctuations in population size have been documented for the past thousand years, times of increased population should correlate with or precede times of relative abundance in charcoal, and times of lowered population should correlate with or precede times of relative scarcity of charcoal in the record. If human action is driving this relationship, then charcoal should never be seen leading population in a statistically significant relationship.

Given the past and present vegetation, and what is known about the impact of fire in this area, specific predictions can also be made for the response of pollen to fluctuations in the population proxies. Times of greater population should correlate or directly precede increases in grasses and herbaceous members of the sunflower family (Asteraceae). Increases in grasses and other herbaceous taxa should correlate with decreases in sagebrush and arboreal colonizers such as alder, fir, and Douglas fir. It is expected that this area will provide a clear signal of anthropogenic fire and vegetation change, and that these changes will vary directly with population size.

Fire frequency is expected to decrease starting 100 years ago, due to the imposition of fire suppression around this time across the entire Northwest. Other effects of imposing European-American land management practices are more difficult to anticipate. On the one hand, decreases in fire should result in the increase in trees and shrubs on the landscape. On the other hand, the introduction of large numbers of domestic herbivores should result in the relative decrease of trees and shrubs as herbaceous "disturbance" taxa such as grasses, composits, and chenopods are favored by increased grazing. It is hard to predict, given these two opposing forces, if ruderal taxa should increase or decrease at the end of the pollen record. Palynological research from other areas of eastern Washington, however, indicate that grazing pressure should have the greatest effect, resulting in increases in nonarboreal pollen (especially chenopods) and decreases of all arboreal types (Davis et al. 1977).

What of the relative effect of humans as compared to climate? Given that past research has not identified significant climatic responses in this area's vegetation over the past thousand years, climate is not predicted to be a significant factor in determining human activity, vegetation, erosion, or fire frequency.

The data that will be generated by this study will be used to address the predictions listed above, but can also be used to address the adequacy of existing protocols and the constraints imposed by the history of the landscape system itself. If human population is positively correlated with charcoal influx in the absence of climatic change, the current practice is to deem this to be clear evidence of anthropogenic change. What of the contributions of other factors, however? What about factors such as prior fires or vegetation type? Can a simple correlation between human action and fire, in the absence of a temperature or precipitation change, be attributed to human impact? How can competing factors be examined, especially when intertwined?

The strengths of the present study area is that it can statistically evaluate the relative contribution of humans and the interdependence of the human population variable with other variables since earlier paleodemographic work has provided a metric measure of population taken at evenly spaced intervals throughout the period of interest. The proxy population measurements, with their even temporal spacing, allow for time series analysis to be conducted and for leads and lags to be entered into statistical models comparing population with other variables like plant populations and fire. Instead of merely correlating events, relative contributions and temporal relationships can be established to more securely identify potential causal connections between the various processes operating long-term on the landscape. In this way, previous models that employ anecdotal data about human presence and activities can be evaluated. If the information from eastern Washington indicates the presence of an anthropogenic signal given current standards, but this signal is not clear given the more strenuous statistical tests and models proposed, then this calls into question the validity of our currently popular method of identifying anthropogenic change in prehistoric records.

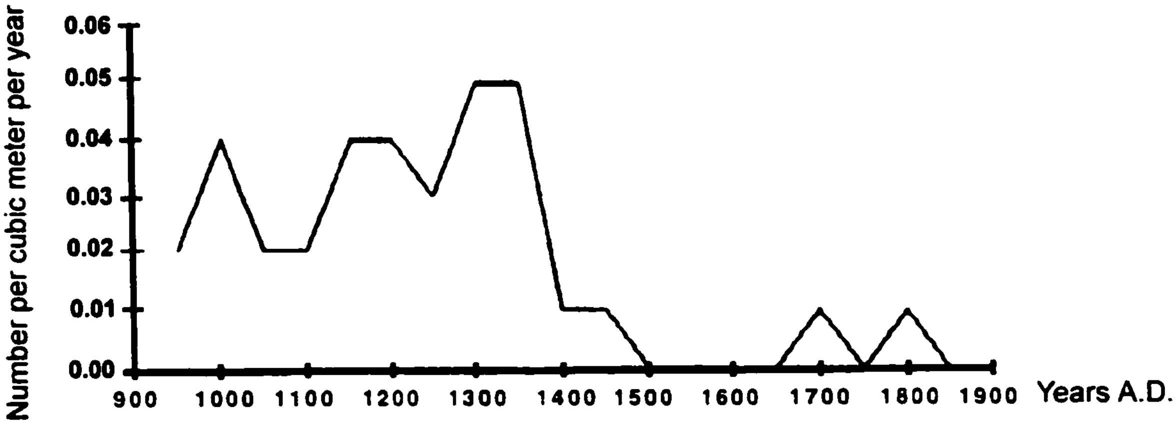


Figure 3.1. The Rate of Occurrence of Features per 50-year Interval, Rufus Woods Lake Study Area (Adapted From Campbell 1989:172)

Figure 3.2 The Rate of Deposition of Bone Debris (Food Waste) per 50-year Interval, Rufus Woods Lake Study Area (Adapted From Campbell 1989:174)

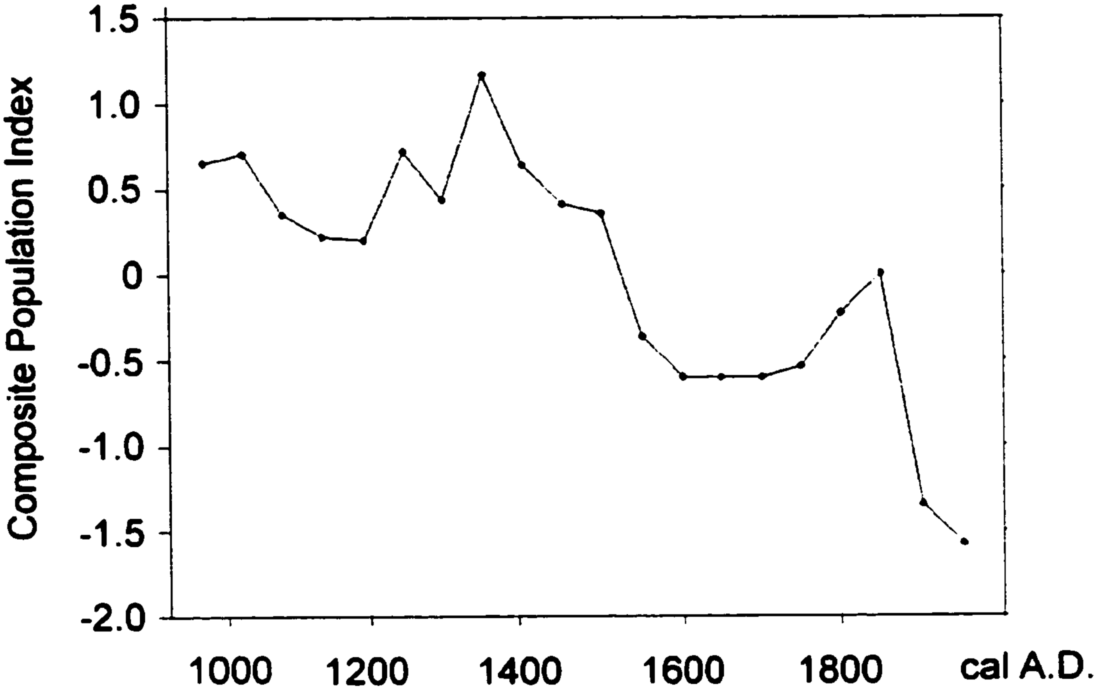


Figure 3.3. Composite Population Index from Study Area (calculated from data in Campbell 1989)

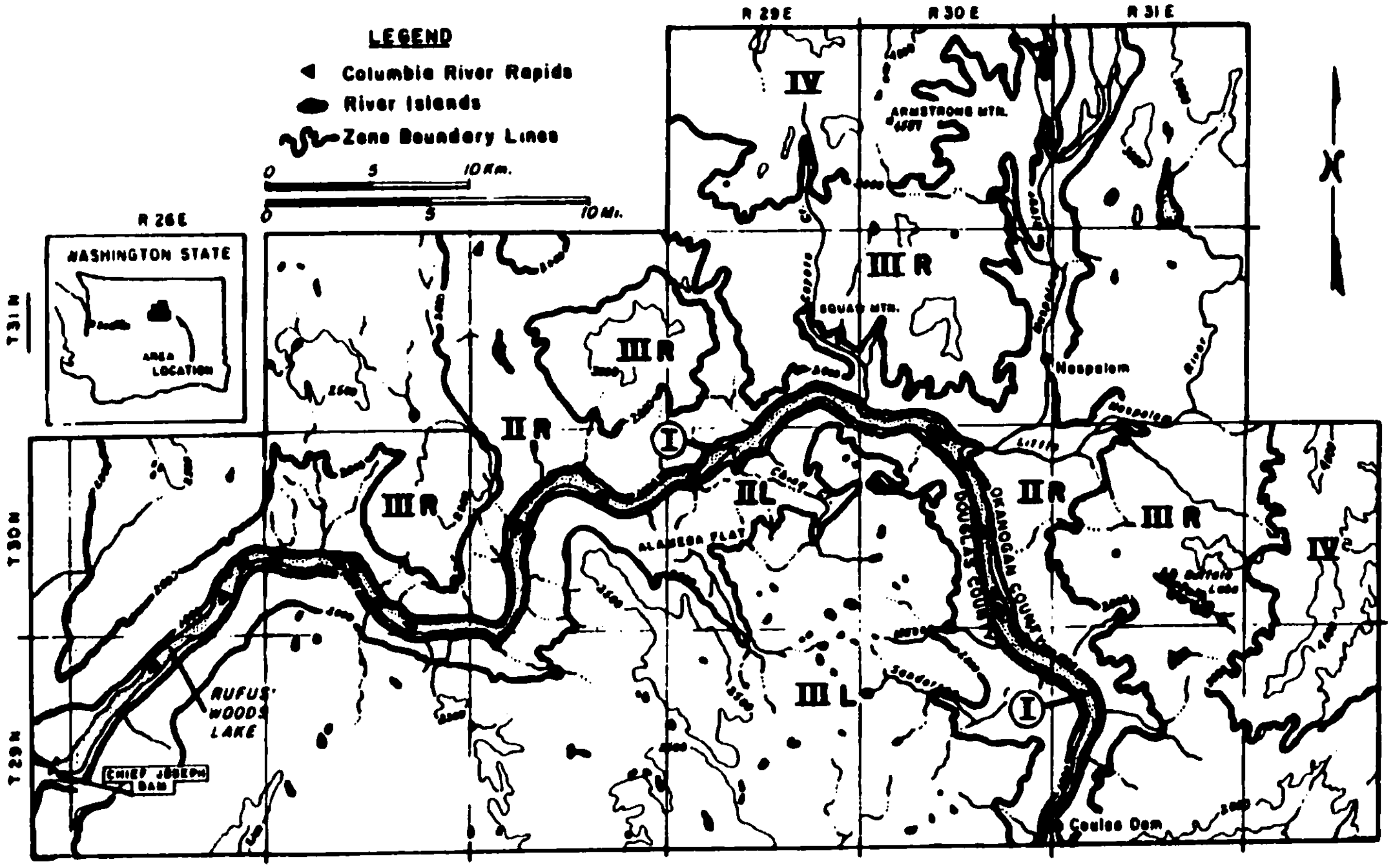


Figure 3.4. Vegetation zones in the Rufus Woods Lake Study Area (modified from Dalan 1985 and Leeds et al. 1985)

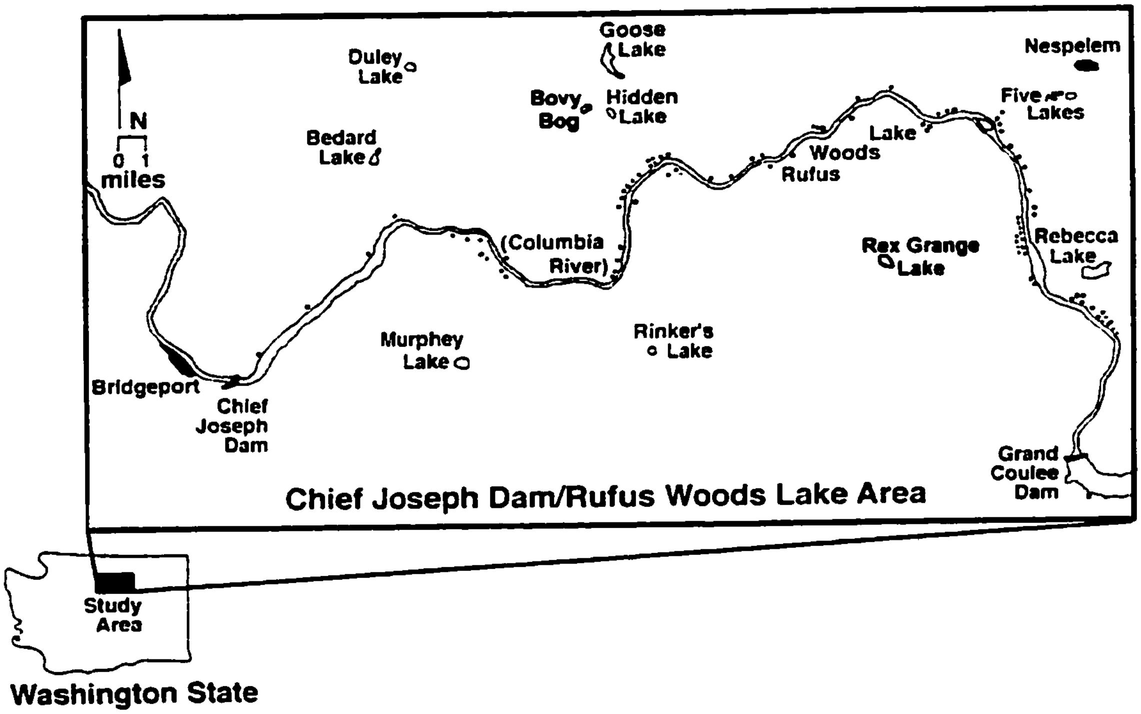


Figure 3.5. Location of Study Area, Showing the Basins Discussed in the Text

(Modern towns, modern dams, and winter villages are shown for reference)
(Dots indicate locations of archaeologically-known winter village sites)

(adapted from Campbell 1985, with information from Dalan 1985b, Forbes 1987, Nickmann and Leopold 1985, USGS 7.5' Belvedere Quad 1990, USGS 7.5' Boot Mountain Quad 1990, USGS 7.5' Bridgeport Point Quad 1990, USGS 7.5' Joe Lake Quad 1990, USGS 7.5' Sanderson Creek Quad 1990, USGS 7.5' Stubblefield Point Quad 1990, USGS 7.5' Trefrey Canyon Quad 1990)

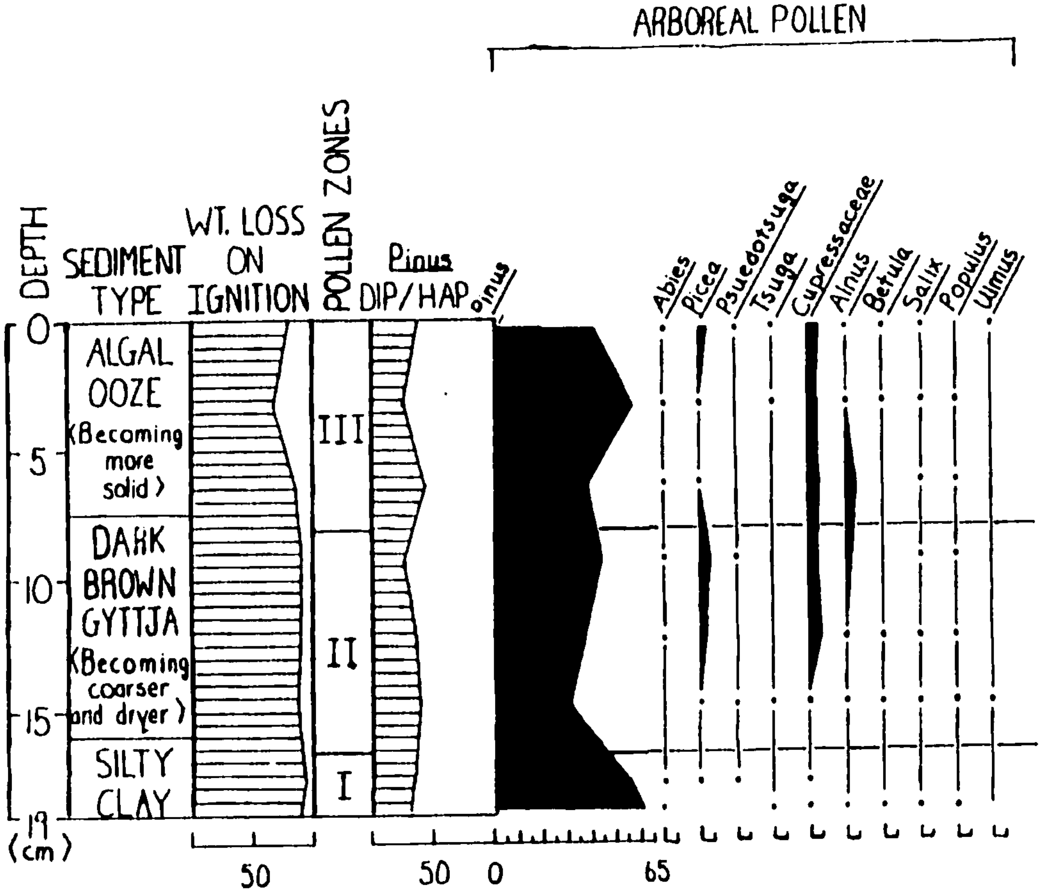


Figure 3.6. Arboreal pollen, upper 19 cm of Rex Grange Lake (Dalan 1985b:524)

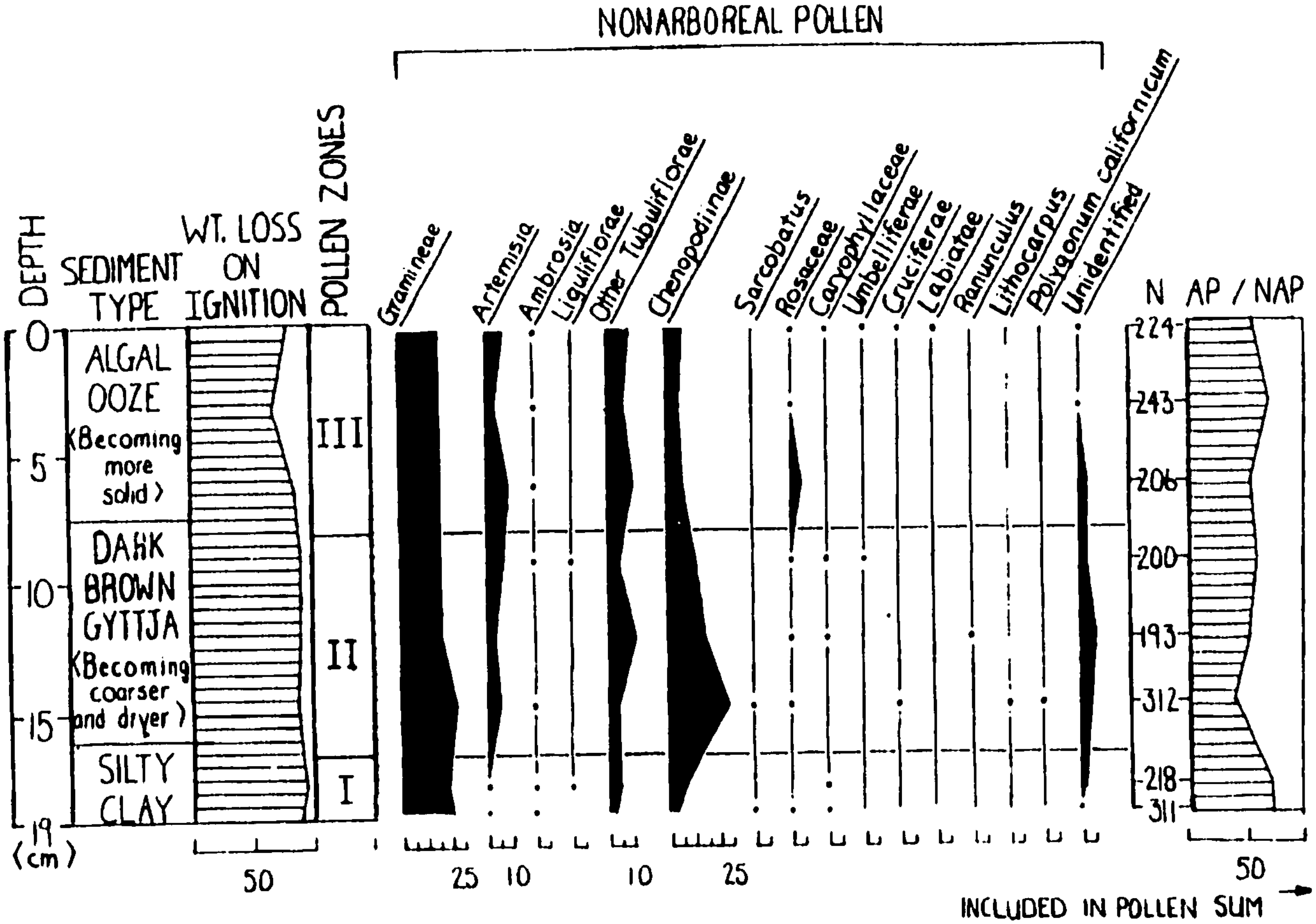


Figure 3.7. Nonarboreal pollen, upper 19 cm of Rex Grange Lake (Dalan 1985b:525)

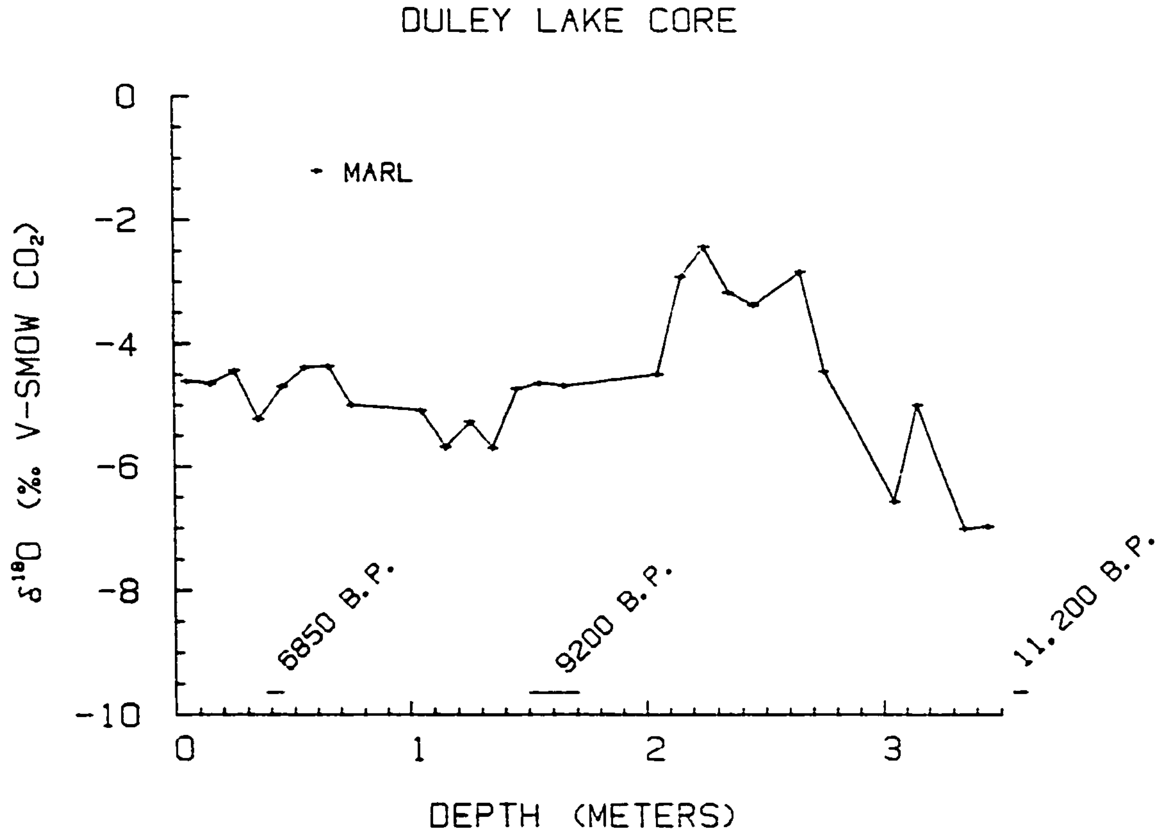


Figure 3.8. Post-Pleistocene Oxygen Isotope Diagram from Duley Lake, in the Study Area (Forbes 1987:62)

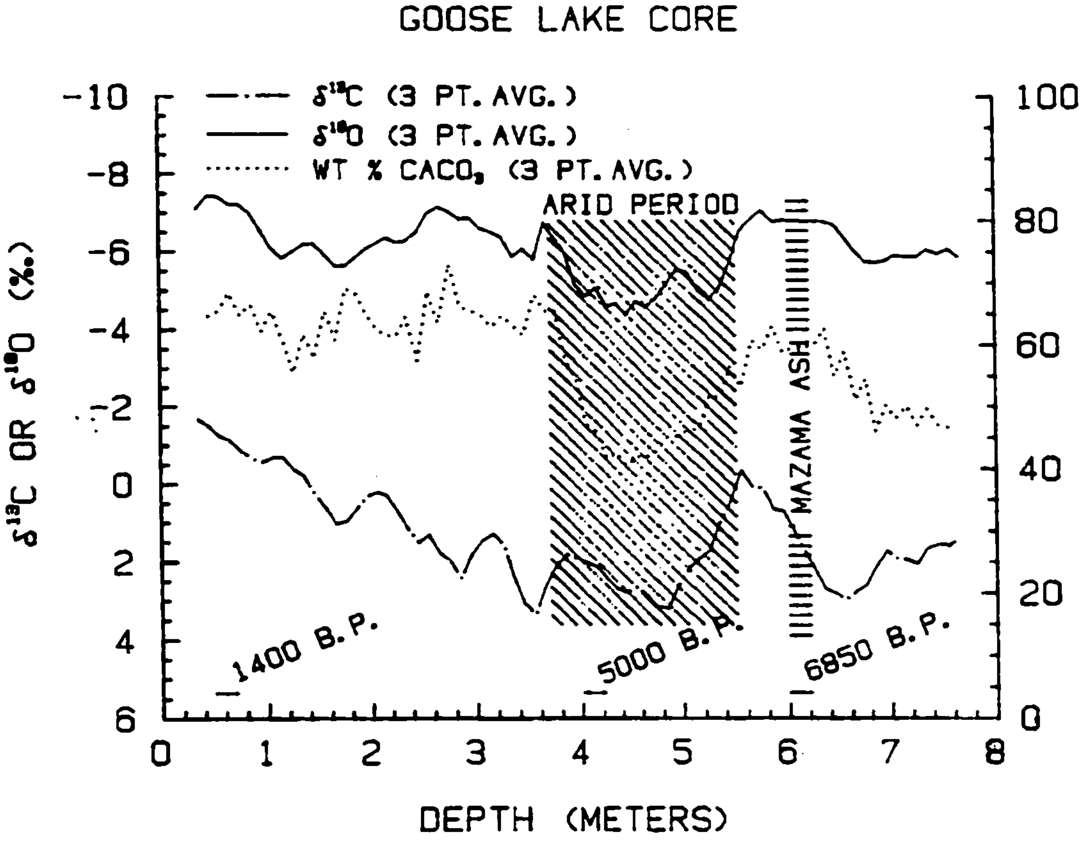


Figure 3.9. Post-Pleistocene Oxygen Isotope Diagram from Goose Lake, in the Study Area (Forbes 1987:90)

Table 3.1. Paleodemographic Record -- Population Surrogates Used

Temporal Interval cal A.D.	Interval Midpoint cal A.D.	# of Comp- onents	Total Area m^2	Average Bone #/m^2/yr	Average Bone g/m^2/yr	Average Shell g/m^2/yr	Average Features #/m^2/yr
1875-1925	1900	8.00	11202.00	71.19	13.49	0.06	0.00
1825-1875	1850	9.00	30402.00	77.26	14.56	0.70	0.00
1775-1825	1800	13.00	37902.00	122.71	39.31	50.66	0.01
1725-1775	1750	17.00	47239.00	104.57	38.46	32.22	0.00
1675-1725	1700	14.00	42729.00	66.93	32.55	24.31	0.01
1625-1675	1650	17.00	57903.00	62.07	21.46	18.32	0.00
1575-1625	1600	17.00	57903.00	62.07	21.46	18.32	0.00
1525-1575	1550	17.00	57903.00	62.07	21.46	18.32	0.00
1475-1525	1500	18.00	61975.00	132.27	47.31	3.13	0.00
1425-1475	1450	26.00	76111.00	159.49	49.91	14.93	0.01
1375-1425	1400	20.00	66404.00	237.79	53.47	18.63	0.01
1325-1375	1350	22.00	49790.00	207.44	54.06	20.25	0.05
1275-1325	1300	27.00	79655.00	234.71	57.87	21.31	0.05
1225-1275	1250	23.00	74609.00	155.53	37.92	21.31	0.03
1175-1225	1200	22.00	75014.00	185.63	54.12	21.31	0.04
1125-1175	1150	18.00	56662.00	148.35	49.31	14.93	0.04
1075-1125	1110	18.00	53020.00	130.60	86.60	14.93	0.02
1025-1075	1050	21.00	55732.00	153.05	87.12	11.80	0.02
975-1025	1000	23.00	64324.00	196.43	77.76	10.73	0.04
925-975	950	31.00	101437.00	129.08	43.72	13.03	0.02
		$\bar{x}$ =19.05	$\bar{x}$=57895.80	$\bar{x}$=134.96	$\bar{x}$=45.10	$\bar{x}$ =17.46	$\bar{x}$ =0.02
		s_x = 5.68	s_x = 19438.24	s_x = 57.47	s_x = 21.63	s_x = 11.07	s_x = 0.02

Data are taken from Campbell 1989:166
Interval midpoints, averages, and standard deviations added later

Table 3.2. Correlation Matrix for Campbell's Population Surrogates

	# Components	Area (m^2)	Bone (#/m^2/yr)	Bone (g/m^2/yr)	Shell (g/m^2/yr)	Features (#/m^2/yr)	Composite Population Index	
# Components	1.00	.932	.632	.525	.057	.577	.632	*r*
	-	.000	.003	.017	.810	.008	.003	sig*
Area (m^2)		1.00	.489	.369	.058	.409	.489	*r*
		-	.029	.109	.808	.073	.029	sig*
Bone (#/m^2/yr)			1.00	.674	.084	.756	.909	*r*
			-	.001	.726	.000	.000	sig*
Bone (g/m^2/yr)				1.00	.023	.580	.673	*r*
				-	.923	.007	.001	sig*
Shell (g/m^2/yr)					1.00	.096	.084	*r*
					-	.686	.724	sig*
Features (#/m^2/yr)						1.00	.756	*r*
						-	.000	sig*
Composite Population Index							1.00	*r*
							-	sig*

**r* is Pearson's *r*, significance is two-tailed

Table 3.3. Standardization of a Variable (# of Components)

Temporal Interval cal A.D.	Interval Midpoint cal A.D.	# of Components	Computation of Normalized z-score (#components-$\bar{x}$)/ s_x	Resulting Normalized z-score
1875-1925	1900	8	(8-19.05)/5.68	-1.95
1825-1875	1850	9	(9-19.05)/5.68	-1.77
1775-1825	1800	13	(13-19.05)/5.68	-1.07
1725-1775	1750	17	(17-19.05)/5.68	-0.36
1675-1725	1700	14	(14-19.05)/5.68	-0.89
1625-1675	1650	17	(17-19.05)/5.68	-0.36
1575-1625	1600	17	(17-19.05)/5.68	-0.36
1525-1575	1550	17	(17-19.05)/5.68	-0.36
1475-1525	1500	18	(18-19.05)/5.68	-0.18
1425-1475	1450	26	(26-19.05)/5.68	1.22
1375-1425	1400	20	(20-19.05)/5.68	0.17
1325-1375	1350	22	(22-19.05)/5.68	0.52
1275-1325	1300	27	(27-19.05)/5.68	1.40
1225-1275	1250	23	(23-19.05)/5.68	0.70
1175-1225	1200	22	(22-19.05)/5.68	0.52
1125-1175	1150	18	(18-19.05)/5.68	-0.18
1075-1125	1110	18	(18-19.05)/5.68	-0.18
1025-1075	1050	21	(21-19.05)/5.68	0.34
975-1025	1000	23	(23-19.05)/5.68	0.70
925-975	950	31	(31-19.05)/5.68	2.10
		$\bar{x}$=19.05 s_x = 5.68		

Data are taken from Campbell 1989:166

Interval midpoints, averages, standard deviations, and z-scores added

Table 3.4. Z-scores and Composite Population Index

Temporal Interval cal A.D.	Interval Midpoint cal A.D.	Column A z-score # Components	Column B z-score of area	Column C z-score of bone (#/m^2/yr)	Column D z-score of bone (g/m^2/yr)	Column E z-score of shell	Column F z-score of features	Column G Composite Population Index*
1875-1925	1900	-1.95	-2.40	-1.11	-1.46	-1.57	-0.97	-1.11
1825-1875	1850	-1.77	-1.41	-1.00	-1.41	-1.51	-0.97	-1.00
1775-1825	1800	-1.07	-1.03	-0.21	-0.27	3.00	-0.42	-0.21
1725-1775	1750	-0.36	-0.55	-0.53	-0.31	1.33	-0.97	-0.53
1675-1725	1700	-0.89	-0.78	-1.18	-0.58	0.62	-0.42	-1.18
1625-1675	1650	-0.36	0.00	-1.27	-1.09	0.08	-0.97	-1.27
1575-1625	1600	-0.36	0.00	-1.27	-1.09	0.08	-0.97	-1.27
1525-1575	1550	-0.36	0.00	-1.27	-1.09	0.08	-0.97	-1.27
1475-1525	1500	-0.18	0.21	-0.05	0.10	-1.29	-0.97	-0.05
1425-1475	1450	1.22	0.94	0.43	0.22	-0.23	-0.42	0.43
1375-1425	1400	0.17	0.44	1.79	0.39	0.11	-0.42	1.79
1325-1375	1350	0.52	-0.42	1.26	0.41	0.25	1.80	1.26
1275-1325	1300	1.40	1.12	1.74	0.59	0.35	1.80	1.74
1225-1275	1250	0.70	0.86	0.36	-0.33	0.35	0.69	0.36
1175-1225	1200	0.52	0.88	0.88	0.42	0.35	1.25	0.88
1125-1175	1150	-0.18	-0.06	0.23	0.19	-0.23	1.25	0.23
1075-1125	1110	-0.18	-0.25	-0.08	1.92	-0.23	0.14	-0.08
1025-1075	1050	0.34	-0.11	0.31	1.94	-0.51	0.14	0.31
975-1025	1000	0.70	0.33	1.07	1.51	-0.61	1.25	1.07
925-975	950	2.10	2.24	-0.10	-0.06	-0.40	0.14	-0.10

*average of all z-scores for six potential population surrogates.
For each row, column G is computed as G=(A+B+C+D+E+F)/6

Table 3.5. Composite Population Index Autocorrelations (Correlations between Population Index and Future Values of Itself)

Significant Autocorrelations

	Correlation (Pearson's *r*)	Significance (*p*)
1 lag (50 years)	0.782	< 0.0001

Insignificant Autocorrelations

	Correlation (Pearson's *r*)	Significance (*p*)
2 lags (100 years)	0.564	< 0.015
3 lags (150 years)	0.505	< 0.039
4 lags (200 years)	0.428	< 0.098
5 lags (250 years)	0.396	< 0.144
6 lags (300 years)	0.434	< 0.121
7 lags (350 years)	0.518	< 0.070
8 lags (400 years)	0.473	< 0.121
9 lags (450 years)	0.461	< 0.153
10 lags (500 years)	0.365	< 0.300

Chapter 4. Field and Laboratory Work -- Technical Considerations and Strategy

Field Work

Since archaeological and demographic information was already available in the study area (Figures 3.1 and 3.5), my work focused on the collection of comparable paleo-environmental data. Although information spanning the past 1,000 years could be drawn from a number of disparate sources such as tree rings, archaeofaunas, archaeobotanical materials and soil profiles, the potential problems with using such discontinuous records and with temporally correlating these separate records were overwhelmingly difficult. Instead, lake cores were sought as a single source for all proxies. Lake cores have the advantage of simultaneously and continuously accumulating a wide range of materials that can be used to reconstruct past temperatures, precipitation, vegetation, salinity, past landscape fires, and erosional episodes.

Coring Site Selection

The selection of lakes for coring was guided by the need for a paleoenvironmental record that was comparable, both spatially and temporally, with the already existing demographic and archaeological records for the Chief Joseph Dam area (Campbell 1989, Linse 1993, Stein 1993). Appropriate lakes for this study would be those that primarily receive inputs from local and extralocal (i.e. about 50 to 100 square kilometers [Delcourt et al. 1983, Jacobson and Bradshaw 1980, Schonmaker and Foster 1991]), rather than regional (i.e.

over 100 square kilometer area) sources. Pollen and charcoal can be carried long distances to basins through suspension in the air, and most of the airfall pollen and charcoal that are deposited in lakes are reflective of regional vegetation (Bradshaw 1981, Jacobson and Bradshaw 1980, Faegri and Iverson 1989, Tauber 1965). In contrast, particles can enter lakes from local and extralocal sources primarily via gravity, slope wash, and stream input (Bradshaw 1981, Jacobson and Bradshaw 1980, Faegri and Iverson 1989, Tauber 1965). Lakes that minimize airfall input, then, would be most likely to provide information on the correct spatial scale for this research.

Previous work on site selection for paleoecological applications provides guidance for finding appropriate coring locations (Jacobson and Bradshaw 1980). The contribution of local, extralocal, and regional sources is controlled by the transport mechanisms bringing particles to lakes. Fortunately, the relative input from each of these sources is correlated with the amount of surface area of a given lake, with larger lakes preferentially receiving a greater regional signal and smaller lakes preferentially receiving a local signal (Jacobson and Bradshaw 1981).

To better isolate a clear extralocal signal appropriate to the scale of this study, research indicates that basins with significant local inputs from surface water should be avoided. Empirical results from basins of different sizes showed that an extralocal signal could be optimized by coring a closed basin smaller than 1 hectare in water surface area (Jacobson and Bradshaw 1981).

Lakes meeting the size and input criteria listed above were identified from the USGS 7.5' quadrangle maps. Of these lakes, those that were more than half a kilometer from a dirt road were excluded for logistical reasons, since these were not easily accessible for fieldwork. In 1994, about 60 potential lake sites were visited. About two-thirds of these basins were excluded from study at this time because they were currently dry, had evidence of extreme disturbance (by cattle, road construction and farm vehicles), or because access permission could not be obtained. Ten likely candidates for coring were measured for maximum depth, and any lakes less than one m deep were also excluded from the study, since they were assumed to have been easily desiccated in the past and thus to have a high potential for a discontinuous sedimentary record. At this stage, six lake basins were identified as good candidates for coring.

These six lakes, and a nearby bog, were revisited and cored in 1997, 1998, and 1999. The basins range from 525 to 750 m in elevation and are located of both sides along the Columbia River corridor that is defined by the study area. The basins chosen for coring were Murphy Lake, Rinker's Lake, Rebecca Lake, Five Lakes, Hidden Lake, Bovy Bog and Bedard Lake North. The location of each lake is shown in Figure 3.5 (with additional information provided in Appendix C).

Lake Coring

Two cores were recovered from each of the seven basins. Coring methods varied slightly depending on equipment availability. Bedard Lake, Bovy

Bog, and Rebecca lake were cored with a 5 cm diameter, multi-stage Davis-Doyle square-rod piston corer from a wooden platform attached to an inflatable pontoon boat. Hidden Lake, Five Lakes, Murphy Lake, and Rinker's Lake were cored with a 5 cm diameter, 1.5 meter long single-stage piston corer (designed by the author) from a wooden platform attached to two inflatable rafts.

Lakes were cored to varying depths depending on the penetrability of the sediments and the nature of the coring device used. Since regional lakes were known to accrue sediments at an average rate of 1 mm per year (Forbes 1987) and the period under study covers the past 1,000 years, the goal was to recover at least 1.5 meters of sediment from each basin. Sediment recovery was recorded in the field, and cores were transported back to the University of Washington in Seattle for description, storage, sampling, and laboratory analysis.

Laboratory Protocol

Loss-on-Ignition Analysis

After basic sediment description, lake cores from all basins were sub-sampled for loss-on-ignition (LOI) analysis. LOI analysis basically followed standard procedures as described in Dean (1974) and the steps are outlined in Appendix D.1. Obtained from this analysis (Dean 1974, Konrad et al. 1970) was an estimate of the percent composition, by weight, of organic materials (such as lignin and cellulose) and carbonates (probably mostly aragonite support structures from aquatic plants and the shells of ostracods). LOI results were scanned to identify discontinuities or rapid changes in sediment composition.

Scanning Electron Microscope Analysis

Sediments from the cores were examined for tephra particles. Previous research done in this part of eastern Washington identified late Holocene ash layers in soil profiles, road cuts, and lake cores (Mack et al. 1979, Smith et al. 1979). Since several of the tephra layers were dated within the period under study (Table 4.1), and since these tephras were morphologically and compositionally distinct, tephrochronology seemed a logical choice for chronological control for this project (Fiacco et al. 1993; Hoblitt et al 1980; Sarna-Wijcicki et al. 1991; Smith et al. 1977; Yamaguchi 1983, 1985).

In contrast to earlier work, no visible tephra layers were seen during the initial sediment scans and analysis done for the current study. This necessitated the use of microscopic means to try to identify and locate tephra layers in the cores. Core segments were indurated with a low-viscosity (SEM quality) resin, vertical thin sections that cross-cut the stratigraphy were made from the core and scanned under a 40x binocular scope. Again, no tephra layers were discovered. Finally, about two hundred LOI residue samples were scanned at 40x under a binocular microscope. A few, isolated potential tephra particles were discovered in the LOI residue. These were examined under a scanning electron microscope, and two particles were shown to be volcanic ash.

Tentative identification of the two tephra particles were made based on the image and composition (via EDS) of these particles. The two particles came from approximately 21 cm depth at Bedard Lake were tentatively identified as a product of the Mt. St. Helens Wn eruption of A.D. A.D. 1479/1480. However, since no discrete ash layers were identified during sediment description, sampling and LOI analysis, tephrochronology was abandoned in favor of radiocarbon dating of the sediment cores.

Radiocarbon Dating

Bulk sediment was submitted for radiocarbon dates. Each radiocarbon sample was restricted to a span of about 0.5 cm of the core, in an attempt to restrict the span of time represented by the deposits. AMS dating was chosen since the resulting samples were small (each about 2 to 4 g) and because AMS, as a direct method of determining radiocarbon content, yields results with narrower error estimations than conventional radiocarbon dating techniques. Fifteen samples from the seven basins were submitted to the University of Arizona laboratory for AMS dating.

Along with the LOI analysis, AMS dates also provided a means for assessing the sedimentation rates and changing sedimentary regimes in each lake basin. At this stage, potential stratigraphic problems like mixing, reversals and hiatuses were identified in some of the lakes, leaving only certain cores fit for further study. Of the cores with no visible sedimentary problems, AMS dates provided chronological controls for sub-sampling the sediment cores for further analysis.

Since sedimentation rates could be estimated, samples could be taken at approximately 50-year intervals from the cores for pollen and charcoal analysis. This strategy was followed so that the proxy lake records produced would have the same temporal resolution as the already-established demographic record for the study area. This sub-sampling strategy, along with lake-site selection, promised to deliver proxy records that were fully comparable to Campbell's population reconstruction (Campbell 1989).

Pollen Analysis

The vegetation proxy for this study was constructed using fossil pollen from the sediments. Standard chemical processing procedures were followed (Appendix A.2., Faegri and Iversen 1989, Gray 1959). The purpose of processing was to eliminate organic and inorganic materials found in the sediment, while retaining and concentrating pollen grains.

After processing, pollen samples were examined under a 400x stereoscopic light-transmissive microscope according to established procedures and conventions (Faegri and Iverson 1989). Using transects that covered the entire visible field of the slide, pollen grains were identified to the lowest possible taxon and recorded. Introduced *Lycopodium* spores were identified and counted when encountered along the pollen transects. An aliquot of these *Lycopodium* spores had been introduced into samples earlier to serve as a standard on which to calculate the pollen accumulation rate (PAR). These two sets of observations provided the raw information needed to create pollen diagrams for the basins. The taxa present, their percent abundance in the assemblage, their concentration, and their PAR could all be calculated from the information gathered.

Along with these traditional pollen counts, pollen condition was also noted. Counts of degraded, corroded or otherwise damaged fossil pollen grains are an ancillary line of evidence pointing to changing sedimentary regimes and erosion since damaged pollen grains are produced by dry or alternating wet/dry conditions (Cushing 1967). Damaged pollen grains found in a lake indicate either that the lake was formerly dry, or that pollen grains were reworked and transported from eroding uplands by surface water. A sudden influx of damaged grains into a wet basin could indicate the sudden arrival of eroded upland materials, which could be caused by any number of external events such as climatic change, overgrazing, deforestation, or similar disturbances.

Along with pollen, other small, chemically resistant materials were recorded when encountered during the examination of slides. Algae (mostly *Pediastrum* spp.) were recorded when observed, as these are good indicators of past water depths and could be used as an ancillary source of information on aridity. Spores were also recorded as encountered, since the presence of certain spores are provide significant paleoenvironmental information. For example, the presence of *Sporormiella* in lake sediments has been linked with intense herbivore grazing and high herbivore populations (Davis et al. 1977).

Charcoal Analysis

Charcoal particles were counted when encountered on the pollen slides -- these were counted, taxonomically identified (when possible) and measured for size (average diameter). Charcoal counts and areas (calculated based on the average diameter) were used to create charcoal influx and grain size records, following established conventions for charcoal studies (Clarke 1988b, 1988c; Clark 1989; Maher 1972; Patterson et al. 1987).

While the preparation, counting, and presentation techniques of pollen analysis are standard, the methods used for charcoal analysis vary from researcher to researcher. Some researchers process lake sediments for charcoal by indurating the sediments with a stiff epoxy, creating thin sections, and point counting charcoal under a binocular dissecting scope (Clark 1988a, 1988b; Clark and Royall 1995b). Some (e.g. Mehringer et al. 1977a, Millspaugh and Whitlock 1995) wet-sieve lake sediment through a set of nested geological screens and count the entire number of recovered particles under a microscope. Others (Backman 1984; Gajewski et al. 1985; Patterson 1978; Swain 1973, 1978) count a subsample of charcoal particles that are visible on pollen slides during pollen counting, and estimate the total number of particles with the aid of a reference aliquot. Still others use less popular methods such as nitric acid digestion (Winkler 1985b), or computer image analysis (Patterson and Backman 1987).

Even given the dizzying array of choices available for producing a charcoal record, the choice for this study was easy -- charcoal was counted using the pollen-slide method. This method was chosen for counting instead of thin sections or sieving for many reasons. First, the pollen slides could be easily sub-sampled because they contained a known amount of a standard *Lycopodium* aliquot. In previous sieving analyses, researchers noted the inconvenience or impossibility of counting the entire sample of recovered charcoal (Mehringer et al 1977a, Millspaugh and Whitlock 1995). Second, the use of pollen slides ensured comparability between the pollen and charcoal samples. Both charcoal and pollen samples were are both drawn from the same original sediment sample and both received the one set of processing treatments, thereby preventing any bias due to differences in stratigraphic origin or laboratory treatment.

Clark (1984) has cautioned that pollen processing methods could bias charcoal results. To control for this, Cwynar (1987) suggests that all samples be treated identically during preparation. More recently, Clark and Royall (1995b) compared charcoal results from the thin-section and pollen-slide methods. They found that results from the two methods provided agreed well with each other for prehistoric samples (Clark and Royall 1995b). The pollen-slide method is considered reliable when used cautiously, and it has many advantages over thin-section preparation and analysis.

An attempt to use thin sections for this study revealed more disadvantages to this method. Undisturbed, unprocessed lake sediments from

Bedard Lake were indurated with low viscosity (SEM-grade) epoxy, cut, mounted and polished. The thin sections thus created were examined under 40x so that charcoal particles could be counted and their diameters measured. This process proved very time intensive, and the smallest charcoal particles (which are the most abundant and ubiquitous) escaped detection using this method. As a result, the thin-section method was abandoned, and pollen-slide counting provided the charcoal record.

The presentation of charcoal data, likewise, is variable from author to author. Some (Mehringer et al. 1977a, Millspaugh and Whitlock 1995, Whitlock and Millspaugh 1996) present data based on simple counts as $\#/cm^2/yr$ (total number of charcoal particles deposited per square centimeter per year). Others (Clark 1988b, Clark and Royall 1995, Maher 1981) present the total area of charcoal particles deposited per year. Area estimations are often expressed as $mm^2/cm^2/year$ (Clark and Royall 1995a, 1995b), and sometimes as $cm^2/cm^2/year$ (Clark 1987, Clark 1988b) or $\mu m^2/cm^2/year$ (Cwynar 1987, Maher 1981). Also seen are presentations of charcoal data as the ratio of charcoal particles to pollen particles within a given sample (Cwynar 1978; Patterson and Backman 1988; Patterson et al. 1987; Swain 1973, 1978), the percent of charcoal by weight in dry sediment (Winkler 1985a, 1985b) or less commonly as counts of charcoal in a given weight or volume of sediment (Fall 1997, Kirch and Ellison 1994, Umbanhowar 1996).

Charcoal on pollen slides was counted in the same manner that pollen was counted. That is, the same transects on the same slides were scanned and tallies were kept of the number of introduced *Lycopodium* (the introduced aliquot standard) and charcoal grains. Size information for charcoal particles was kept by recording grains under one of three size categories: 75-125 µm diameter, 125-250 µm diameter, and 250-500 µm diameter. All charcoal smaller than 75 µm was ignored, since most research has show that particles of these sizes provide little to no information for reconstructing extralocal or catchment fire histories (Clark 1995,1988a; Mehringer et al. 1977a; Millspaugh and Whitlock 1995; Whitlock and Millspaugh 1996; Patterson and Backman 1987). This counting method allowed both size and ubiquity of particles to be taken into consideration so that charcoal counts could be easily converted into any of the popular measures (whether size- or abundance-based) commonly used for reporting charcoal results.

Isotope Analysis

A second set of sediment samples was used for the climate proxy. Two indicators of past climates easily reconstructed from lake sediments are water depth and salinity, and many lines of potential evidence are available for measuring these variables. For this study, isotopic fractionation was used as the climate proxy since previous research on lacustrine sediments from Goose and Duley Lakes (see Figure 3.5 and Appendix C for lake locations) showed that isotope values observed in these fresh water lakes could and did accurately and sensitively track the area climate (Forbes 1987).

Sediment samples for oxygen isotope analysis and carbon isotope analysis were drawn from two lakes -- Rinker's Lake and Hidden Lake. Differences between the two records were treated as local signals that were unique to each lake, and commonalities between the two records were considered to reflect an overarching extralocal climate signal that was being manifested simultaneously in both lakes.

Table 4.1. Recent Mt. St. Helens Tephra Reported from the Study Area

Date (A.D.)	Tephra
1980	Set "D"
1800	Layer "T"
1479-1480	Layer "Wn"

(Information drawn from Fiacco et al. 1993; Hoblitt et al 1980; Sarna-Wijcicki et al. 1991; Smith et al. 1977; Yamaguchi 1983, 1985).

Chapter 5. Depositional Histories of Basins and Suitability of Cores for Further Analysis

Requirements for Suitability

Lakes were chosen for coring based on their morphology, hydrology, and location, in order to maximize an extra-local spatial-scale signal appropriate for the study of human activity. After coring, lake and bog sediments had to meet four additional criteria to be used as a source of proxy records for this research. Each basin had to provide a record that (1) was the product of continuous sedimentation (not the product of a series of discrete depositional events) (2) reflected changes in the sources of particles and not changes in sedimentary processes transporting and depositing the particles (3) spanned the entire period of interest from the present back to A.D. 950 (1,000 B.P.) and (4) contained materials appropriate for the analyses being conducted.

This chapter evaluates the suitability of each core, in turn, using as evaluative criteria a combination of radiocarbon dating, sediment descriptions, and LOI analysis. The results of these techniques indicate that, of the seven basins cored, only Hidden Lake, Rinker's Lake and Five Lakes were appropriate for further study. Of these lakes, Five Lakes was most likely to provide a solid and well-preserved pollen record, while Hidden and Rinker's Lakes were better suited for oxygen isotope analysis.

Evaluating Cores for Continuous Deposition

Evaluating interactions between people, vegetation, climate, and fire logically requires complete records for each variable, without temporal discontinuities. The use of time series and other statistical analyses, likewise, demands that there be no temporal gaps or missing values in the data set being used. An uninterrupted temporal sequence is necessary given both the questions being asked and the statistical techniques being used.

A continuous record is a traditional requirement of palynological studies, and simple techniques have been established for evaluating cores on this basis (Faegri and Iversen 1989). Palynologists commonly use radiocarbon dating to estimate the sedimentation rate and combine this information with sediment descriptions to identify problems in lake cores (Faegri and Iversen 1989, Webb and Webb 1988). The apparent sedimentation rate in a lake core is calculated by using linear interpolation between two dates from different stratigraphic depths (Webb and Webb 1988). Normal sedimentation rates for lakes average 0.91 millimeters per year (or mm/yr), with an associated 95% confidence interval from 0.16 to 2.57 (Webb and Webb 1988). An abnormal sedimentation rate lower than 0.16 mm/yr is "characteristic of nonconstant processes of accumulation" (Webb and Webb 1988: 293) and often signals the presence of a hiatus in deposition or net erosion from a basin.

Previous work in the study area itself has shown that these sedimentation rates are useful guides for distinguishing between disrupted and uninterrupted sedimentary sequences. In three separate analyses of Goose Lake, researchers found no evidence for discontinuities in the core (Dalan 1985, Forbes 1987, Nickmann and Leopold 1985). Radiocarbon dates from Goose Lake (from Forbes 1987), when calibrated, confirm this (Table 5.1). The Holocene sedimentation rate at Goose Lake varied from 0.43 to 1.11 mm/yr, in agreement within expectations for a conformable sequence. Earlier work on Duley Lake, in contrast, showed that the upper part of the core contained an unconformity (Forbes 1987). Not surprisingly, the associated sedimentation rate calculated from calibrated radiocarbon assays at Duley Lake was anomalous at 0.03 mm/yr (Table 5.1). An analysis of sedimentation rates, then, promises to provide a good method for screening additional basins for potential stratigraphic problems.

In order to evaluate the basins cored for the present study, bulk sediment samples were taken from each core and submitted for AMS radiocarbon dating. The samples submitted, along with the results in ^{14}C years (uncalibrated radiocarbon years before present corrected for $\delta^{13}C$), are listed in Table 5.2. Radiocarbon dates were calibrated using Calib v.4.3 calibration program (Stuiver and Reimer 1993), and results are listed in Table 5.3, along with the 2σ (95.4%) confidence interval for each calibrated date. In addition to AMS dates, chronological control was also provided by the core-top as well. Since deposition was occurring at the sediment-water interface at the time the cores were collected, 0 centimeters below interface (cm bi, with regards to the sediment-water interface) was assumed to have a modern date.

Along with the mean calibrated radiocarbon dates and core-top stratigraphic dates, linear interpolation was used to calculate apparent sedimentation rates. The results of these calculations are presented in Table 5.3 and will be discussed on a case-by-case basis. In addition to sedimentation rate, sediment descriptions were used to identify interruptions in sedimentary sequences. This information is presented for each basin in Figures 5.1 through 5.7.

Evaluating Cores for Uniform Transport and Deposition

Although it is important for basins to be constantly receiving sediment, they must also be receiving material without undergoing significant changes in the mechanisms delivering the sediments. This is important in the analysis because measured changes in each proxy variable need to reflect changes in the underlying variable of interest rather than changes in depositional processes. Changes in sediment sources, transport agents, or the environment of deposition can all interfere with proxy signals. For example, increases in the amount of grass pollen entering a lake cannot be assumed to reflect changing abundances of grass on the landscape if there have been fluctuations in the amount of sheetwash transporting pollen into the basin or a change in preservation of pollen over time.

Evidence for steady *versus* changing sedimentary regimes can be garnered from several lines of evidence. Sedimentation rates, again, help identify problematic sequences, as radical changes in accumulation rates signal gross changes in sediment transport and origins. Sediment descriptions can be used to identify changes in lithology reflective of changes in depositional processes as well. Additionally, LOI can be used to trace changes in the relative contribution of different sediment sources by quantifying the organic, carbonate, and other inputs into lakes.

Evaluating Cores for Record Length

Even steady and continuous sedimentary records will be useless for study unless they extend back to A.D. 950. Some of the cores have AMS dates drawn from the lowest stratigraphic depth in the sequence, and this is a direct indication of the time-span represented by the core. For example, recovery was 410 mm from Murphy Lake and the bulk sediment from 410 mm bi has an associated calibrated date of 471 B.P. (see Table 5.4), showing that the core from Murphy Lake is too short for use in the present study.

For some cores, the lowest stratigraphic depth is below the lowest dated material. In this case, sedimentary rates and AMS dates are used to extrapolate downcore to calculate a date for the oldest material recovered. For example, the Five Lakes core is 1,450 mm long, but the lowest date of 1,271 B.P. comes from 1,250 mm bi. Using the mean sedimentation rate of 0.79 mm/yr (from Table 5.3) associated with the lowest date, the additional 200 mm of sediment should represent an additional 254 years of deposition for an total of 1,525 years of sedimentation in the core. Record lengths as determined from radiocarbon dates and sedimentation rates are presented in Table 5.4.

Evaluating Cores for Appropriate Material Types

Also of interest is the chemical and particulate composition of the cores, which determines whether they are appropriate for the laboratory techniques employed to measure the proxy variables. The most useful pollen record would be derived from a basin that originally received a high, steady input of pollen and had good preservation of that pollen. Basins to be avoided would be those with relatively low organic content or with evidence of shallow or dry conditions. Promising basins would have the opposite characteristics -- high relative organic composition, acidic conditions and lithology consistent with open water conditions. Gyttja, a highly organic lake mud, indicates open water conditions favoring pollen accumulation and preservation. On the other hand, sediments with high inputs of terrigenous sediments (like sand), as well as peats, often point to unfavorable emergent or drying conditions in which little pollen is deposited and destruction of grains is high. In this study, sediment descriptions and LOI results are used to identify those cores with highly organic lake sediments that are reflective of open water conditions.

Lithology and LOI can, likewise, be used to identify sediments with compositions likely to preserve a strong, clear oxygen isotope record that is reflective of changing climate. Since oxygen isotope assays are done on the carbonates in lake sediments, LOI measurements can identify those sediments with high concentrations of the necessary minerals. Lithologic descriptions can, again, be used to differentiate between sediment sequences derived from basins that underwent emergent periods and those that permanently maintained open water. This is necessary because one of the biggest potential confounding factors in oxygen isotope analysis is changing water volumes in lakes. Promising candidates for isotope work are marls (Forbes 1987), which are carbonate-rich and usually accumulate in standing water. Especially desirable would be sequences of uninterrupted marls, indicative of constant open water conditions and carbonate deposition over long periods of times. Much less desirable would be sediments low in carbonate, or those indicative of fluctuating water depth and chemistry, such as alternating bands of peat and marl.

Basin-specific Results and Conclusions

Bedard Lake North

The first criterion that any lake must meet for further analysis is that of a continuous record. The AMS date from Bedard Lake North provides an anomalously low calculated sedimentation rate of 0.13 mm/yr. This indicates the presence of either a hiatus in deposition or a net removal of sediment from the lake. The sediment description from Bedard Lake North in Figure 5.1 shows that there is a high input of terrestrial sediments into the lake. Although marls in the upper 35 cm of the core indicate conditions of standing water, the silt and sand particles that dominate the sediment from 35 to 61 cm in depth show that the lake was likely dry at earlier times and possibly underwent deflation.

Results from LOI also show discontinuities in the composition of the Bedard sediments. Figure 5.8 shows a plot of the relative contribution of sediment that is neither carbonate nor organic in nature, referred to as the "index of terrigenous input." Drastic changes in composition occur during two intervals, labeled with arrows on Figure 5.9. If deposition had been constant, these would be more gradual transitions. All the various lines of evidence examined agree that Bedard Lake North does not pass the test for constant and steady deposition.

Bovy Bog

Dating at Bovy Bog, like Bedard Lake North, results in an anomalously low calculated sedimentation rate. The date of 5,926 years from 115 cm bi yields a mean apparent sedimentation rate of 0.08 mm/yr and signals a disruption of sediment accumulation. The sediment description for the Bovy Bog core (given in Figure 5.2) provides further evidence of this. Sediments low in the sequence (16 to 115 cm bi) in Figure 5.2 tend to be marls and these switch to peats near the core top (by 16 cm bi), showing that standing water once existed in the basin but has since disappeared as the lake was converted into a bog. Again, evidence of emergent conditions paired with low sedimentation rates argues for an incomplete sequence. LOI results in Figure 5.10 show discontinuity as well. Figure 5.10, like Figure 5.8, presents the LOI data as the percentage of non-carbonate, non-organic materials with stratigraphic depth. Figure 5.10 exhibits at least one clear break in the type of sediment being delivered to Bovy Bog (indicated with an arrow in the annotated Figure 5.11). Like Bedard North, Bovy Bog seems to have suffered from discontinuous deposition of materials, which disqualifies it from further pollen, charcoal, and isotope analysis.

Rebecca Lake

Rebecca Lake provided over 500 cm of sediment, and four samples of bulk sediment were submitted for radiocarbon analysis. The dates from Rebecca Lake (Table 5.2) and the sedimentation rates calculated from these dates (Table 5.3) indicate discontinuities in the record. Two of the samples -- AA34605 and AA34607 -- from Rebecca lake have younger mean sample dates than the samples that lie above them stratigraphically and lead to the negative sedimentation rates calculated and reported in Table 5.3. Such reversals indicate erosion with resuspension and/or redeposition of materials in the lake.

How probable is it that these represent real reversals and not accidents of sampling? Table 5.3 presents the 2σ (95.4%) confidence interval around each mean calibrated date. The confidence intervals for successive dates do not overlap. The lowest date in the core (512 cm bi) has a high ($p \leq 0.954$) probability of being between 1,568 and 1,918 years old. Yet the date above it (385 cm bi) has the same high probability of being 2,734 to 2,916 years old. The situation is the same for the two upper dates from the Rebecca core. The date from 295 cm bi has a 95.4% chance of falling between 2,067 and 2,346 years old. Yet the date above it (at 260 cm bi) is just as likely to be 3,780 to 4,089 years old. In both cases, the reversed dates are highly unlikely to be due to chance; the evidence strongly points to a real stratigraphic reversal.

LOI results from this lake also testify to disruptions within the core. Data from a short segment, spanning 430 to 510 cm bi in the core, is given in Figure

5.12. This sequence clearly shows a gap in the values of the index of terrigenous input around 470 cm bi. (An arrow points to this interval in the annotated Figure 5.13).

The sediment description, given in Figure 5.3, is in agreement with this interpretation. Figure 5.3 shows that the lithology of Rebecca lake is highly variable over short vertical intervals, switching between marls and peats, or between different kinds of peat, over as little as 1 cm of depth in the core. The contacts between the units are abrupt, as unconformable sequences are expected to appear. The nature of the contacts, the frequent abrupt changes in the character of the sediment, and the out-of-sequence AMS dates in this core all point to several erosion and redeposition events. A map of the local topography around Rebecca Lake (Figure 5.14), and shows that the lake sits in the bottom of a very steep bedrock canyon. It is probable that the topography has funneled periodic flash floods into Rebecca Lake, ripping up some of the older sediments and causing the stratigraphic problems observed. Regardless of the exact reconstruction of events, it is obvious that this stratigraphic sequence cannot be considered continuous or steady, and that Rebecca Lake is not acceptable for further study.

Murphy Lake

The Murphy Lake core is 41 cm long and has one associated radiocarbon date (Tables 5.3, 5.4) of 471 years (A.D. 1479) at the bottom of the core. The 0.79 mm/yr average sedimentation rate associated with this date is well within the normal range, and similar to known rates of accumulation from continuous sequences in other area lakes. The lithology of Murphy Lake is given in Figure 5.4, and shows a single unbroken episode of marl sedimentation. This single layer of marl points to conditions of standing water and is also indicative of continuous and steady deposition. Murphy Lake fails, however, to provide a long enough record. The bottom of Murphy Lake, at A.D. 1479, is too young to be useful in examining the long-term processes of interest here.

Hidden Lake

Hidden Lake produced a 56 cm-long core with a date of 524 years from 25 cm bi. The apparent mean sedimentation rate of 0.44 mm/yr for Hidden Lake (Table 5.3) is consistent with both the expectations of "normal" lacustrine sedimentation and similar to the average rate of 0.45 to 1.10 mm/yr seen at nearby Goose Lake. The stratigraphy from Hidden Lake (Figure 5.5) is simple and consists of a single unit of silty marl indicative of constant and continuous deposition in open water. Based on the depth of the calibrated AMS date, the Hidden Lake sediments represent a sequence dating back to A.D. 715, providing a record that is adequate for the research questions under study.

Rinker's Lake

Rinker's Lake is also promising, and the sediment description for this record is presented in Figure 5.6. Rinker's Lake sediments consist of a 53 cm long unit of silty clayey marl. This unbroken layer of marl indicates that the basin has steadily accrued material under open-water conditions. This is consistent with the sedimentation rate of 0.33 (Table 5.3) calculated for these sediments. Rinker's Lake, then, fits the requirements of uninterrupted and unchanging deposition. With a calibrated date of 1,543 years (A.D. 407 -- Table 5.4) from the core bottom, this basin satisfies the temporal length requirement as well.

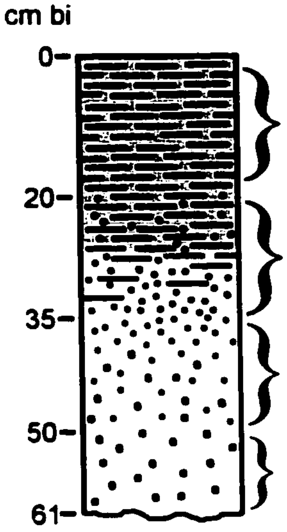
Five Lakes

Five lakes also satisfies the requirements for continued laboratory analysis. This lake was the source of a 145 cm long core composed primarily of gyttja, and this record shows no major changes in lithology and no evidence of drying conditions (Figure 5.7). Four samples from this sequence were submitted for radiocarbon dating, and the series (see Tables 5.2 and 5.3) of dates conforms to all expectations -- radiocarbon ages increase with depth, sedimentation rates do not vary significantly throughout the core, and the apparent sedimentation rates, which range from 0.78 to 1.68 mm/yr, are all in the normal range. Again, this basin shows strong evidence that it has an unbroken and unchanging depositional history. The length of this history can be extrapolated from the stratigraphically lowest AMS date and its related sedimentation rate. The results show that the Five Lakes core spans 1,525 years (back to A.D. 425), more than the minimum requisite. Additionally, the presence of gyttja throughout the core indicates that this basin contained standing water throughout its past 1,525 years.

Basins Selected for Pollen and Isotope Work

Five Lakes can be compared with Rinker's Lake and Hidden Lake to determine which sediments are most appropriate for oxygen isotope analysis and which are best suited for pollen and charcoal work. Of the three basins, the gyttja from Five Lakes has the highest organic content, with 31.2 % organics by weight. The marls from Rinker's and Hidden Lakes, in contrast, have only 5.2 and 20.8%, respectively. Based on organic content, Five Lakes can be expected to have the best pollen record and was chosen as the source of the vegetation and fire proxies.

Rinker's and Hidden Lakes, in contrast to Five Lakes, are composed of lake marls with relatively high (15.8 to 23.6%) carbonate content. Previous work with oxygen isotopes from other area lakes has confirmed that marls are the best choice for $\delta^{18}O$ work, since they give the clearest climate signal, the most consistent results and the best sample sizes (Forbes 1987). Based on their lithology and LOI, Rinker's and Hidden Lakes were determined to be more suitable for oxygen isotope analysis.



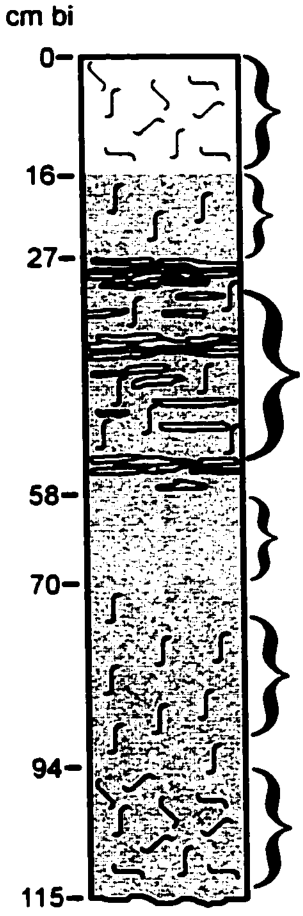
0-20 cm bi 10YR3/1 black clayey marl. Lower boundary is gradational.

20-35 cm bi 10YR3/1 black silty clayey marl, becoming more silty with depth. Lower boundary is gradational.

35-50 cm bi 10YR4/2 dark grayish brown fine-sandy silt, becoming more sandy with depth. Lower boundary is gradational.

50-61 cm bi 10YR6/2 light brownish gray fine sand

Figure 5.1. Sediment Description for Bedard Lake North



0-16 cm bi 10YR2/1 black peat with randomly-oriented plant fibers. Lower boundary is abrupt.

16-27 cm bi 10YR2/1 marl with vertical plant fibers (perhaps roots in living position). Lower boundary is diffuse.

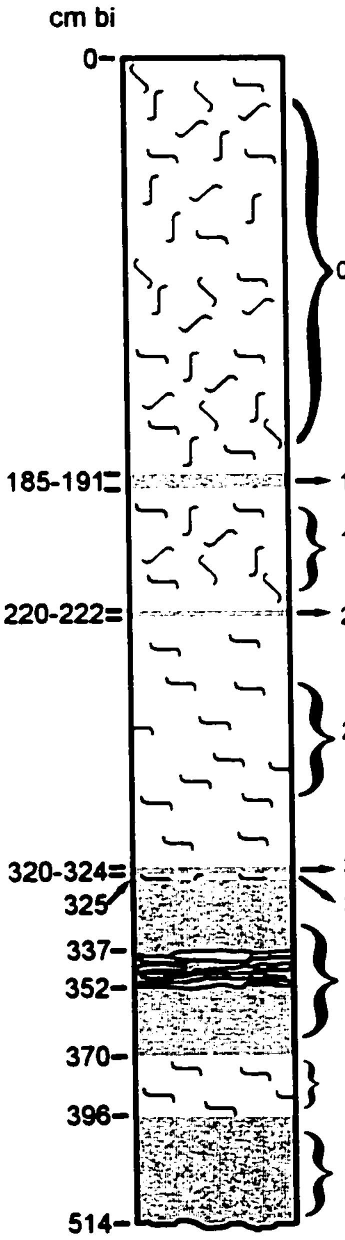
27-58 cm bi 10YR2/1 black marl with 10YR8/1 small lenses (1 mm or less in thickness) and mottles of carbonate-rich material and vertical plant fibers (perhaps roots in living position)

58-70 cm bi 10YR5/1 gray marl with no plant fibers. Lower boundary is gradational

70-94 cm bi 10YR5/1 gray marl with vertical plant fibers (perhaps roots in living position). Lower boundary is gradational.

94-115 cm bi 10YR5/1 gray marl with randomly-oriented plant fibers

Figure 5.2. Sediment Description for Bovy Bog



0-185 cm bi peat with randomly-oriented plant fibers. Lower boundary is sharp.

185-191 cm bi marl with no fibers, with sharp lower boundary.

191-220 cm bi peat with randomly-oriented fibers, with abrupt lower boundary.

220-222 cm bi peat with randomly-oriented plant fibers, with sharp lower boundary

222-320 cm bi peat with horizontal plant fibers with sharp lower boundary.

320-324 cm bi marl with no fibers, abrupt lower boundary.

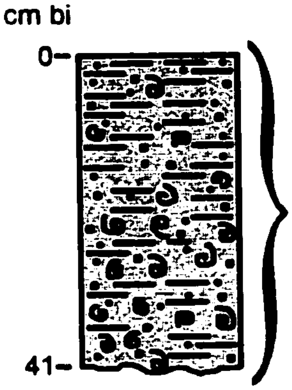
324-325 cm bi peat with randomly-oriented plant fibers, with sharp lower boundary.

325-370 cm bi marl with carbonate-rich mottles and small lenses (1 mm or less in thickness) clustering around 337-352 cm bi, with abrupt lower boundary

370-396 cm bi peat with horizontal plant fibers with sharp lower boundary.

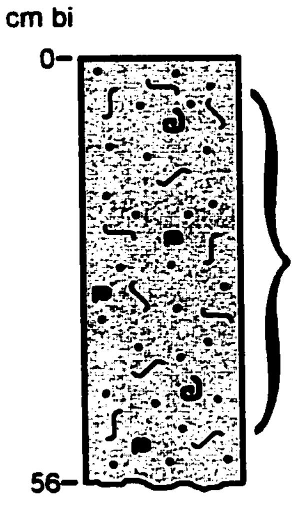
396-514 cm bi marl with no fibers

Figure 5.3. Sediment Description for Rebecca Lake



0-41 cm bi 10YR3/2 dark grayish brown sandy clayey silty marl with visible gastropod shells (approx. 1 mm in diameter), increasing with depth

Figure 5.4. Sediment Description for Murphy Lake



0-56 cm bi 10YR3/2 dark grayish brown silty marl
with visible gastropod shells (approx. 1 mm in diameter),
and randomly-oriented plant fibers throughout.

Figure 5.5. Sediment Description for Hidden Lake

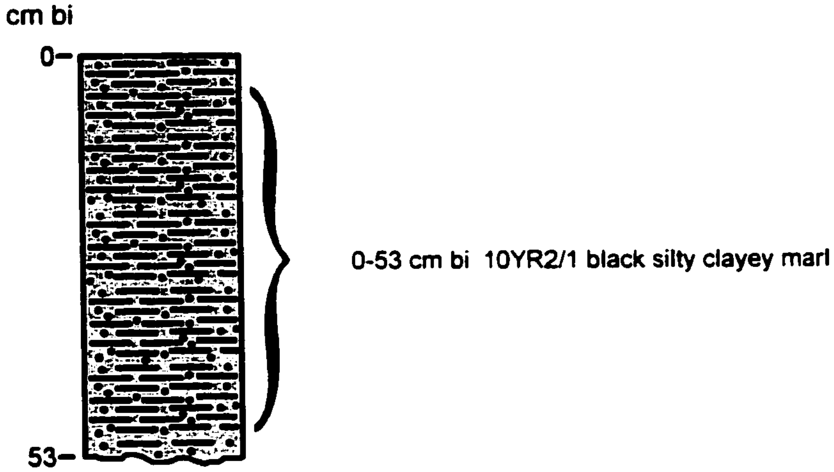
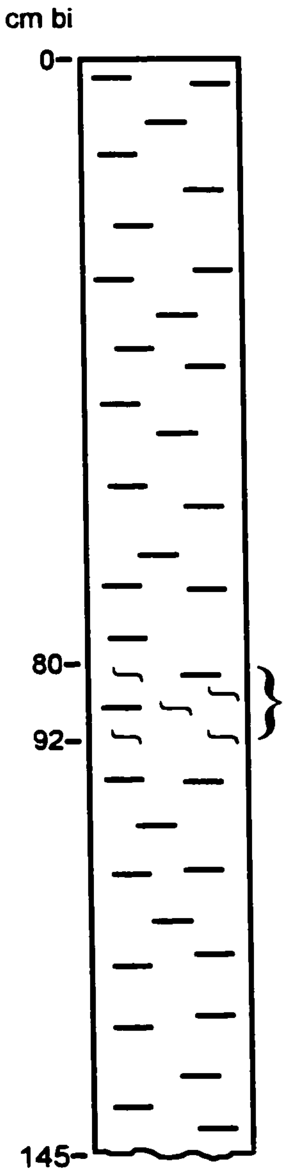


Figure 5.6. Sediment Description for Rinker's Lake



0-145 cm bi Variable in color from 10YR2/1 black to 10YR4/3 dark brown slightly clayey gyttja, with a zone containing some horizontally-oriented plant fibers from 80-92 cm bi.

Figure 5.7. Sediment Description for Five Lakes

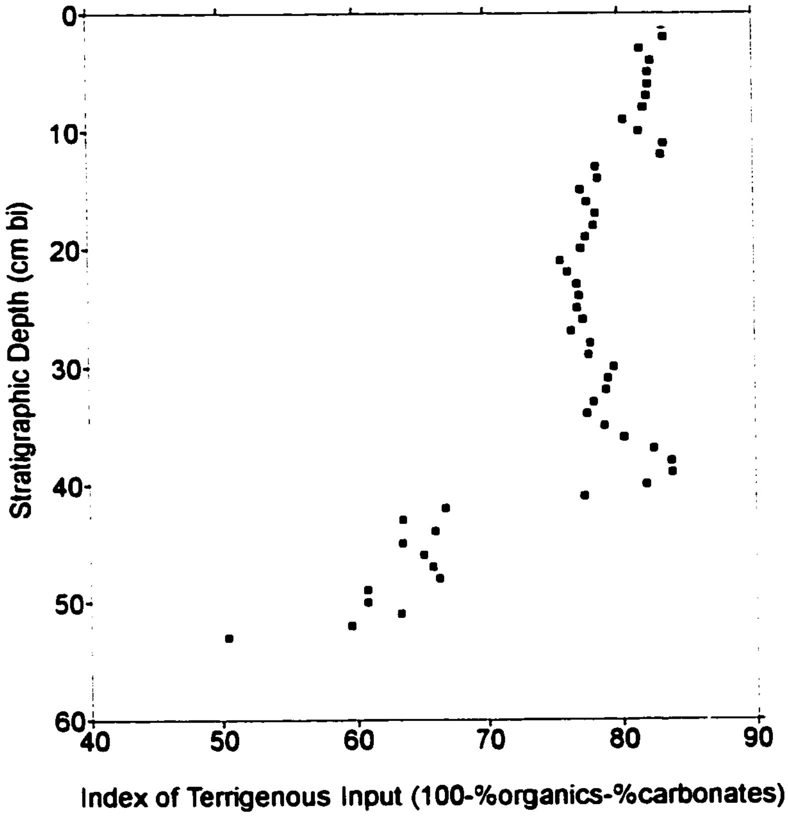


Figure 5.8. LOI Results for Bedard Lake North

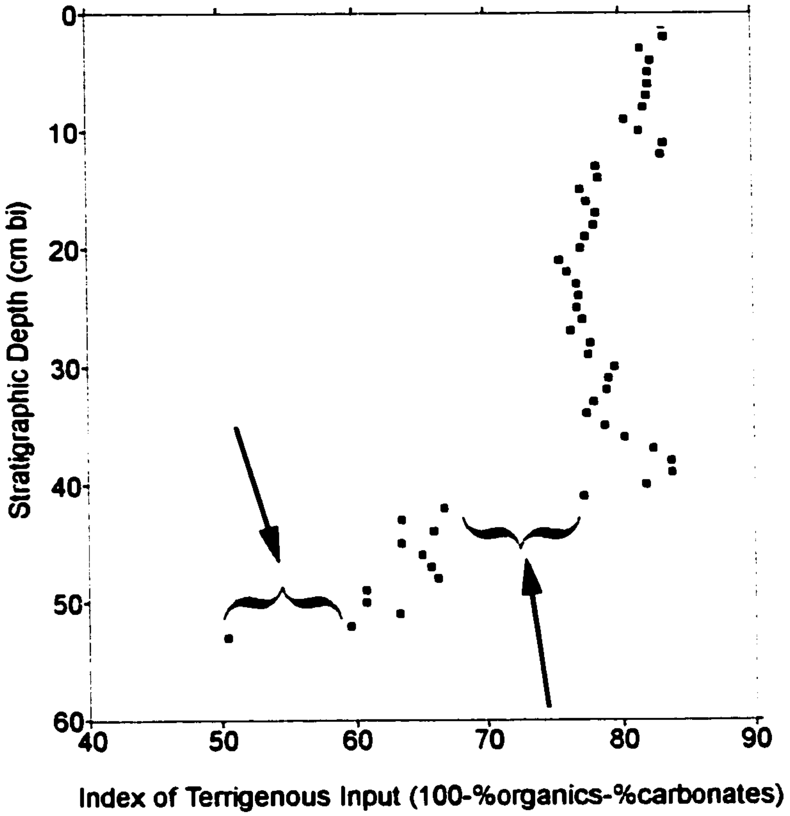


Figure 5.9. Annotated LOI Results for Bedard Lake North

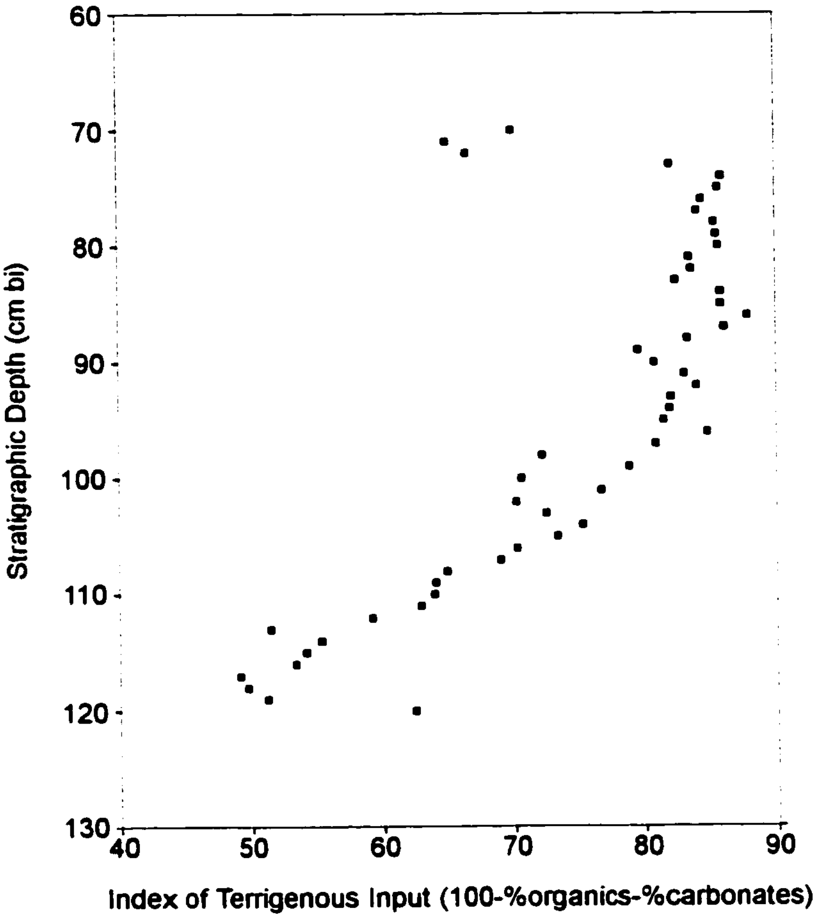


Figure 5.10. LOI Results from Bovy Bog

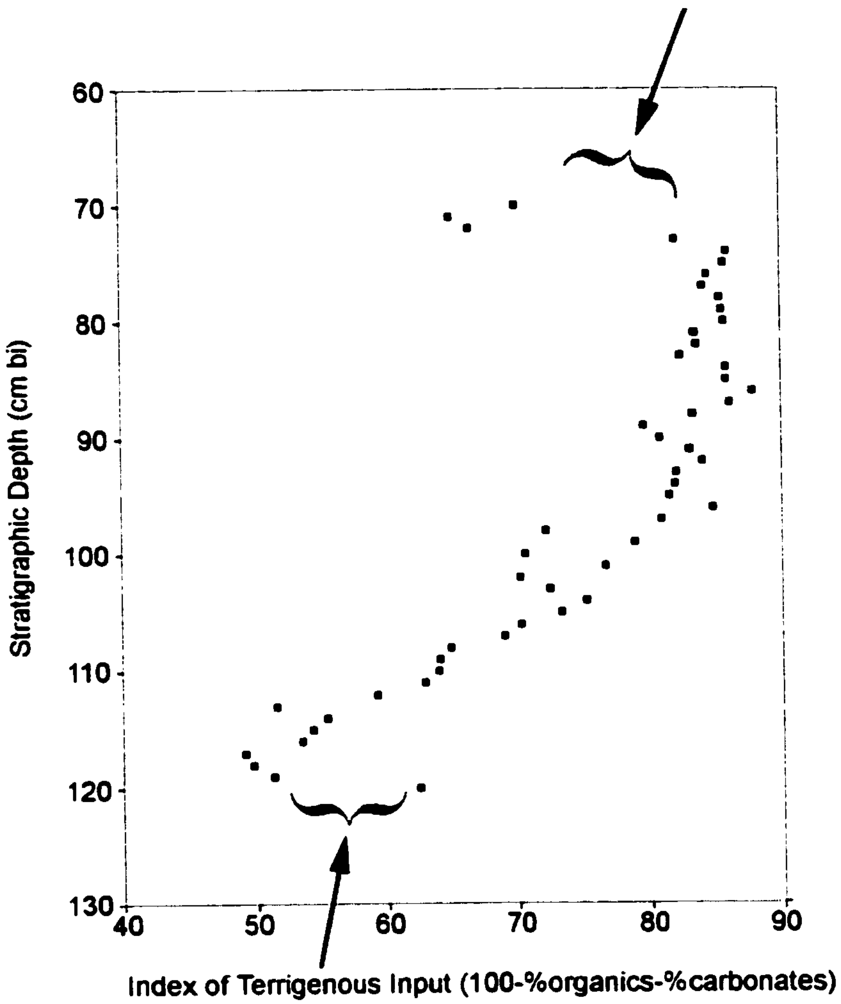


Figure 5.11. Annotated LOI Results from Bovy Bog

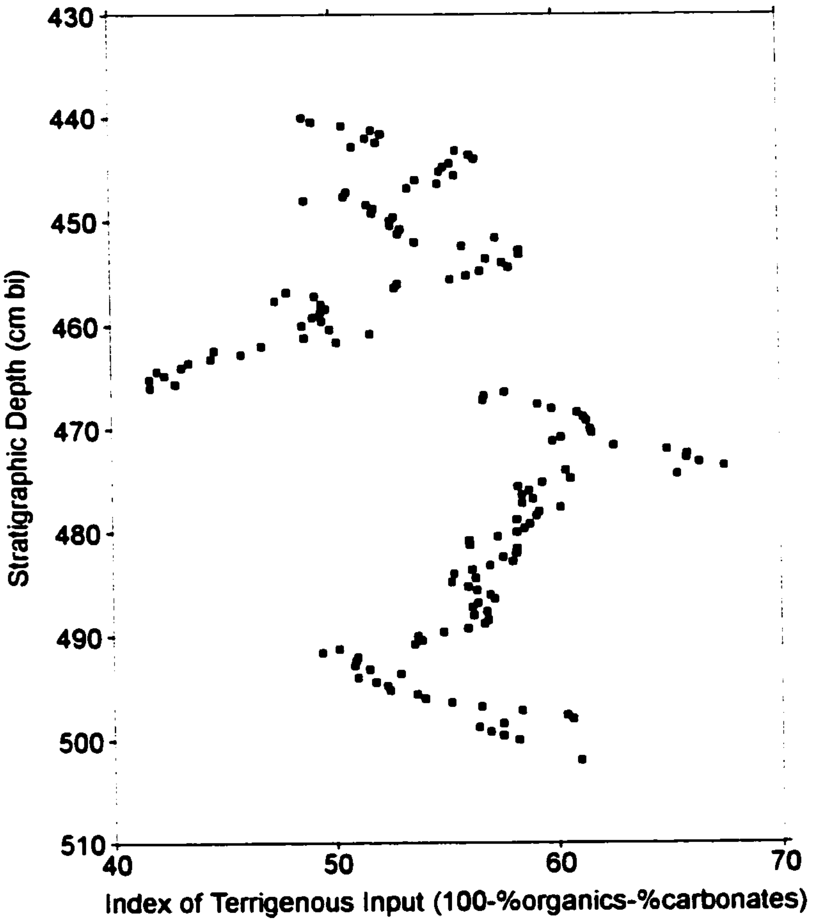


Figure 5.12. LOI Results from Rebecca Lake

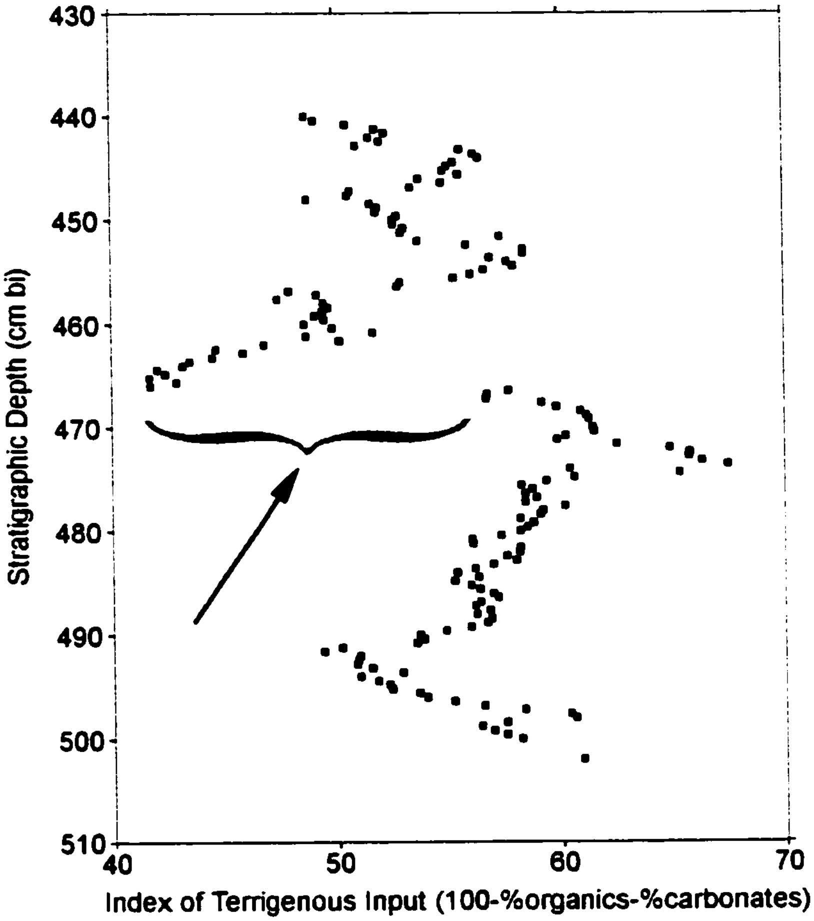
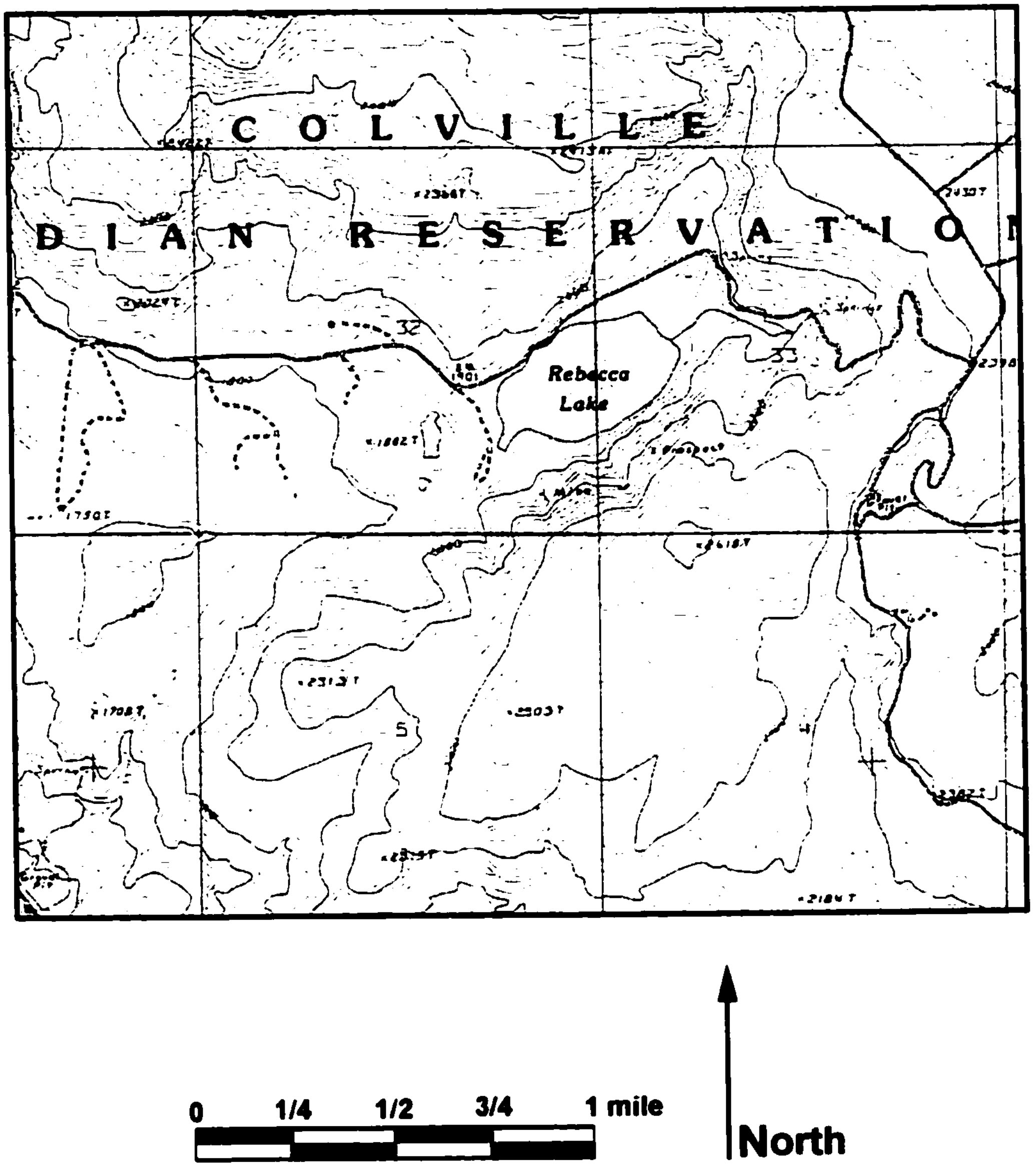


Figure 5.13. Annotated LOI Results from Rebecca Lake



Contour Interval = 40 feet

Figure 5.14. Detailed Location Map for Rebecca Lake

Table 5.1. Holocene Dates and Sedimentation Rates from Previous Work on Goose and Duley Lakes

Lake Name	depth In core (in mm)*	^{14}C date (^{14}C yrs)*	mean date(s), calibrated (cal B.P.)	95.4 % confidence interval(s) (2σ) on calibrated date (cal B.P.)	mean sedimentation rate (mm/cal yr)	95% confidence interval on sedimentation rate (mm/cal yr)	
						slowest	fastest
Goose Lake	600	1,420 ±20	1,307	(1,290-1,348)	0.45	0.45	0.43
	4,100	4,850 ±60	5,593	(5,688-5,707) (5,672-5,680) (5,566-5,661) (5,470-5,559)	0.82	0.80	0.84
	6,300	6,770 ±50	7,611 7,595 7,593	(7,566-7,682) (7,511-7,529)	1.10	1.08	1.11
Duley Lake	100	2,930 +30	3,135 3,132 3,077	(3,180-3,208) (2,958-3,167)	0.03	0.03	0.03
	1,600	8,170 ±70	9,126 9,105 9,088 9,045 9,033	(9,377-9,399) (9,357-9,373) (9,341-9,350) (9,310-9,325) (8,999-9,303)	0.25	0.17	0.25

*information in these two columns is taken from Forbes 1987. All other numbers are calculated based on this information, using Calib v. 4.3

Table 5.2. AMS Radiocarbon Dates for Lakes Cored for This Study

Lake Name	Radiocarbon Years B.P. (uncalibrated)	Lab No.	stratigraphic depth (cm bi)	weight of sample (grams)	material dated
Bedard North	3430±55	AA33775	50	1.5	dry lake sediment 4.1% organic 34.1% carbonate
Bovy Bog	post-bomb	AA33776	70	.0063	4 *Scirpus* seeds
	5180±75	AA33777	115	1.5	dry lake sediment 37% organic 7% carbonate
Rebecca	3635±50	AA34604	260	0.2	dry lake sediment 71% organic 4% carbonate
	2220±55	AA34605	295	0.7	dry lake sediment 39% organic 7% carbonate
	2670±60	AA34606	385	0.7	dry lake sediment 12% organic 8% carbonate
	1825±65	AA34607	512	1.5	dry lake sediment 29% organic 10% carbonate
Murphy	385±55	AA34947	41	2.9	dry lake sediment
Hidden	500±50	AA34828	25	2.0	dry lake sediment 12% organic
	Not reported by ^{14}C lab	AA34829	50	2.3	dry lake sediment 10% organic
Rinker's	1660±55	AA34948	53	2.9	dry lake sediment
Five	580±45	AA34830	50	3.6	dry lake sediment 40% organic
	820±45	AA34831	75	3.6	dry lake sediment 31% organic
	1050±55	AA34832	100	3.9	dry lake sediment 40% organic
	1325±45	AA34833	125	3.9	dry lake sediment 46% organic

Table 5.3. Dates and Sedimentation Rates for Lakes Cored for This Study

Lake Name	depth In core (in mm)*	^{14}C date (^{14}C yrs)*	mean date(s), calibrated (cal B.P.)	95.4% confidence interval(s) (2σ) on calibrated date (cal B.P.)	mean sedimentation rate (mm/cal yr)	95% confidence interval on sedimentation rate (mm/cal yr)	
						slowest	fastest
Bedard North	500	3,430 ±55	3,688 3,655 3,644	(3,553-3,832) (3,494-3,494)	0.13	0.14	0.13
Bovy Bog	700	post-bomb (modern)	NA	NA	>>3.00	>>3.00	>>3.00
	1,150	5,180 ±75	5,926	(6,139-6,171) (6,067-6,113) (5,837-6,061) (5,745-5,833)	0.08	0.08	0.07
Rebecca	2,600	3,635 ±50	3,963 3,947 3,928	(3,830-4,089) (3,780-3,787)	0.65	0.68	0.63
	2,950	2,220 ±55	2,303 2,240 2,205 2,200 2,181 2,166 2,162	(2,103-2,346) (2,067-2,082)	-0.20	-0.20	-0.20
	3,850	2,670 ±60	2,770	(2,912-2,916) (2,734-2,872)	1.60	1.58	1.35
	5,120	1,825 ±65	1,731	(1,912-1,918) (1,588-1,896) (1,568-1,583)	-1.22	-1.27	-1.09

*information in these two columns is taken from Forbes 1987. All other numbers are calculated based on this information, using Calib v. 4.3

Table 5.3. Dates and Sedimentation Rates for Lakes Cored for This Study (cont.)

Lake Name	depth In core (in mm)*	^{14}C date (^{14}C yrs)*	mean date(s), calibrated (cal B.P.)	95.4% confidence interval(s) (2σ) on calibrated date (cal B.P.)	mean sedimentation rate (mm/cal yr)	95% confidence interval on sedimentation rate (mm/cal yr)	
						slowest	fastest
Murphy	410	385 +55	471	(306-524)	0.79	1.15	0.72
Hidden	250	500 +50	524	(602-624) (477-558)	0.44	0.48	0.37
Rinker's	530	1,660 +55	1,543	(1,413-1,705)	0.33	0.36	0.30
Five	500	580 +45	593	(518-653)	0.78	0.88	0.71
	750	820 ±45	729	(870-881) (814-826) (667-792)	1.68	1.89	1.09
	1,000	1,050 ±55	953	(909-1,061) (833-854) (798-809)	1.10	1.91	1.39
	1,250	1,325 ±45	1,271	(1,172-1,307)	0.79	1.02	0.67

*information in these two columns is taken from Forbes 1987. All other numbers are calculated based on this information, using Calib v. 4.3

Table 5.4. Temporal Length of Sediment Records Extrapolated from Calibrated AMS Dates

Lake Name	Column A	Column B	Column C	Column D	Column E	Column F
	core length (in mm)	lowest ^{14}C date (mm bi)	oldest date, calibrated (B.P.)*	mean sedimentation rate (mm/ yr)	record length (yrs)**	oldest (lowest) sediment
Bedard Lake North	610	500	3,688 3,655 3,644	0.14	4,510 4,469 4,456	2560 cal B.C. 2519 cal B.C. 2506 cal B.C.
Bovy Bog	1,150	1,150	5,926	0.08	5,926	3976 cal B.C.
Rebecca Lake	5,140	5,120	1,731	-1.22	1,715	cal A.D. 235
Murphy Lake	410	410	471	0.79	471	cal A.D. 1479
Hidden Lake	560	250	524	0.44	1,235	cal A.D. 715
Rinker's Lake	530	530	1,543	0.33	1,543	cal A.D. 407
Five Lakes	1,450	1,250	1,271	0.79	1,525	cal A.D. 425

*all dates and years, unless otherwise noted, are calibrated

**Column E, the record length, was determined in the following manner:
If the stratigraphically lowest sample was dated, the record length (Column E) simply equals the lowest calibrated date (Column B).
If the lowest dated sample is stratigraphically above the lowest sample in the core, then the age of the lowest sample was calculated by extrapolating from the lowest known date to the lowest point in the core, using the average calibrated sedimentation rate. This can be expressed for the columns as $E=((A-B)/D)+C$.

Chapter 6. Isotope Record (Climate Proxy) from Hidden and Rinker's Lakes

Oxygen Isotope Composition as Paleoclimate Proxy

Oxygen isotope fractionation is highly temperature dependent, since water molecules containing ^{18}O and ^{16}O have different kinetic energies (vapor pressures). As a result, the relative proportions of ^{18}O and ^{16}O in water in a small closed basin are a function of the temperature and duration of evaporation. Stable isotope ratios records can therefore be used as a source of information on past climatic condition and are especially sensitive to changes in aridity.

By convention, the relative proportions of ^{18}O and ^{16}O are reported by calculating $\delta^{18}O$ for a substance, using the formula:

$$\delta^{18}O = 1000(R_{sample}/R_{standard} - 1)$$

where $R = {}^{18}O/{}^{16}O$ and the $R_{standard}$ is VSMOW-CO_2, with a $\delta^{18}O=0$. This value is reported in permil (‰) as a proportion of one thousand, analogous to the reporting of proportions of a hundred as percent (%). The more positive the $\delta^{18}O$ value, the more enriched it is in ^{18}O; the more negative the $\delta^{18}O$ the more depleted it is in ^{18}O.

Most past research on using $\delta^{18}O$ in climate reconstructions has focused on global-scale temperatures and ice volumes, employing marine carbonates from vast ocean reservoirs (e.g. Emiliani 1955 or Shackleton and Opdyke 1973). In contrast, smaller reservoirs are more responsive to the conditions near them and terrestrial lakes are "sensitive recorders of relatively minor and localized climatic changes" (Forbes 1987:1). According to previous research, small, closed lakes such as those used in this study should be the best choices for creating an extra-local paleoclimate reconstruction (Forbes 1987, Stuiver 1970).

Stable oxygen isotope ratios of lake sediments are controlled by several factors, such as the composition of the lake water and the fractionation of isotopes due to carbonates precipitation. The composition of the water in the lake is primarily dependent on two factors; the $\delta^{18}O$ of precipitation entering the lake, and the $\delta^{18}O$ of water vapor leaving the basin through evaporation. Warm conditions deliver ^{18}O-enriched precipitation to a lake (Dansgaard 1964), leading to increased $\delta^{18}O$ in both the lake water and the carbonates created there. Warm dry conditions also result in increased evaporation from a lake, further enriching lake water in ^{18}O (Craig et al. 1963, Forbes 1987).

The isotopic composition of carbonates produced in a lake are a function of more than just the water chemistry (reservoir composition). The temperature of the water at the time of crystallization (McConnaughey 1986) and the energetics of the crystallization itself (Grossman and Ku 1982, Taruntani et al. 1969) also influence $\delta^{18}O$. Again, warmer conditions lead to greater concentrations of ^{18}O, and the $\delta^{18}O$ of carbonates increases with rising temperatures (Epstein et al. 1953, Forbes 1987, McConnaughey 1986). The physics of crystallization also enriches carbonates (the solid phase) in ^{18}O relative to the composition of lake water (the liquid phase)(McConnaughey 1986). This last factor is easy to control for because, all other things being equal, the disequilibrium between the solid and liquid phases is constant.

Previous Isotope Studies from the Study Area

Forbes' research on Duley and Goose Lakes confirmed that oxygen isotope records from lakes in the study area actually did track changes in climate. For example, the record from Duley Lake (Figure 3.7) showed an increase in $\delta^{18}O$ from about 11,000 to 9,500 years ago, consistent with the temperature rise that marked the transition from the Pleistocene to the Holocene. Likewise, he found that Goose Lake was controlled by climate, with a sequence of increased $\delta^{18}O$ values corresponding to the known mid-Holocene period of aridity documented from other records (Forbes 1987).

Forbes has cautioned that changes in $\delta^{18}O$ could not be directly converted to a ratio-scale temperature record, even though work done on modern samples shows that an increase of 1 °C usually results in a 0.7 to 1.3 permil (‰) increase in $\delta^{18}O$ values of precipitation into a basin (Dansgaard 1964, Stuiver 1970). Instead, Forbes (1987) suggested that oxygen isotope records from small lakes in eastern Washington be considered more indicative of relative aridity. He reasoned that if temperature were the only factor determining the $\delta^{18}O$ of lake water, then lake water and precipitation recharging the lakes would be equal. He found, instead, that lake water was 10 permil enriched in ^{18}O with respect to local precipitation, which could only happen if evaporation was preferentially removing the lighter isotope. Forbes (1987) calculated that it would take an annual loss of roughly 30% from the lake's volume to account for the observed enrichment; independent observations confirmed that a third of the water in Goose Lake was lost each year to evaporation (Forbes 1987, Washington State University 1975 in Forbes 1987). In lakes in the study area, Forbes showed that more positive, enriched values could be interpreted as warm, dry conditions, and negative values would be characteristic of cool, moist conditions. Consequently, no attempt will be made to convert $\delta^{18}O$ values directly to paleotemperature (°C) values.

Isotope records from the Hidden and Rinker's Lakes

For this analysis, isotope samples were taken from the Hidden and Rinker's Lake cores (Figures 6.1 and 6.2). Eleven marl samples of between 0.2 and 1.7 g (dry weight) were taken from each lake and submitted to Matt Emmons at Mountain Mass Spectrometry (Evergreen Colorado). A list of the twenty-two samples submitted and the resulting stable isotope measurements are reported in Table 6.1. Dates for each sample, in years B.P., were interpolated based on each sample's stratigraphic depth relative to the mean calibrated radiocarbon dates and sedimentation rates from Table 5.3.

Individual samples were taken from a narrow range of stratigraphic depths, in order to minimize the span of time represented by any one sample. Each of the samples submitted spanned 5 mm, or approximately 11-13 years of sedimentation, in the core. Besides sedimentation rate, the turnover rate of the lakes also had to be considered in sampling. If these were large lakes, the water in the basin itself and its isotopic composition could be the product of 100 years or more of precipitation and evaporation, and thus would block any attempt to achieve a decadal-scale resolution. However, the turnover, or residence time, of the water in these shallow perennial basins is only one to three years (Forbes 1987) resulting in isotopic water composition that is representative, at any one point in time, of at most three years' worth of rain and evaporation. Each sample represents, at worst, a palimpsest of 16 years of climatic history. This satisfies the requirement that each data point span 50 years or less, so that it can be meaningfully compared with the already established paleodemographic record.

Results from the samples taken in the manner described are plotted in Figure 6.3. These data span the past 1,458 years, and results from both Hidden and Rinker's Lakes are displayed together. This plot shows that both records display short-term, centennial-scale, warming and drying episodes over the past thousand years. The high frequency of this variability shows that a decadal-scale signal is reflected in the data; any loss of resolution would have produced a smoother record.

Visual inspection of this graph also shows that, for any given point in time, the two lakes have different isotopic compositions, with Hidden Lake consistently more enriched in ^{18}O than Rinker's Lake. This is probably due to a difference in how the carbonates in the two lakes have mineralized. Carbonate, $CaCO_3$, can form different solid phases (such as dolomite, calcite, and aragonite). The energetics involved in the crystal formation of each phase differs, such that each phase has its own fractionation signature (Forbes 1987, Grossman and Ku 1982, Taruntani et al. 1969). Aragonite, for example, is isotopically heavy, incorporating proportionately more ^{18}O in its crystalline structure than calcite under equivalent conditions of water composition and temperature (Forbes 1987, Grossman and Ku 1982). Composition of aragonite itself can vary under constant conditions if different pathways are used to fix the oxygen. For example, photosynthetic algae and gastropods living in the same lake secrete biogenic aragonite with different $\delta^{18}O$ signatures; carbonates precipitated by algae tend to be more depleted in ^{18}O (have more negative $\delta^{18}O$ values) than carbonates in gastropod shells (Forbes 1987, Fritz and Poplawski 1974, Stuiver 1970)

Deposition of different carbonate phases in the two lakes is a reasonable explanation of the higher, relatively depleted $\delta^{18}O$ values seen at Hidden Lake (Figure 6.3). This is in agreement with the sediment descriptions from Hidden and Rinker's Lakes. Hidden Lake sediments had gastropod shells in the algal carbonates and lake marl, whereas Rinker's Lake did not contain gastropod shells, just algal carbonates and lake marl (Figures 5.5, 5.6). The lake with the gastropods (Hidden) should have higher $\delta^{18}O$ values, and the lake lacking gastropods (Rinker's) should have more negative $\delta^{18}O$ values; this is exactly what is seen in the results.

Forbes (1987), likewise, observed that Goose and Duley Lakes had different basal $\delta^{18}O$ values, but that the two lakes still reacted in kind to climatic fluctuations. Again, only one lake (Goose) contained gastropod remains, and this was the lake with more positive $\delta^{18}O$ baseline values (Forbes 1987). Based on Forbes' findings, Hidden and Rinker's Lakes can be expected to behave in a similar fashion; although starting with different isotope enrichment values, changes in $\delta^{18}O$ values both lakes can be expected to parallel one another. Visual inspection of the results from the two lakes (Figure 6.1) demonstrate that Hidden and Rinker's Lakes do indeed covary with one another, synchronously tracking changes in climate in the study area.

Combining Results into a Composite Isotope Index

Given that Hidden and Rinker's Lakes should be recording the same climatic fluctuations, it would be advantageous to combine the two records in some meaningful way into a composite index that reflects area trends over time. Although the samples are associated with different radiocarbon ages, linear interpolation can be used to estimate the values of the intervening points so that $\delta^{18}O$ can be estimated for coeval points from the two lakes. Interpolation between stable oxygen isotope samples can also be used to create a local climate record that is comparable to the existing paleodemographic record by calculating $\delta^{18}O$ values for each 50 cal-year interval from A.D. 950 to 1900. The resulting values are presented in Columns B and C of Table 6.2.

Another barrier to combining the two records is that the basal composition of the two lakes differed by several permil. As seen in Figure 6.3 and Table 6.2, oxygen isotope values at Hidden Lake averaged -4.47‰, while those at Rinker's Lake averaged -7.53‰. Isotope values were mathematically transformed in order to compensate for this difference in isotope enrichment between the two lakes and allow information from both lake records to be combined into a single isotopic composition index for the study area. Observations from each lake were taken separately and re-expressed in terms of their deviations from the mean isotopic composition of the lake, and these values were standardized by dividing them by the standard deviation of $\delta^{18}O$ values from each lake. Use of these standardized deviations (or "z-scores") for each observation removed the systematic bias (the 3.06 ‰ average difference between the lakes), and made it possible to meaningfully combine the isotopically enriched record from Hidden Lake with the relatively isotope-poor record from Rinker's Lake. Since all the original values were negative, the new composite data were multiplied by a factor of -1 to preserve the sign of the original observations. The composite index computed in this manner is given in Table 6.2 (Column F), and is plotted in Figures 6.4 (against calibrated B.P. dates) and 6.5 (fit with a spline and plotted against calendrical dates).

The composite isotope index from the Hidden and Rinker's Lake (Figure 6.4), suggests that climate conditions in the study area a thousand years ago were a little drier than today. The records indicate that, starting about a thousand years ago, there was a trend towards moister conditions which attained a local maximum at about 600 B.P., and then began to swing towards more xeric conditions. Based on the isotope data, this drying trend reached its local maximum at around 400 B.P., and was then followed by a final trend towards moister that continues until the present.

Relating this record to other regions and global climate, there is evidence for a local expression and recording of two short-term climatic events identified elsewhere as the "Medieval Warm Period" (MWP) and the "Little Ice Age" (LIA). The trend towards more mesic conditions, as seen in the Hidden and Rinker's lake cores, begins about 1,000 B.P. and ends around 600 B.P. (A.D. 950 to A.D. 1350). The timing of this event is similar to that of the "Medieval Warm Period," which was globally characterized as a slight rise in annual temperature that occurred between A.D. 900 and A.D. 1350 (Crowley and Lowery 2000, Grove and Switsur 1994, Hughes and Diaz 1994, Meese et al. 1994). In this study area, a coeval event is observed, but is expressed locally as a period of relatively moist conditions, not higher temperatures.

The second major feature seen in the Hidden and Rinker's Lake cores is an arid episode that roughly corresponds in time to the climatic fluctuation called the "Little Ice Age" (LIA). As it was globally expressed, the LIA was a period of lowered mean temperatures between the sixteenth and nineteenth, culminating in maximally cold conditions between A.D. 1570 and 1730 (Bradley and Jones 1993). In the records provided by Hidden and Rinker's Lake, there is a small climatic event that began about 600 B.P. (A.D. 1350), reached a maximum at 400 years ago (A.D. 1550) and ended in the last hundred years. This is similar in timing to the stereotypical characterization of the Little Ice Age, although in the study area, this climatic event seems to have a slightly later onset. The nature of this event is unique in the study area as well; it is typified by more arid conditions rather than the cooler conditions seen both globally and in other regions.

Historical Constraints on Climate

How much is climate historically constrained in the study area, and on what time scales? To what extent is the oxygen isotope record conditioned by past values of itself? One way to examine the extent to which past climatic conditions influence future climatic conditions is to introduce lags into a correlation model. For a lag of 50 years, for instance, the isotope value from A.D. 1900 can be compared to A.D. 1850, the value from A.D. 1850 is compared to A.D. 1800, and so on. In like manner, lags of 100, 150, 200 or even 500 years can also be introduced and correlations run between observations and the values that preceded them. Results of such an analysis are presented in Table 6.3.

As Table 6.3 shows, the oxygen isotope record is significantly and positively correlated with future values of itself when one (50-year) or two (100-year) lags are entered into the model. For longer time periods (150 to 300 years), there is no statistically significant relationship. As one might logically expect, climate is not truly a random variable but is historically constrained. However, the proxy record indicates that this effect only operates simply and clearly on the relatively short term (up to 100 years).

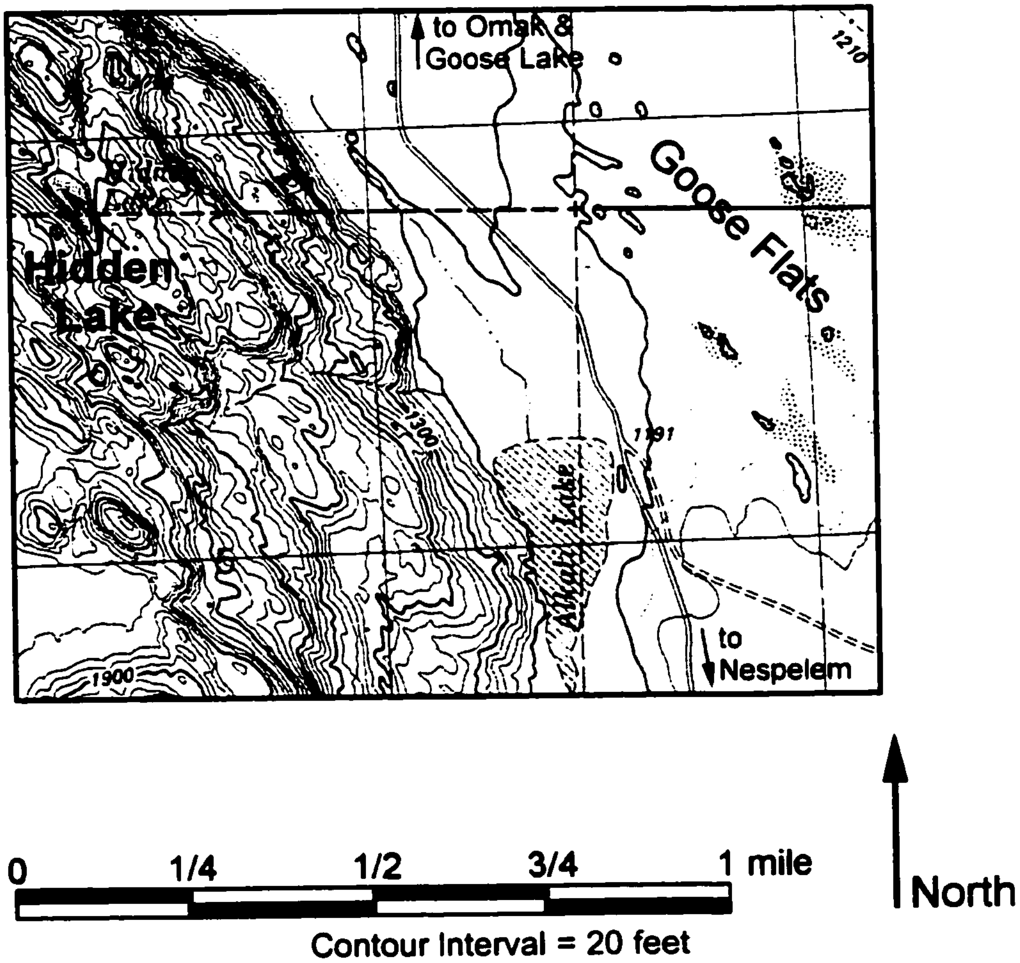


Figure 6.1. Detailed Location Map of Hidden Lake
(Adapted from USGS 7.5' Boot Mountain, WA 1980)

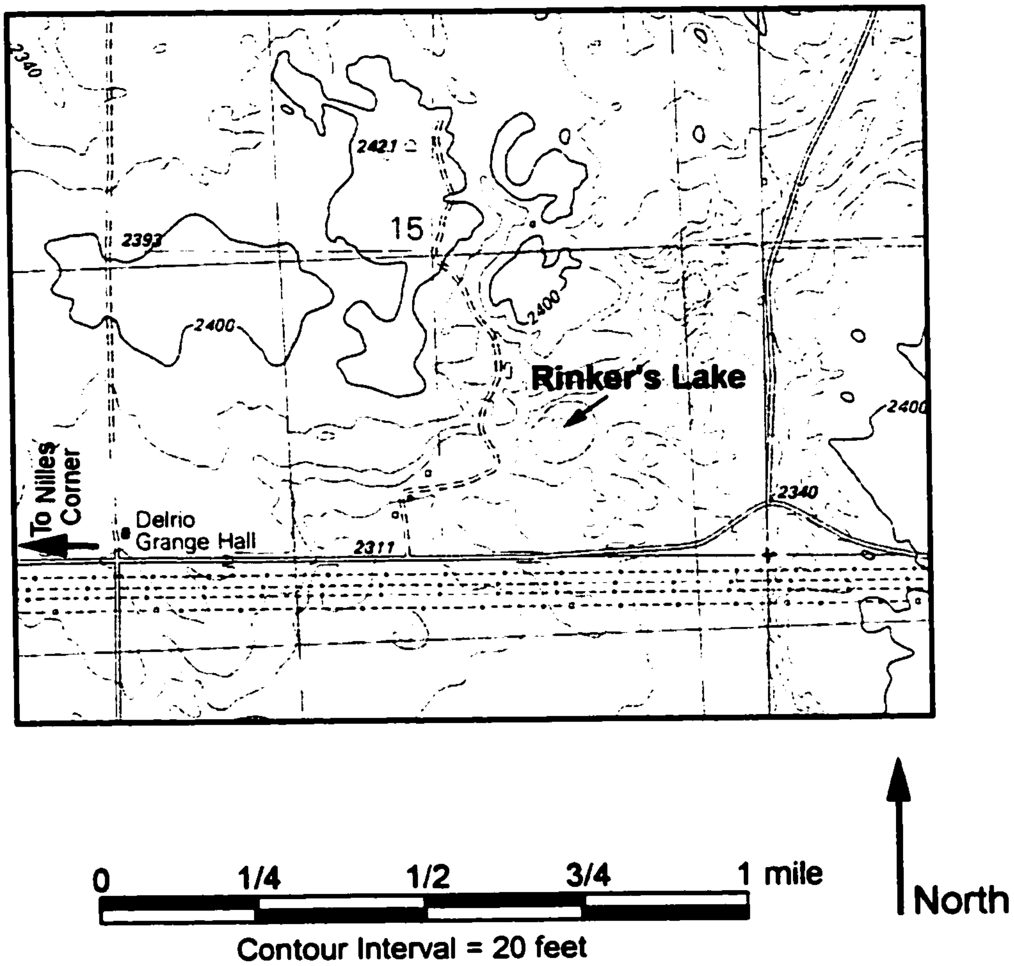


Figure 6.2 Detailed Location Map of Rinker's Lake
(Adapted from USGS 7.5' Trefry Canyon, WA 1980)

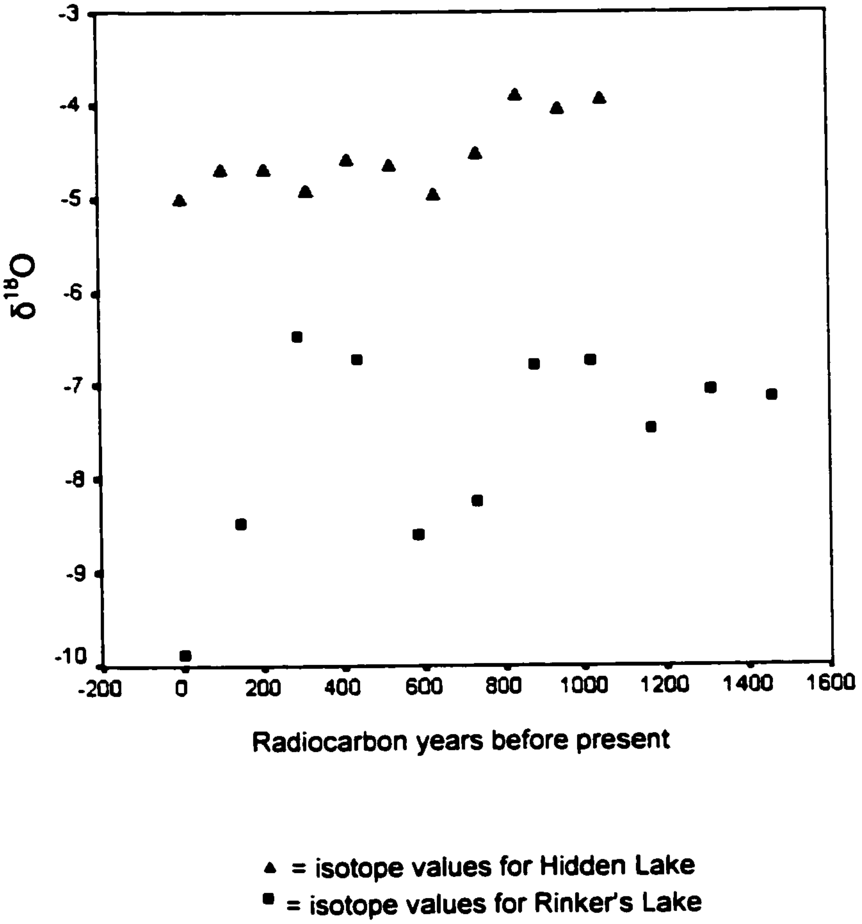


Figure 6.3. Oxygen Isotope δ^{18}O Results for Hidden and Rinker's Lakes

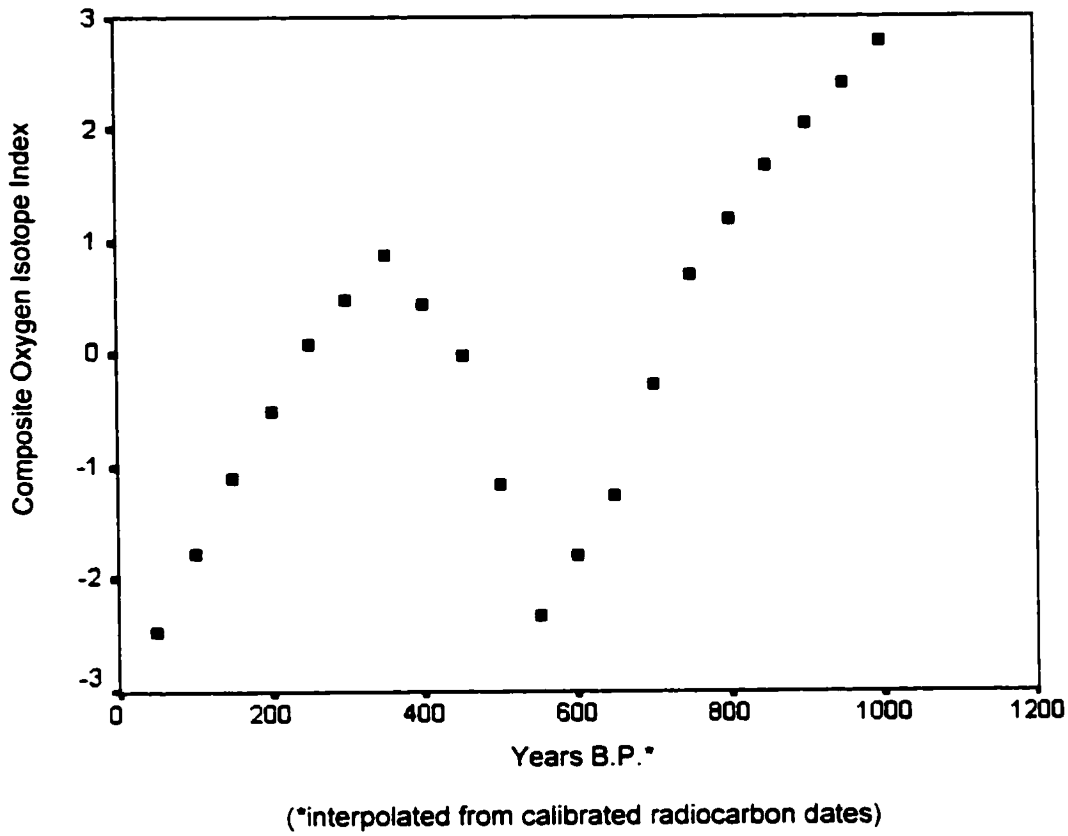


Figure 6.4. Composite Oxygen Isotope Index (Climate Proxy) *Vs* Radiocarbon Years Before Present

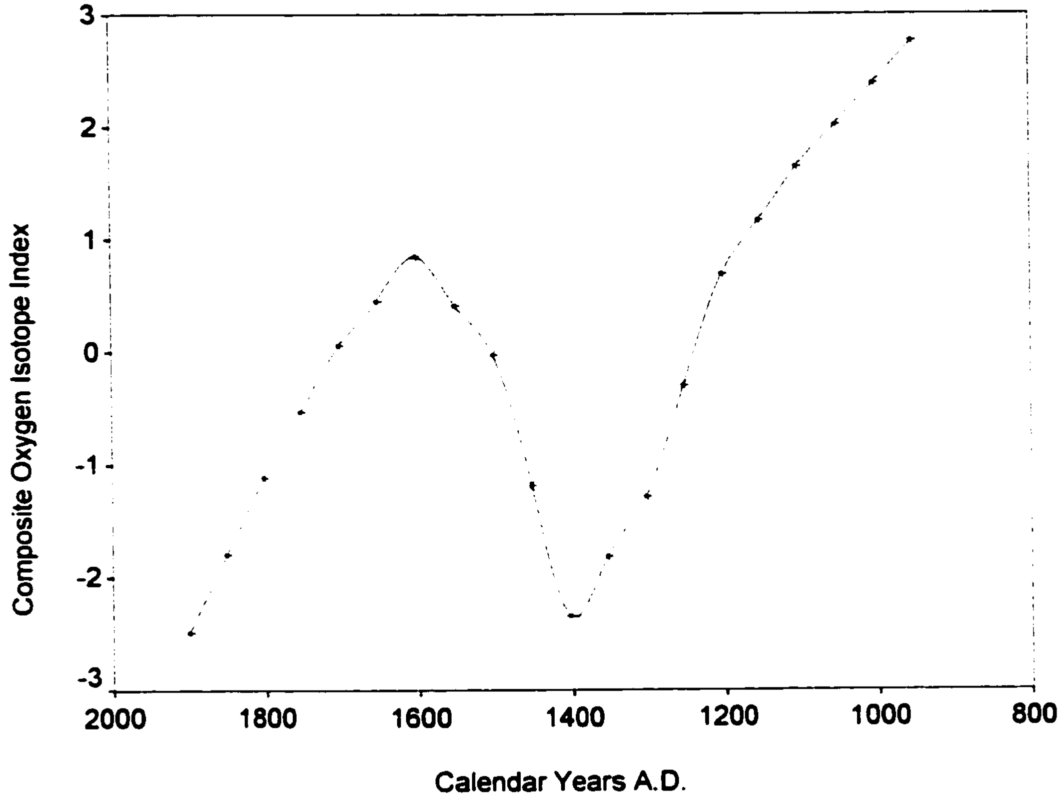


Figure 6.5. Composite Oxygen Isotope Index (Climate Proxy) *vs* Calendar Years A.D.

Table 6.1. Oxygen Isotope Sample Description and Results

Lake	Depth (cm bi)	Age B.P.*	Dry weight (g)	$\delta^{18}O$ reported by lab (‰)
Hidden	0	0	0.2	-5.00
Hidden	5	105	1.0	-4.70
Hidden	20	210	0.5	-4.69
Hidden	15	314	0.8	-4.92
Hidden	20	419	0.6	-4.59
Hidden	25	524	0.7	-4.65
Hidden	30	629	0.7	-4.96
Hidden	35	734	0.8	-4.52
Hidden	40	839	0.5	-3.90
Hidden	45	943	0.6	-4.04
Hidden	50	1048	1.7	-3.94
Rinker's	0	0	0.4	-9.87
Rinker's	5	146	0.6	-8.47
Rinker's	20	292	0.5	-6.46
Rinker's	15	437	0.5	-6.71
Rinker's	20	583	0.7	-8.61
Rinker's	25	729	0.9	-8.24
Rinker's	30	875	1.1	-6.79
Rinker's	35	1020	1.0	-6.75
Rinker's	40	1166	1.2	-7.47
Rinker's	45	1311	1.6	-7.06
Rinker's	50	1458	1.1	-7.13

*based on interpolation from calibrated radiocarbon date

Table 6.2. Interpolated Oxygen Isotope Values for each 50-cal year Study Interval

Column A Date cal A.D.	**Column B** Hidden Lake Interpolated $\delta^{18}O$	**Column C** Rinker's Lake Interpolated $\delta^{18}O$	**Column D** z-score for Hidden Lake Isotope Values	**Column E** z-score for Rinker's Lake Isotope Values	**Column F** Composite Isotope Index*
1900	-4.70	-8.98	-0.58	-1.88	-1.23
1850	-4.70	-8.45	-0.58	-1.20	-0.89
1800	-4.70	-7.92	-0.58	-0.51	-0.55
1750	-4.80	-7.28	-0.84	0.33	-0.25
1700	-4.90	-6.63	-1.09	1.17	0.04
1650	-4.75	-6.62	-0.71	1.19	0.24
1600	-4.60	-6.60	-0.33	1.21	0.44
1550	-4.65	-6.84	-0.46	0.89	0.22
1500	-4.70	-7.08	-0.58	0.58	0.00
1450	-4.85	-7.69	-0.96	-0.20	-0.58
1400	-5.00	-8.29	-1.34	-0.99	-1.16
1350	-4.75	-8.37	-0.71	-1.08	-0.90
1300	-4.50	-8.44	-0.08	-1.18	-0.63
1250	-4.20	-8.26	0.67	-0.95	-0.14
1200	-3.90	-8.08	1.43	-0.71	0.36
1150	-3.95	-7.62	1.30	-0.11	0.59
1100	-4.00	-7.15	1.18	0.49	0.83
1050	-3.95	-6.96	1.30	0.74	1.02
1000	-3.90	-6.77	1.43	0.99	1.21
950	-3.85	-6.58	1.55	1.23	1.39
	$\bar{x}$ = -4.47	$\bar{x}$ = -7.53			
	s_x = 0.40	s_x = 0.77			

Table 6.3. Composite oxygen Isotope Index Autocorrelations (Correlations between the Composite Isotope Index and Future Values of Itself)

Significant Autocorrelations

	Correlation (Pearson's *r*)	Significance (*p*)
1 lag (50 years)	+0.910	< 0.0001
2 lags (100 years)	+0.658	< 0.003

Insignificant Autocorrelations

	Correlation (Pearson's *r*)	Significance (*p*)
3 lags (150 years)	+0.283	< 0.271
4 lags (200 years)	-0.132	< 0.626
5 lags (250 years)	-0.439	< 0.101
6 lags (300 years)	-0.592	< 0.026
7 lags (350 years)	-0.464	< 0.111
8 lags (400 years)	-0.159	< 0.623
9 lags (450 years)	+0.243	< 0.472
10 lags (500 years)	+0.718	< 0.019

Chapter 7. Pollen Record (Vegetation Proxy) from Five Lakes

Geographical Context

Of all the basins cored for this study, Five Lakes was the most likely to produce a good pollen record. Five Lakes is located in Okanogan County, 9.5 km north of the Grand Coulee Dam and 5.5 km southeast of the modern town of Nespelem (Figure 3.5). The basin cored was the largest in the cluster of basins that make up the Five Lakes, and a detailed map of the basins and coring location is given in Figure 7.1. Because the basin is closed and small, the pollen it receives is expected to come predominantly from vegetation sources within about a 10 km radius of the lake.

Figure 3.5 shows the proximity of both modern and prehistoric population centers to Five Lakes. A group of known prehistoric winter villages that cluster along a bend in the Columbia River lie 6 km southwest of the coring site -- well within the pollen source area for the lake. Pollen being deposited in Five Lakes should literally be derived from the vegetation with which people have interacted for over a millennium.

A further advantage of using Five Lakes derives from its location at an elevation of 750 m asl. This places the lake near the modern elevational boundary between the pine woodlands and the open sagebrush-grass shrub steppe. Since the lake is located at the ecotone between major vegetation zones and is expected to provide an extralocal pollen signal, it should track subtle changes in the dominance and elevational distribution of woodlands *versus* steppe over time.

Five Lakes Pollen Dataset

The pollen counts from Five Lakes are recorded for reference purposes in Appendix G. These raw data were converted into percent abundances, and are given in graphical form in Figure 7.2. The record is dominated by pine (*Pinus*), with lesser contributions from larch (*Larix*), Douglas fir (*Pseudotsuga*), hemlock (*Tsuga*), maple (*Acer*), oak (*Quercus*), birch (*Betula*), alder (*Alnus*), spruce (*Picea*), fir (*Abies*), other trees (e.g. *Populus* and other rare types) goosefoot family (Chenopodiaceae), sagebrush (*Artemesia*), other composits (Asteraceae), grasses (Poaceae family), and other rare herbaceous types (from the Apiaceae and Polygonaceae). Of these, only a few taxa ever contribute significantly to the pollen percentage. If insignificant taxa are defined as those that never contribute over 5% to any pollen assemblage, then the significant minor taxa include only members of the following genera and families: *Picea*, *Artemesia*, *Betula*, *Alnus*, Chenopodiaceae, Asteraceae, and Poaceae.

Table 7.1 lists the taxa from Five Lakes, and divides them into categories of major, minor, or rare taxa. These designations are important from a vegetation (community) standpoint as well as from a statistical standpoint. Rare taxa occur so infrequently in the 500-grain pollen counts used in this study that the error of estimating their abundance is too great to allow their measured percent contribution to the pollen spectra to be statistically reliable. Statistical tests presented in this chapter, as well as in the results section (Chapter 9) will therefore ignore the role of rare taxa.

Interpretation of Pollen Results

The most striking aspect of the pollen percentage diagram (shown in Figure 7.2) is that the record of the past 1,525 years has been dominated by *Pinus* throughout. Looking at the record as a whole, several trends are evident. Figure 7.2 shows that *Pinus* decreases in abundance over time, while the relative contributions of *Betula*, Chenopodiaceae, Poacea, *Artemesia*, and other Asteraceae simultaneously increase. Statistics confirm these impressions, and correlations between the abundance of each taxon and depth are presented in Tables 7.2 and 7.3. These data demonstrate that the taxa listed above do show significant directional changes in percent abundance; *Betula*, Chenopodiaceae, Poacea, *Artemesia*, and some other Asteraceae (*Aster* and *Ambrosia*) are all significantly negatively related with depth, with *Pinus* positively correlated with depth.

Although most of the taxa show a directional change throughout the core, even this overall trend can be broken down further into two separate zones within the pollen record. Visual inspection of the pollen diagram in Figure 7.2 indicates that there is a lower zone extending from about 50 to 145 cm bi (593 to 1,525 B.P.), characterized by high and constant domination by *Pinus*. In contrast, there is an upper zone characterized by a lower and more variable abundance of *Pinus* starting around 50 cm bi and extending to the top of the core (0 cm bi).

Pollen data were submitted to PCA (principal components analysis) using SPSS v.10, and results are listed in Tables 7.4 and 7.5. Figure 7.3 presents samples plotted as a function of the two main multivariate axes, showing the placement of the successive samples relative to each other in multidimensional space. The graph suggests that there are two main spaces being occupied by the samples. These two multidimensional spaces are shown as shaded areas in Figure 7.4, an annotated version of the same data provided in Figure 7.3. Figure 7.4 shows that the series of samples in multidimensional space can be easily divided into two separate sets of contiguous samples. One coherent set of points is made up of samples from the upper zone of 0-40 cm bi, as seen grouped together in the shaded area to the left of the plot in Figure 7.4. A second coherent set of points is made up of the more closely spaced set samples that are all drawn from 45 to 145 cm bi (as seen at the right in Figure 7.4).

The two zones differ in two main ways – in their abundance of arboreal (mostly pine) pollen and in the stability of the pollen types within the zones. The lower zone from 145 to 45 cm bi corresponds to a time period from roughly 1,525 to 529 B.P. This zone contains a high and consistent domination of *Pinus* at an average of 80% throughout the zone. Nonarboreal taxa – shrubs and herbaceous plants -- account for a small percentage of the assemblage, averaging only 11% of the pollen sum for the whole time period. In comparison, the upper, more recent pollen zone shows a significantly lower and more variable amount of pine, with an average of only 60% of all pollen grains coming from the genus *Pinus* (see Figure 5.2).

This difference can be interpreted in several ways. This trend in pine and nonarboreal pollen types indicates that during the early period, pine was relatively more abundant than it is today. Pine was more common on the landscape and pine forests covered a greater areal extent and extended into lower elevations at that time than they do today. This also implies that herbaceous and shrubby taxa were relatively less common and less important during the early part of this record, as shown by Figure 7.2.

This is confirmed by the influx data, an absolute measure of *Pinus* pollen deposition. *Pinus* pollen accumulation rates (PAR, measured in grains/cm^2/yr) can be taken as a proxy measure for the number of trees of this genus present on the landscape. Figure 7.6 (based on data in Appendix G) shows the influx of pine pollen, indicating that there were more pine pollen grains being produced and deposited during the early part of the pollen record. Likewise, the influx record for nonarboreal pollen (shown in Figure 7.7, from data in Appendix G) confirms that lower relative abundance of nonarboreal taxa in the lower zone is a reflection of a lower absolute number of nonarboreal plants on the landscape.

Other than being more heavily dominated by pine, the lower zone also has a less variable taxonomic composition and representation -- there are no smaller scale low-amplitude or low-frequency events that can be resolved. The upper zone shows a less stable vegetation, with higher variability within the zone. This was suggested by the plot of samples in multidimensional space, shown in Figures 7.3 and 7.4. These figures show that the points representing samples in the lower zone are more closely clustered together than are the points for samples from the upper zone. Obviously, the samples from the lower zone are more coherent and more similar to each other than are the samples from the upper zone.

For greater clarity, the same information gleaned from principle components analysis can be transformed and presented in a simplified manner using detrended components analysis (DCA). DCA results are in Figure 7.8, with detrended scores from the first axis (which explains over 80% of all variability) plotted against sample depth. This shows that the scores change little between 145 and about 60 cm bi. Starting at 60 cm bi, the values begin to rise and fall with a greater amplitude, indicating greater rates of change between samples in the 60 to 0 cm bi portion of the core.

An examination of the pollen zones and the changing abundances of pollen taxa over time suggests that certain sets of taxa covary with one another. A calculation of the correlation between taxa, as measured by Pearson's *r*, is given in Tables 7.6-7.9. Tables 7.6 and 7.7 list only statistically significant ($p \leq 0.01$) correlations between taxa, which will be discussed below.

As one might expect, the dominant taxon, *Pinus*, is negatively correlated with nearly all of the minor taxa (Tables 7.1 and 7.7) since a decrease in *Pinus* on the landscape opens the land for colonization by other plants. *Pinus* is significantly negatively correlated with many of the important minor taxa such Chenopodiaceae, Poaceae, *Alnus*, *Betula*, and most of the members of the Asteraceae family (*Artemesia*, *Aster*, and *Ambrosia*). This confirms that pines expand at the expense of more seral herbaceous and shrubby species, and that decreases in pine woodlands encourage the expansion of open "disturbance" vegetation.

Looking at the nondominant taxa shows that several pairs of minor (but not rare) taxa in the pollen diagram covary with each other. For example, *Alnus* and Poaceae are significantly positively correlated with each other, as are *Betula* and Chenopodiaceae, *Betula* and *Artemesia*, as well as Poaceae and *Artemesia*. The PCA results confirm this; the scores for all these taxa (*Alnus, Betula* Chenopodiaceae *Artemesia, Ambrosia,* and *Aster*) on the first principle component are very similar in both sign and magnitude, and this dimension explains more than 60% of the variability in all samples over time (Table 7.5) All of these taxa are considered to be indicative of disturbance or land clearance when found in pollen diagrams in the Northwest. And, indeed, the bivariate correlations and PCA confirm that these taxa form a coherent suite of taxa. When any one of these pollen types increases, it signals a change in underlying disturbance variable and signals changes in the amount of disturbed, open land.

Again, all of these indicators are high in the upper 50 cm of the core, indicating a period of relatively high disturbance and a recession of wooded areas in the past 593 years. This confirms the results of previous pollen studies that indicated a rise in disturbance taxa, such as Chenopodiaceae, in recent historical times. It is at odds, however, with the exact magnitude and timing of similar events seen in other pollen cores in the interior Northwest. For example, at Wildcat Lake, the historic rise in Chenopodiaceae was more substantial, with Chenopodiaceae accounting for a full 47% of the modern pollen spectrum (Davis et al. 1977). At Five Lakes, modern Chenopodiaceae never exceed 10% of the entire assemblage at any time over the past 1,525 years. At Wildcat lake, disturbance species increase starting about 100 years ago (Davis et al. 1977); at Five Lakes the disturbance indicators rise much earlier, around 593 years ago.

Overall, then, the pollen record at Five Lakes follows the trends expected from earlier pollen work in the region. As expected, the late prehistoric period is dominated by arboreal pollen. Also, as expected, the historic period shows an increase in the abundance and absolute influx of disturbance, steppe and understory taxa such as *Artemesia*, Asteraceae, *Betula*, and Chenopodiaceae.

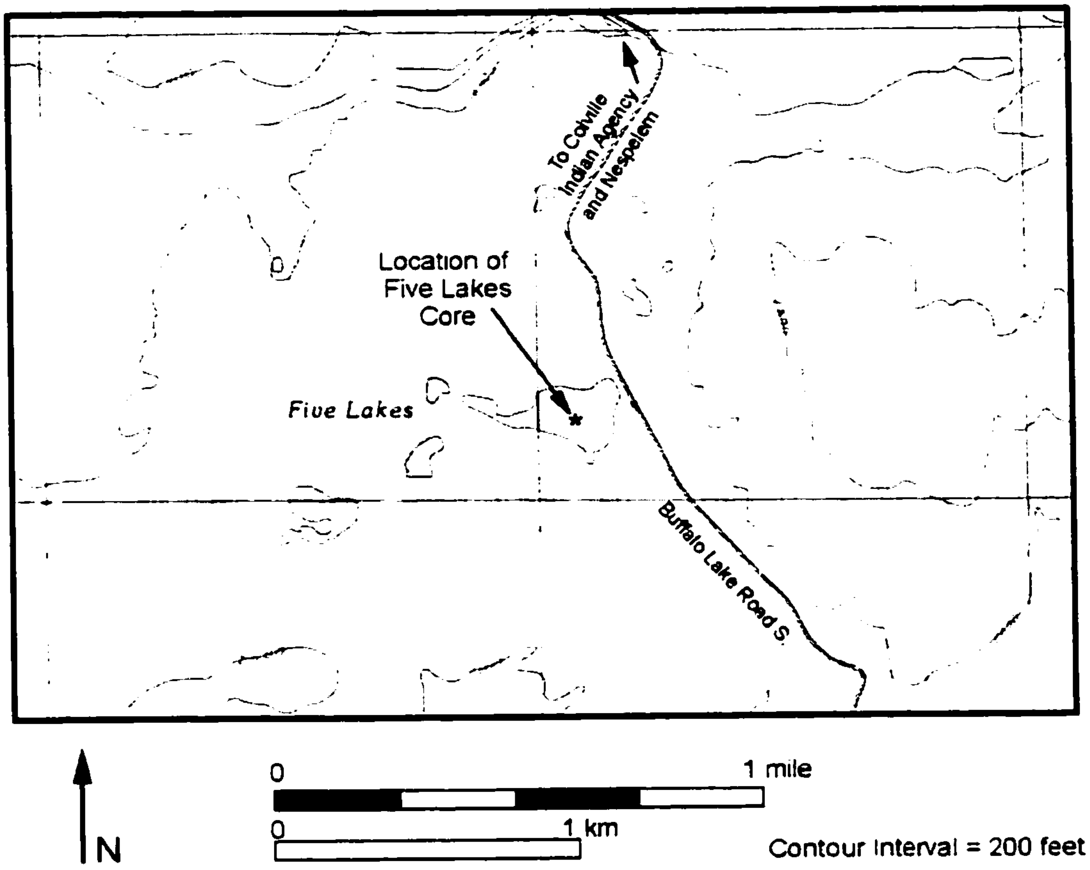


Figure 7.1. Detail Map of Five Lakes Showing Coring Location within the Basin

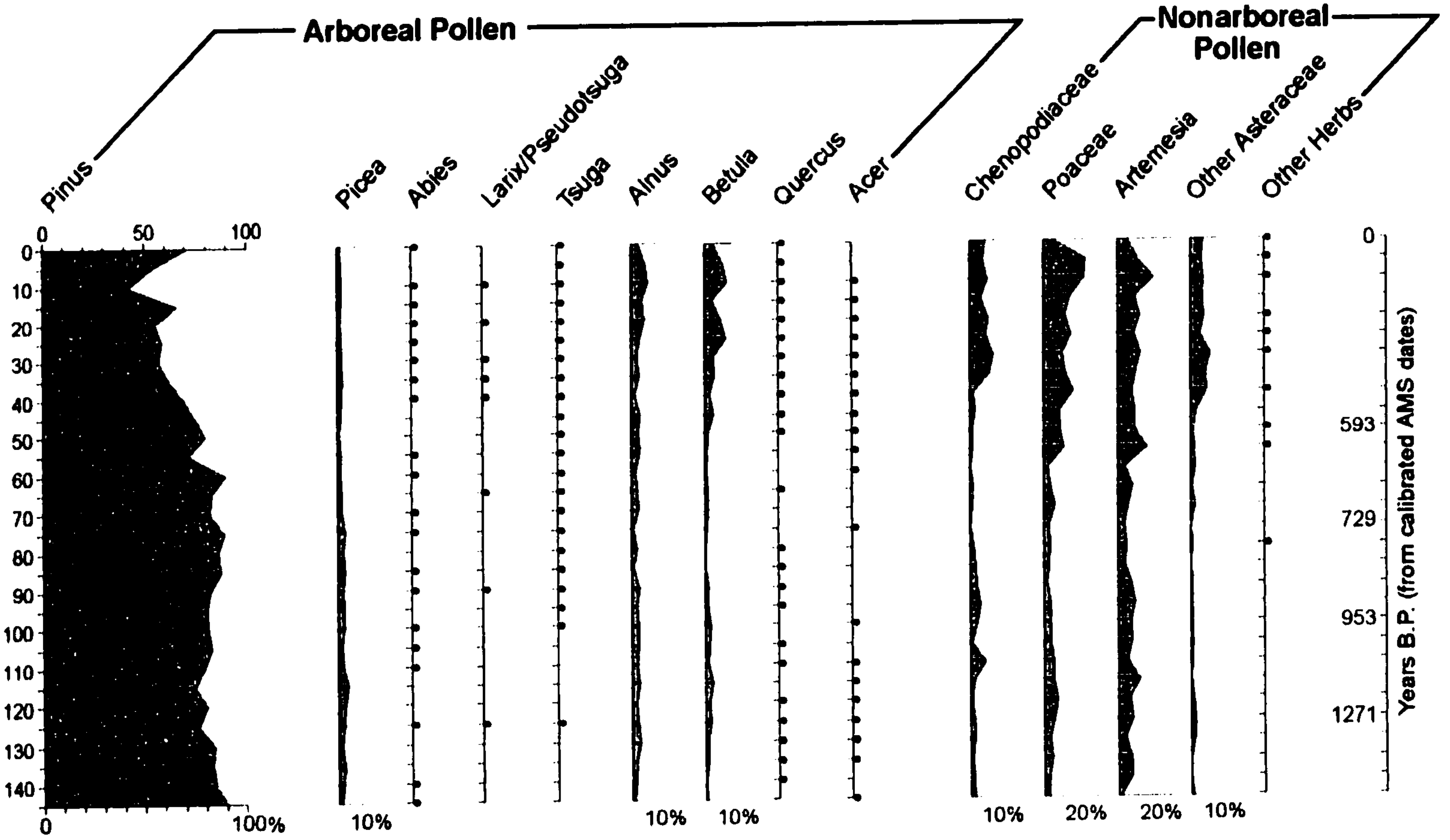


Figure 7.2. Pollen Diagram for Five Lakes, OK Co., WA

Note: dots indicate the presence of taxa at levels consistently less than 5% of the assemblage.
"Other herbs" includes rarely occurring taxa such as Polygonaceae and Apiaceae.

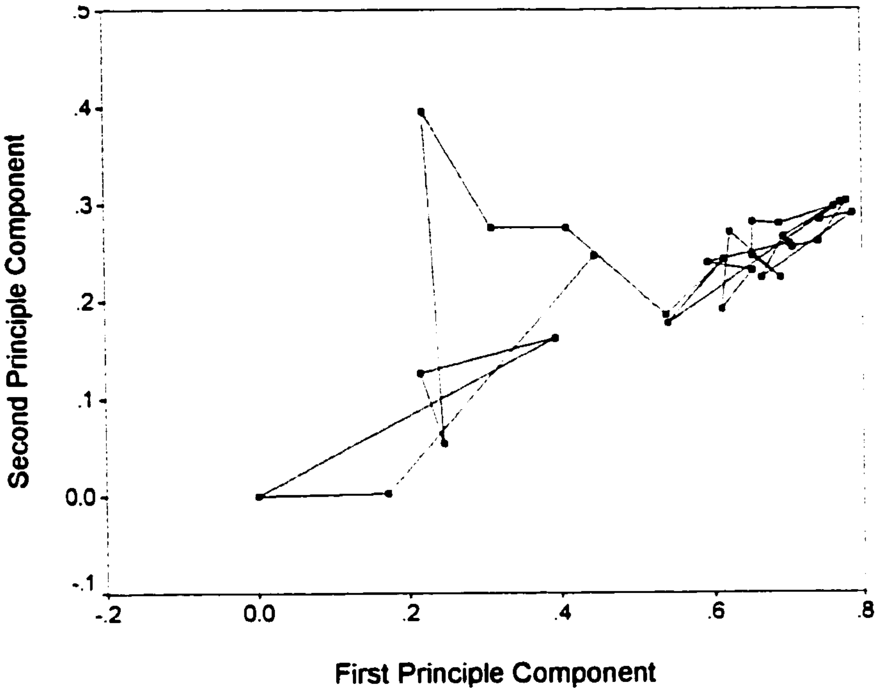


Figure 7.3. First and Second Principle Components Derived from Pollen Spectra

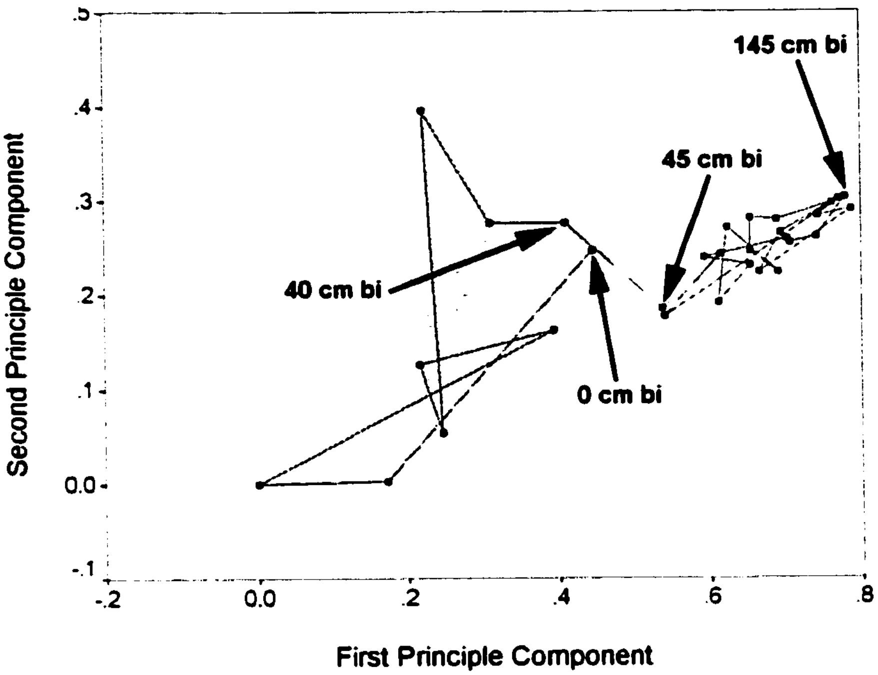


Figure 7.4. Annotated First and Second Principle Components

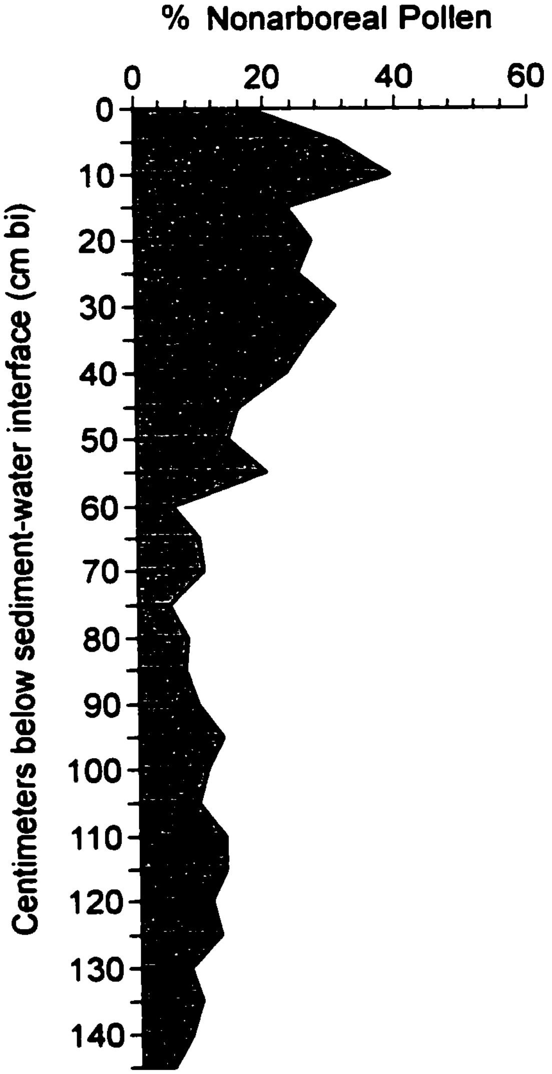


Figure 7.5. Percent of Nonarboreal Pollen with Stratigraphic Depth

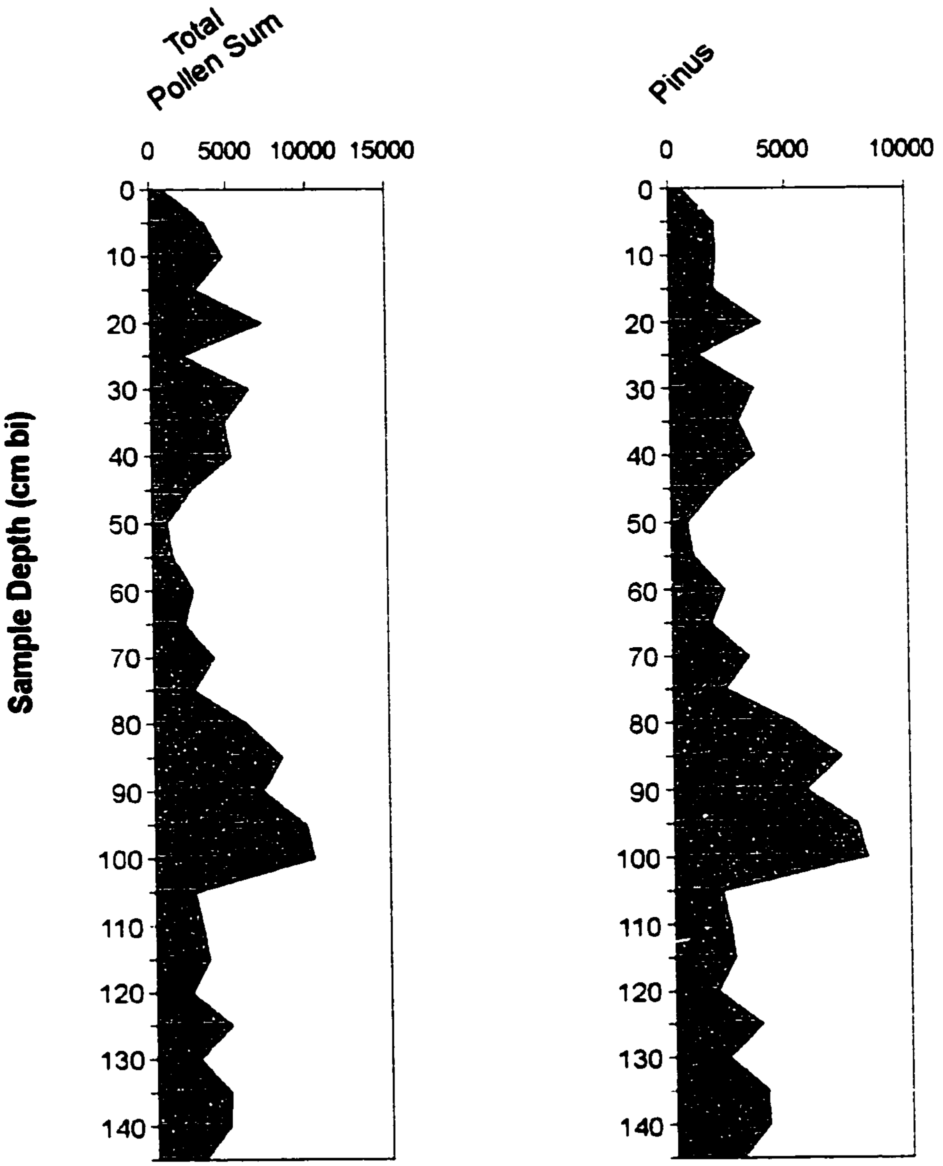


Figure 7.6. Absolute Influx* of for all Pollen Grains (left) and Pine grains (right)

*Pollen Accumulation Rate (PAR) in grains/cm^2/yr

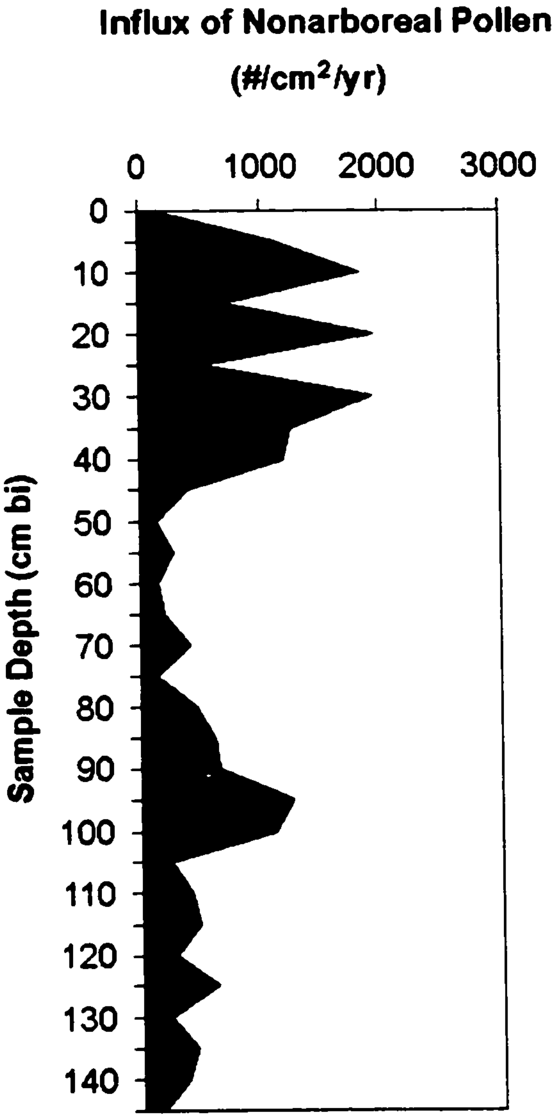


Figure 7.7. Absolute Influx* for Nonarboreal Pollen

*Pollen Accumulation Rate (PAR) in grains/cm^2/yr

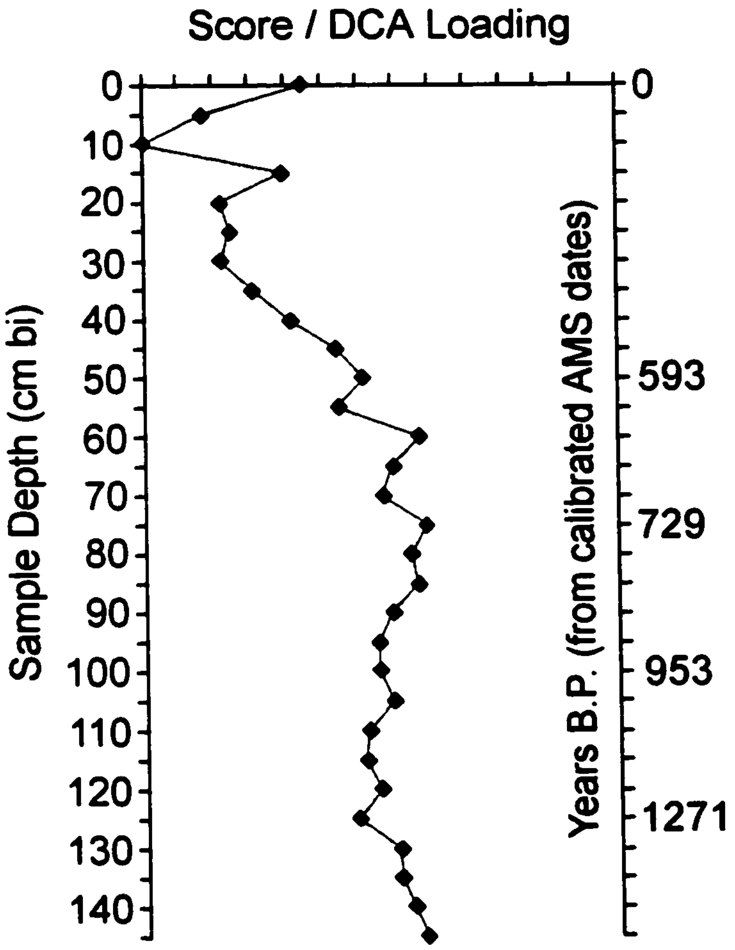


Figure 7.8. DCA* (Detrended Components Analysis) Scores by Depth and Time

(*DCA values calculated using MVSP v3.1 for Windows)

Table 7.1. List of Taxa from Five Lakes Pollen Record

Characterization of Taxa from Five Lakes Pollen Record

Dominant Taxon (most abundant -- over 30% of any sample)
- Pinus

Minor Taxa (significant contributors under 20% of any sample)
- Chenopodiaceae
- *Picea*
- *Betula*
- Poaceae
- *Alnus*
- Asteraceae:
  - *Artemesia*
  - *Ambrosia*
  - *Aster*
  - Ligulaflorae

Rare Taxa* (never contribute 5% or more to any sample)
- Apiaceae
- *Larix/Pseudotsuga*
- *Abies*
- *Quercus*
- *Acer*
- *Tsuga*
- Polygonaceae

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*rare taxa have such low percent abundances that their contributions cannot be estimated with stastical confidence with sample sizes such as those employed in this study. (Pollen samples were counted to a minmum of 500 terrestrial grains per sample for this study). These taxa should be ignored in statistical tests.

Table 7.2. Significant Correlations between Taxa and Sample Depth from Five Lakes

Positive Correlations

Taxon/Taxonomic Group	Correlation (Pearson's *r*)	Significance (*p*)
Pinus	+0.730	< 0.0001
Picea	+0.585	< 0.001
AP	+0.764	< 0.0001

Negative Correlations

Taxon/Taxonomic Group	Correlation (Pearson's *r*)	Significance (*p*)
Betula	-0.658	< 0.0001
Alnus	-0.523	< 0.003
Quercus	-0.604	< 0.0001
Chenopodiaceae	-0.588	< 0.001
Poaceae	-0.484	< 0.007
Artemesia	-0.711	< 0.0001
Ambrosia	-0.726	< 0.0001
Aster	-0.696	< 0.0001
Polygonaceae	-0.550	< 0.002
Apiaceae	-0.503	< 0.005
NAP	-0.764	< 0.0001

Table 7.3. Insignificant Correlations between Taxa and Sample Depth from Five Lakes

Positive Correlations

Taxon/Taxonomic Group	Correlation (Pearson's *r*)	Significance (*p*)
Tsuga	+0.298	< 0.110

Negative Correlations

Taxon/Taxonomic Group	Correlation (Pearson's *r*)	Significance (*p*)
Larix/Pseudotsuga	-0.302	< 0.105
Acer	-0.246	< 0.189
Abies	-0.143	< 0.451
Liguliflorae	-0.317	< 0.088

Table 7.4. PCA Scores for Pollen Samples

Sample Depth cm bi	First Component Score	Second Component Score
0	0.446	0.247
5	0.173	0.003
10	0.000	0.000
15	0.394	0.162
20	0.216	0.126
25	0.247	0.054
30	0.221	0.396
35	0.310	0.276
40	0.410	0.276
45	0.539	0.185
50	0.615	0.243
55	0.542	0.177
60	0.770	0.301
65	0.694	0.266
70	0.666	0.224
75	0.787	0.290
80	0.743	0.283
85	0.761	0.297
90	0.689	0.279
95	0.654	0.281
100	0.654	0.246
105	0.691	0.224
110	0.624	0.271
115	0.612	0.191
120	0.654	0.231
125	0.593	0.239
130	0.703	0.259
135	0.707	0.255
140	0.741	0.261
145	0.779	0.303

Table 7.5. PCA Scores for Taxa

Taxon	First Component Score	Second Component Score
Pinus	0.886	0.344
Larix/Pseudotsuga	-1.444	6.122
Acer	-0.68	3.409
Betula	-1.179	-1.962
Alnus	-0.129	-0.949
Tsuga	0.727	-0.892
Abies	-0.214	-1.061
Picea	0.869	0.464
Quercus	-1.227	-0.384
Chenopodiaceae	-0.807	1.06
Poaceae	-0.18	0.253
Artemesia	-0.803	-0.805
Ambrosia	-1.157	1.464
Aster	-1.243	1.507
Polygonaceae	-2.66	-3.281
Liguliflorae	-0.535	-1.894
Apiaceae	-1.328	4.063

Table 7.6. Significant Positive Correlations between Taxa from Five Lakes

Taxonomic Pairs	Correlation (Pearson's *r*)	Significance (*p*)
Pinus-Tsuga	+0.211	< 0.0001
Pinus-Picea	+0.352	< 0.0001
Larix/Pseudotsuga-Acer	+0.744	< 0.0001
Larix/Pseudotsuga-Betula	+0.292	< 0.0001
Larix/Pseudotsuga-Alnus	+0.142	< 0.0001
Larix/Pseudotsuga-Abies	+0.245	< 0.0001
Larix/Pseudotsuga-Quercus	+0.413	< 0.0001
Larix/Pseudotsuga-Chenopodiaceae	+0.527	< 0.0001
Larix/Pseudotsuga-Ambrosia	+0.608	< 0.0001
Larix/Pseudotsuga-Aster	+0.566	< 0.001
Larix/Pseudotsuga-Apiaceae	+0.479	< 0.007
Acer-Betula	+0.273	< 0.0001
Acer-Alnus	+0.031	< 0.006
Acer-Abies	+0.097	< 0.0001
Acer-Quercus	+0.282	< 0.0001
Acer-Chenopodiaceae	+0.489	< 0.0001
Acer-Ambrosia	+0.612	< 0.0001
Acer-Aster	+0.606	< 0.0001
Betula-Alnus	+0.742	< 0.0001
Betula-Abies	+0.237	< 0.0001
Betula-Quercus	+0.738	< 0.0001
Betula-Chenopodiaceae	+0.695	< 0.0001
Betula-Poaceae	+0.627	< 0.0001
Betula-Artemesia	+0.814	< 0.0001
Betula-Ambrosia	+0.664	< 0.0001
Betula-Aster	+0.588	< 0.001
Betula-Polygonaceae	+0.661	< 0.0001
Alnus-Abies	+0.243	< 0.0001
Alnus-Quercus	+0.420	< 0.0001
Alnus-Chenopodiaceae	+0.475	< 0.0001
Alnus-Poaceae	+0.719	< 0.0001
Alnus-Artemesia	+0.670	< 0.0001
Alnus-Polygonaceae	+0.598	< 0.0001
Tsuga-Abies	+0.122	< 0.0001
Tsuga-Picea	+0.073	< 0.0001
Tsuga-Quercus	+0.201	< 0.0001
Abies-Quercus	+0.219	< 0.0001
Abies-Chenopodiaceae	+0.142	< 0.0001
Quercus-Chenopodiaceae	+0.741	< 0.0001
Quercus-Artemesia	+0.514	< 0.004
Quercus-Ambrosia	+0.799	< 0.0001

Table 7.6. Significant Positive Correlations between Taxa from Five Lakes (cont.)

Taxonomic Pairs	Correlation (Pearson's *r*)	Significance (*p*)
Quercus-Aster	+0.589	< 0.001
Quercus-Polygonaceae	+0.602	< 0.0001
Quercus-Apiaceae	+0.486	< 0.007
Chenopodiaceae-*Artemesia*	+0.532	< 0.002
Chenopodiaceae-*Ambrosia*	+0.761	< 0.0001
Chenopodiaceae-*Aster*	+0.626	< 0.0001
Chenopodiaceae-Polygonaceae	+0.466	< 0.009
Poaceae-Artemesia	+0.689	< 0.0001
Poaceae-Polygonaceae	+0.581	< 0.001
Artemesia-Ambrosia	+0.546	< 0.002
Artemesia-Aster	+0.768	< 0.0001
Artemesia-Polygonaceae	+0.565	< 0.001
Aster-Apiaceae	+0.572	< 0.001

Table 7.7. Significant Negative Correlations between Taxa from Five Lakes (cont.)

Taxonomic Pairs	Correlation (Pearson's r)	Significance (p)
Pinus-Larix/Pseudotsuga	-0.494	< 0.0001
Pinus-Acer	-0.479	< 0.0001
Pinus-Betula	-0.908	< 0.0001
Pinus-Alnus	-0.746	< 0.0001
Pinus-Abies	-0.336	< 0.0001
Pinus-Quercus	-0.726	< 0.0001
Pinus-Chenopodiaceae	-0.785	< 0.0001
Pinus-Poaceae	-0.793	< 0.0001
Pinus-Artemesia	-0.892	< 0.0001
Pinus-Ambrosia	-0.748	< 0.0001
Pinus-Aster	-0.787	< 0.0001
Pinus-Polygonaceae	-0.661	< 0.0001
Larix/Pseudotsuga-Tsuga	-0.190	< 0.0001
Larix/Pseudotsuga-Picea	-0.080	< 0.0001
Acer-Tsuga	-0.338	< 0.0001
Betula-Tsuga	-0.123	< 0.0001
Betula-Picea	-0.318	< 0.0001
Alnus-Tsuga	-0.085	< 0.0001
Alnus-Picea	-0.400	< 0.0001
Tsuga-Chenopodiaceae	-0.179	< 0.0001
Abies-Picea	-0.161	< 0.0001
Picea-Quercus	-0.396	< 0.0001
Picea-Chenopodiaceae	-0.221	< 0.0001
Picea-Chenopodiaceae	-0.221	< 0.0001
Picea-Ambrosia	-0.462	< 0.010

Table 7.8. Insignificant Positive Correlations between Taxa from Five Lakes

Taxonomic Pairs	Correlation (Pearson's *r*)	Significance (*p*)
Larix/Pseudotsuga-Poaceae	+0.414	< 0.023
Larix/Pseudotsuga-Artemesia	+0.269	< 0.150
Larix/Pseudotsuga-Polgonaceae	+0.125	< 0.511
Larix/Pseudotsuga-Liguliflorae	+0.046	< 0.807
Acer-Picea	+0.005	< 0.661
Acer-Poaceae	+0.381	< 0.038
Acer-Artemesia	+0.339	< 0.067
Acer-Liguliflorae	+0.154	< 0.415
Acer-Apiaceae	+0.451	< 0.012
Betula-Liguliflorae	+0.284	< 0.128
Betula-Apiaceae	+0.290	< 0.121
Alnus-Ambrosia	+0.382	< 0.037
Alnus-Aster	+0.356	< 0.053
Alnus-Liguliflorae	+0.244	< 0.193
Alnus-Apiaceae	+0.011	< 0.954
Tsuga-Polygonaceae	+0.020	< 0.917
Abies-Poaceae	+0.329	< 0.075
Abies-Artemesia	+0.275	< 0.141
Abies-Ambrosia	+0.203	< 0.281
Abies-Aster	+0.240	< 0.202
Abies-Polygonaceae	+0.313	< 0.092
Abies-Liguliflorae	+0.253	< 0.595
Abies-Apiaceae	+0.026	< 0.892
Quercus-Ligulaflorae	+0.055	< 0.773
Chenopodiaceae-Ligulaflorae	+0.216	< 0.252
Chenopodiaceae-Apiaceae	+0.361	< 0.050
Poaceae-*Ambrosia*	+0.400	< 0.029
Poaceae-*Aster*	+0.424	< 0.019
Poaceae-Ligulaflorae	+0.177	< 0.349
Poaceae-Apiaceae	+0.255	< 0.173
Artemesia-Ligulaflorae	+0.325	< 0.079
Artemesia-Apiaceae	+0.385	< 0.035
Ambrosia-Ligulaflorae	+0.215	< 0.255
Aster-Polygonaceae	+0.325	< 0.080
Aster-Ligulaflorae	+0.236	< 0.210
Polygonaceae-Ligulaflorae	+0.109	< 0.567
Polygonaceae-Apiaceae	+0.417	< 0.022
Ligulaflorae-Apiaceae	+0.065	< 0.734

Table 7.9. Insignificant Negative Correlations between Taxa from Five Lakes

Taxonomic Pairs	Correlation (Pearson's *r*)	Significance (*p*)
Pinus-Liguliflorae	-0.299	< 0.109
Pinus-Apiaceae	-0.421	< 0.020
Acer-Polygonaceae	-0.020	< 0.916
Tsuga-Poaceae	-0.174	< 0.357
Tsuga-Artemesia	-0.359	< 0.051
TsugaAmbrosia	-0.165	< 0.383
Tsuga-Aster	-0.354	< 0.055
Tsuga-Liguliflorae	-0.260	< 0.165
Tsuga-Apiaceae	-0.271	< 0.148
Picea-Poaceae	-0.173	< 0.362
Picea-Artemesia	-0.422	< 0.020
Picea-Aster	-0.430	< 0.018
Picea-Polygonaceae	-0.374	< 0.042
Picea-Liguliflorae	-0.101	< 0.595
Quercus-Poaceae	-0.349	< 0.058

Chapter 8. Charcoal Record (Fire Proxy) from Five Lakes

Preliminary laboratory analyses identified Five Lakes as a good candidate for charcoal analysis. All fire proxy data were derived from Five Lakes sediments, and charcoal counts were done under the microscope at the same time as the pollen counts presented in the last chapter. The resulting raw charcoal counts, made for three different size classes, are recorded in Appendix H.

Figure 8.1 shows a fairly straightforward presentation of the absolute charcoal influx throughout the core, shown as a simple measurement of the total number of particles deposited per square centimeter per year ($\#/cm^2/yr$). Charcoal influx is also commonly expressed in terms of the $mm^2/cm^2/yr$ deposited in a lake, and this popular measure is plotted next to the plot of $\#/cm^2/yr$ in Figure 8.2 so that the results from these two techniques can be easily compared. Simple visual inspection of all the plots in Figures 8.1 and 8.2 show that charcoal was deposited in greater amounts during the lower part of the core, and that the charcoal influx exhibits many peaks (local maxima). Visual inspection also shows that the two popular methods of expressing charcoal influx ($\#/cm^2/yr$ and $mm^2/cm^2/yr$), as plotted in Figure 8.2, show nearly identical trends and features over time (these methods are correlated with an $r=+0.943$ and $p<0.0001$). This indicates that the charcoal results are robust -- the same trends reveal themselves no matter how the charcoal is quantified.

Another trend evident from Figure 8.1 is that the representation of different particle size fractions changes over time, with large diameter particles (125 to 500 µm-diameter) being deposited in significant numbers early on, then declining and virtually disappearing around 500 B.P. (about 45 cm bi). This is of interest because charcoal particle size is a clue to the transport mechanism and distance traveled by each particle (Clark 1988a, Patterson et al. 1987). Since this study poses questions on a local and extralocal scale, it is advantageous to use particle size as a way to focus on only those portions of the charcoal record that are extralocal, but not regional or global, in scale.

Extralocal and Local Charcoal

An extralocal signal best characterized by the influx of large charcoal particles that could have traveled only a short distance (Clark 1988a, Patterson et al. 1987). Generally, researchers believe that charcoal from 1 to 125 µm in size can easily travel long distances in suspension in the air. Small charcoal (under 125 µm) is assumed to represent material from local, extralocal, regional, continental or even global source areas (Clark 1988a). Since larger particles (those over 125 µm in diameter) only move over relatively short distances, charcoal records composed solely of large charcoal grains are assumed to reflect processes occurring on a smaller-than-regional scale distances (Clark 1988a).

Studies of charcoal as a proxy fire record, when checked against historical and fire scar records of vegetation fires, confirm this relationship between particle size and transport distance. Several studies have shown that small particles, under 125 μm in diameter, did not correlate with known fires in the extralocal area (Clark 1988a, Whitlock and Millspaugh 1996). Larger particles between 125 and 250 μm, however, provided records that corresponded with known fire events within the catchment of a lake (Clark 1988a; Clark and Royall 1995b; Whitlock and Millspaugh 1996). A separate examination of different size classes from Five Lakes, then, should tease apart fire proxies with different spatial-scale signals.

Large (>125 μm) Particles

Figure 8.3 shows a graph of charcoal influx for all particles larger than 125 μm in diameter, assumed to be produced by fires that burned relatively close to the basin. Figure 8.3 shows a series of about eleven peaks of varying size over the 1,525-year record covered by the Five Lakes core. Peaks in the plot of the large particle influx (i.e. Figure 8.3) are labeled in Figure 8.4. All local maxima on the graph are identified as fire events for the purposes of this research. Figures 8.3 and 8.4 indicate that there are eleven separate significant fire events evident in the Five Lakes charcoal record. These events, along with their associated depths and ages, are listed in Table 8.1.

One trend that is evident from the large-particle influx plot is that there is a systematic change in the charcoal influx over time. In Figure 8.3, the three most recent fire events (from 40 to 0 cm bi) are the smallest in the core. In contrast, both the background influx of large charcoal particles, and the local maxima are greatest from 40 cm bi to the lowest point in the core. The sediments from Five

Lakes, then, record a drastic decrease in large charcoal particle deposition into the lake around 500 B.P.

Of greater interest than amplitude is peak frequency. The number of years that elapses between peaks is referred to in the fire literature as the return interval between fires. This information, along with the change in return intervals, is listed in Table 8.1. As Table 8.1 shows, the return interval between fire events averages 148.4 years and ranges from 94 to 232 years. A plot of the return intervals associated with each fire event is given in graphic form in Figure 8.6. As both the plot and table show, there is no obvious pattern to the return intervals; the charcoal record at Five Lakes cannot be subdivided into periods of greater or lesser fire frequencies.

The influx of large particles can also be used to investigate if, and how, the outbreak of past fires influences future fires in an area. Table 8.2 shows the results of running correlations between past and future charcoal influx values with successively longer lags introduced into the model (in 50-year increments). Since vegetation fires consume the available fuel on the landscape, one might expect fire to be negatively correlated with itself over the short term. The opposite trend is seen in the charcoal dataset, however. Statistically significant autocorrelations do exist over the short term, but these are positive relationships. This could be due to the processes structuring the proxy itself, and not indicative of trends in the underlying nature of the area fires. For example, positive correlations between two consecutive charcoal samples could be due to the use of linear interpolation (which by its nature produces new interpolated points that are mathematically related to both neighboring samples). Positive correlations between successive charcoal samples are also likely to be due to the fact that all charcoal from a fire is not instantaneously deposited in a lake but arrives for many years after the event (Whitlock and Millspaugh 1996). Delayed transportation, and reworking of charcoal both result in an up-core "smearing" of a charcoal peak derived from a single fire (Whitlock and Millspaugh 1996).

Summary of Charcoal Results

The record of charcoal particles from local and extralocal (but not regional) fire sources stretches back to 1,525 B.P. at Five Lakes. This proxy record shows that fire events occurred every 148 years on average, with no clear trends or periods of increased or decreased fire frequency. Also, charcoal influx is greatest from 1,525 B.P to about 500 B.P, drops around 500 B.P. and remains low until the present. The cause of this is unclear, and could be due to a change in the type, size, or distance of the fire of origin. Charcoal values are also highly positively autocorrelated in the short term (50-100 years), but this seems to be a function of the sedimentary processes at work rather than a function of the source fires producing the charcoal.

Putting Five Lakes Charcoal Results in Context

How do the return intervals obtained at Five Lakes compare with other records of fire frequency? The higher elevations in the study area are dominated by pine forests and have been dominated by pine throughout the span of the record being examined. From historical records and fire scar studies in the

Northwest, pine forests tend to have return intervals of 6 to 47 years between fires (Hall 1976; Langston 1999; Maruoka 1994; Soeriaatmadja 1966; Weaver 1959, 1961, 1967). Palynological studies of forested areas of Washington, Oregon, Idaho and Wyoming show that charcoal records indicate return intervals of 40 to 283 years are recognizable in the proxy record (Chatters 1998, Chatters and Leavell 1995, Millspaugh and Whitlock 1995).

The data from Five Lakes, indicating return intervals averaging 148 years, and ranging from 94 to 232 years is perfectly in line with expectations from palynological data, but longer than one would expect based on historical and fire scar records. It is probable that charcoal proxies are merely less sensitive than historical and fire scar records -- charcoal seems to only record larger, more infrequent events. In comparison to other charcoal records, Five Lakes seems to record local fire frequencies that are normal for prehistoric proxy records throughout the western United States.

In other analyses of charcoal records from the interior Northwest, authors have tended to identify shorter return intervals (40-90 years) as evidence of anthropogenic fire regimes (Chatters 1998). If this is the case, then the longer return rates (averaging 148 years) seen at Five Lakes might be attributable to natural and not cultural fires.

Does fire, as recorded by charcoal, show a relationship with climate? Return intervals between fires do not change throughout the record, but climate does (Chapter 6). This is surprising, but other researchers have noted anomalous disjunctures between the expected relationship between climate and fire frequency. For example, Bergeron and Archambault (1993) expected fire frequency to increase during the warming that took place after the end of the LIA, but fire frequency decreased instead.

Although fire frequency seems to be unrelated to climate, there is an interesting potential relationship between fire amplitude (magnitude of charcoal the influx) and local aridity. Oxygen isotope records from area lakes record a period of relatively warm, dry conditions starting 600 B.P. and reaching maximum aridity around 400 B.P. (Figure 6.4). Somewhere between 500 and 600 B.P. when values of *Pinus* pollen dropped, disturbance taxa increased (Figure 7.2), and the influx of large charcoal particles plummeted (Figure 8.3). This coincident change in several records gives tantalizing clues pointing to a potential relationship between fire frequency, climate, and vegetation.

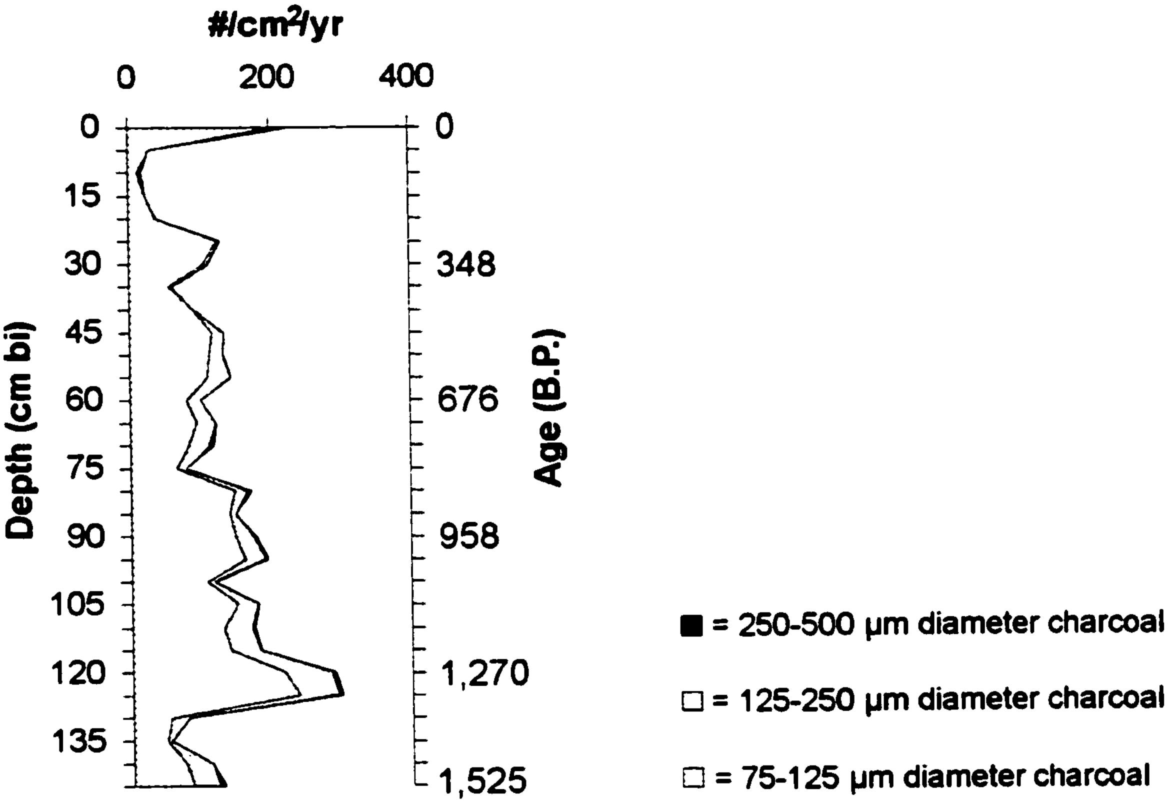

Figure 8.1. Charcoal Particle Influx (#/cm^2/yr) for Five Lakes

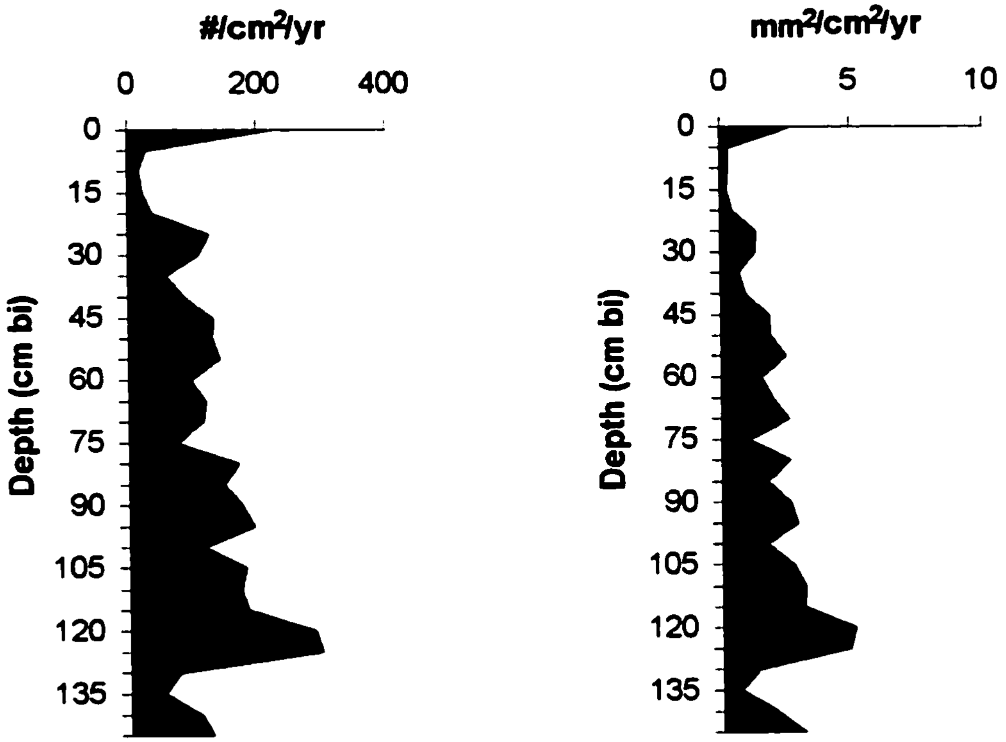

Figure 8.2. Total Charcoal Influx Presented Following Two Conventions (#/cm^2/yr at left and mm^2/cm^2/yr at right) for all Particle Sizes at Five Lakes

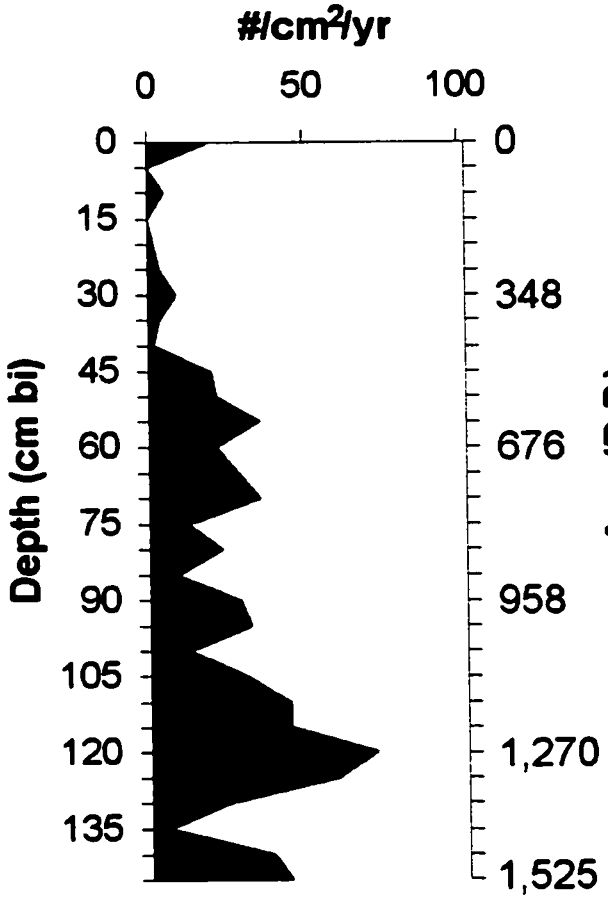

Figure 8.3. Influx (#/cm^2/yr) of Large (>125 µm) Charcoal Particles for Five Lakes

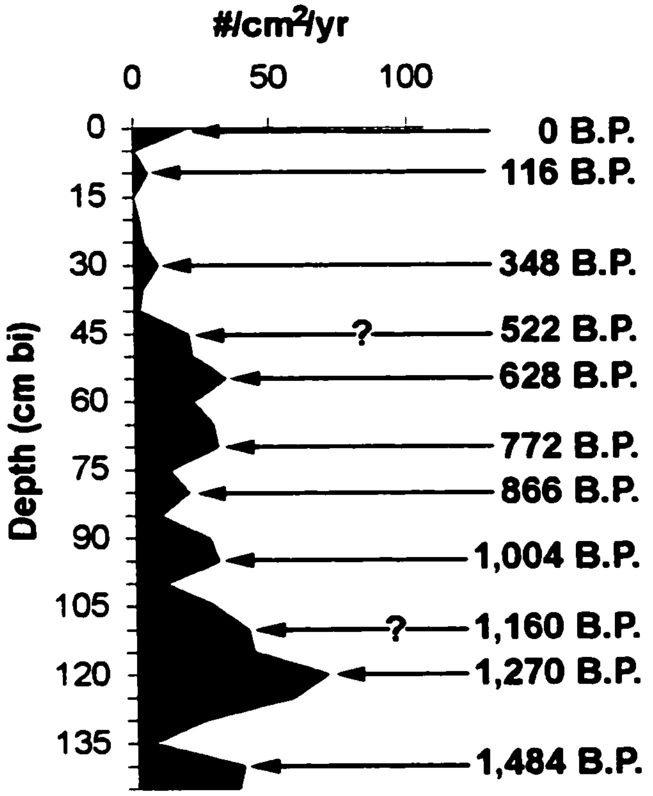

Figure 8.4. Annotated Influx (#/cm^2/yr) of Large (>125 μm) Charcoal Particles for Five Lakes

Note: Question marks (?) are used to identify peaks that are unclear, flat, or appear as shoulders on larger peaks. Events marked with question marks are those that are more difficult to resolve, yet are still considered as extralocal fire events for the purposes of this analysis.

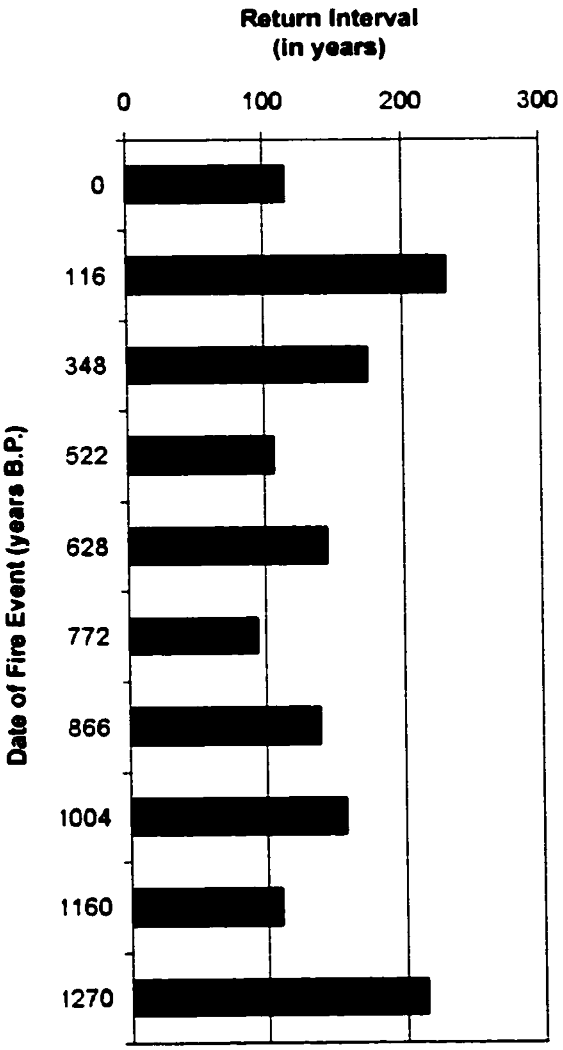

Figure 8.5. Fire Return Intervals at Five Lakes (Based on Peaks in 125- 250 μm Charcoal Influx Plot)

Table 8.1. Fire Events from Large (>125 μm) Charcoal

Sample Depth cm bi	Estimated Date of Event (B.P.)	Return Inteval (yrs)	Change in Return Inteval (yrs)
0	0	116	-116
10	116	232	58
30	348	174	68
45	522	106	-38
55	628	144	50
70	772	94	-44
80	866	138	-18
95	1,004	156	46
110	1,160	110	-104
120	1,270	214	
140	1,484	N.A.	
	Average:	148.4	

Table 8.2. Fire Proxy Autocorrelations: Correlations of Charcoal Influx with Future Values of Itself

Significant Autocorrelations

	Correlation (Pearson's *r*)	Significance (*p*)
1 lag (50 years)	+0.763	< 0.0001
2 lags (100 years)	+0.615	< 0.007

Insignificant Autocorrelations

	Correlation (Pearson's *r*)	Significance (*p*)
3 lags (150 years)	+0.536	< 0.027
4 lags (200 years)	+0.435	< 0.092
5 lags (250 years)	+0.323	< 0.241
6 lags (300 years)	+0.072	< 0.806

Chapter 9. Results and Discussion

A major product of this study is a database, consisting of comparable proxies for fire, human population, vegetation, and climate, sampled at 50-year intervals from A.D. 950 to 1900. These data are listed in Appendix I and provide an invaluable resource for investigating questions about the long-term dynamics of human ecology. Elements of this database were either generated by this study (e.g. the charcoal, pollen, and isotope data) or drawn from earlier work in the area (the population proxy). To make all variables comparable, values are given for each variable at the same 50-year intervals over the same time span as the pre-existing population proxy (Campbell 1989). This ensures that values from the same interval are coeval, and ensures that sampling is done for each variable at the same resolution. To accomplish this, mathematical interpolation between existing data points was required to match temporal scales between variables and provide sampling at equal intervals over time (allowing for such statistical analyses as time series). The resulting database provides the basis for the statistical analyses provided in this chapter, and allows for the investigation of a wide range of questions about the interaction and interrelationships in the landscape over time at different time scales.

Population was entered into the analysis using a population index that is a composite of all of Campbell's (1989) proxy population variables (as presented in Chapter 3). The climate proxy used here is also a combination of two records --

oxygen isotope records from Hidden and Rinker's Lakes. The population and isotope indexes were constructed in analogous manners, by standardizing and compiling separate records into a single synthetic product. For each, the individual sets of values were re-expressed as standardized deviations from a sample mean, and these z-scores were added together for each successive time period. This produced an average score for each set of observations for each time period, as described and presented in Chapters 3 and 6.

The vegetation proxy used in this chapter was the percent composition of different taxa from Five Lakes sediments. The proxy used for fire was the absolute influx ($\#/cm^2/yr$) of large (> 125 μm) charcoal particles into Five Lakes. All these proxies are listed in Appendix I, and used for running correlations and time series tests to better understand the interactions between these variables.

Autocorrelations were run on each variable, comparing it to future values of itself. Successive correlations were run, introducing an additional 50-year (one interval) lag each time using SPSS v.10. This was a simple way to determine if a variable was autocorrelated, or dependent upon past values of itself. Many autocorrelations were expected to be found since the factors being studied -- human population, fire frequency, climate, and vegetation -- are logically conditioned by their own history. Although autocorrelations were already presented earlier, they will be reviewed here as well.

In addition to autocorrelations, bivariate correlations were run between different variables for coeval sets of values (again using SPSS V.10). This helped to determine, for example, if contemporaneous values of human population and fire were linked with one another. In order to better assess the potential cause-effect relationships between variables, bivariate correlations were run between variables again once a time lag was introduced in the model (using SPSS v.10). High correlations between a leading proxy and lagging proxy provide suggestive evidence about the response of the system and possible causal relationships. For example, a leading population proxy positively correlated with a lagging fire proxy could indicate that the increased presence of humans somehow causes an increase in the amount of fuel being consumed by fire on the landscape.

The logical last step in the statistical analysis was to evaluate if the correlations seen in the lagged univariate and bivariate analyses had explanatory value in a multivariate system. This is equivalent to asking if human population, and human population alone, adequately predicts future fire. Determining if human population is both significantly and linearly independent from other potential explanatory factors requires a more sophisticated procedure than simple bivariate correlations.

To understand the interrelationships of all factors, simultaneously, time series analysis was run on the database given in Appendix I (using the eViews V.4 -- a statistical software package used primarily by economists). Time series analysis allows multiple correlations, autocorrelations, and linear independence of many variables to be considered simultaneously, while successively introducing lags of varying lengths into the model.

Granger causality was used for the time series portion of this analysis. A leading variable is said to "Granger cause" a lagging variable if the leading variable is: (1) significantly correlated with the lagging variable, (2) linearly independent of other competing independent variables, and (3) not autocorrelated with itself. That is, Granger causality helps to identify those variables that are acting as external forcing agents in a system. Using such statistical tools as time series and bivariate correlation, especially in combination, the long-term interactions of ecological systems can be examined in depth. The analysis, presented below, looks at the potential factors influencing each variable, in turn, starting with fire. For all the statistical procedures used, a p-value of 0.01 or less was considered to be significant. The analysis, presented below, begins by looking at simple models of bivariate correlation, and then proceeds to more complex analyses involving lead-lag relationships and assessments of the differential contribution of factors within a multivariate analysis.

What factors influence the fire proxy?

Is fire statistically influenced by humans?

It is assumed by many researchers that humans increase fire frequency on a landscape by increasing the number of ignition events that could start vegetation fires (Pyne 1982). If human presence and fire in eastern Washington are linked, then increases in human population should have a significant positive correlation with the deposition of large charcoal particles into area lakes. Correlations between contemporaneous values of charcoal influx and human population (see Table 9.1) from my dataset support this idea, as they are significantly correlated at the 0.01 level ($r=+0.771$ $p\leq 0.0001$).

Although coeval proxies of fire and human population are significantly correlated, it would be even more informative to introduce leads and lags between the two variables and rerun bivariate correlations. If the two are statistically significantly correlated once lags are introduced, the leading (and likely causal) factor can be identified. This can reveal if changes in population lead to changes in fire. In order to investigate this, a series of bivariate correlations were run with either fire or human proxies in the lead. The first pair was run with a lag of 50 years, the next with a lag of 100 years, then 150 years, etc.

The sets of increasingly lagged bivariate correlations run on the fire proxy (large particle charcoal influx) and the human population indicate that the two are interrelated, and in the manner assumed by paleoecologists. Results from this lead-lag type of analysis (given in Table 9.2) show that when population is allowed to assume the lead role, significant correlations between population and later values of charcoal (fire) are seen. Significant positive correlations are seen when lags of one interval (50 years), two intervals (100 years), or three intervals

(150 years) are introduced into the model. Whether examined synchronically or diachronically, population and fire show a strong interrelationship, with fire correlated with population size up to 150 years in the past.

Does past fire history statistically influence future fire regimes?

Researchers believe that fire frequency in a given area is partially dependent upon the extent and frequency of past fires in an area. Vegetation fires should deplete fuels available on the landscape, and lead to a decreased chance of fires in the near future (Martin et al. 1977,). A lack of fire should cause a buildup of fuel and increase the likelihood or "danger" of fire (Rauw 1980). The use of prescribed burns to prevent intense and damaging forest fires, and the contribution of historic fire suppression activities to the devastating Yellowstone fires of 1988 are examples of this (Romme and Despain 1989). Based on this scenario, the charcoal proxy for fire should be significantly negatively correlated with future fire.

This question relies, again, on an approach that introduces lags into a model that attempts to correlate values of charcoal influx from different times in the study area. The results of an autocorrelation analysis, run on the charcoal fire proxy, were presented earlier, and are listed in Table 8.2. As expected, there are significant correlations at the 0.01 level between charcoal and future charcoal values when one or two lags (50-100 year lags) are entered into the model. As the lags get longer and time more distant, the magnitude and significance of the relationship decrease.

Contrary to expectations, the significant correlations between charcoal and future charcoal values are *positive* correlations, not negative ones. Charcoal influx during one time period is very similar to influx during the next period. This could be because the incidence of fire increases the likelihood of fire in the near future on the landscape. It could also be a purely mechanical or stratigraphic problem inherent in the proxy itself. Charcoal in one sample could be diffused or "smeared" a short distance up the stratrigraphic column by limited sediment mixing. Small scale bioturbation within the lake sediment sequence bring some charcoal particles upwards in the stratigraphy. Also, years of reworking and redeposition of charcoal originally deposited the uplands could explain the observed positive autocorrelation in this variable.

Does local climate influence fire frequency?

Climate is yet another factor assumed to influence the fire history of an area. In many areas, warm dry years promote the buildup of fuel, the outbreak of fire, and the spread of established fires (Hall 1989). Is climate seen as having any effect on fire in the proxy records from the past 1,000 years in the study area? Comparing the contemporaneous values of the charcoal fire proxy and oxygen isotope climate proxy (Table 9.1), the two are positively but not significantly correlated with one another (r=+0.110, p<0.645). Climate, as measured by oxygen isotope values (which, in turn, reflect relative aridity) is not related to the coeval incidence of fire at a 0.01 significance level.

Perhaps climate influences fire, but that influence takes time to manifest itself in the record. This could well be, if, for instance, drying conditions took several years to influence the vegetative growth of plants already growing on the landscape, or if drying conditions took many years to influence the abundance of different plant taxa on the landscape. Vegetation change would then affect the type and amount of fuel available on the landscape, and that, in turn, could pattern fire regimes. With such mechanisms at work, it is perfectly reasonable to assume that fire response to climatic conditions could take years, decades, or centuries to manifest themselves.

Does fire respond, but with a lag, to climate? A series of lagged correlation analyses relating climate and fire proxies is presented in Table 9.3. According to the statistical results, charcoal values are significantly related to prior oxygen isotope values when 5 or 6 lags (250 and 300 years) are introduced into the model. This relationship is statistically significant and positive, indicating that times of more positive oxygen isotope values, indicative of arid conditions, lead to times of increased deposition of large charcoal particles as evidence of resulting local fires some 250 to 300 years in the future.

Does vegetation type influence the fire proxy?

The outbreak and spread of fire should be related to the condition, amount, and types of fuels on the landscape (related to the amount of fuel, its moisture content, and the type or taxonomic origin of the dead material), as well as to the presence of an ignition source (humans, lightning, etc). Modern ecological studies have shown that the type of vegetation in an area influences the outbreak and spread of fire (Marouka 1994). Grasses, sagebrush, and ponderosa pine, for instance, all produce different kinds of dead tissues, with different characteristics as a fuel for combustion. The structure, particle size, chemical content, and density of materials (Ellis 1980) are all dependent on the taxa providing the fuel and the packing of individual plants together. It stands to reason that the vegetation variables provided by the pollen analysis would have some relation to charcoal influx as a measure of local fires.

The role of vegetation can be evaluated by first comparing contemporaneous values of different plant taxa with the influx of large charcoal particles. Table 9.4 lists the significant correlations between plant taxa from Five Lakes and contemporaneous large charcoal influx; Table 9.5 lists those taxon-charcoal correlations that are not significant. Although results of all taxonomic types are given in these tables, results from the rare taxa will be ignored, as the abundances of these categories can not be reliably estimated from the 500-grain pollen counts. Rare taxa (and aggregate categories like NAP and AP) appear in the tables in normal typeface, whereas the major and minor taxa (the ones discussed in the text) appear in bold typeface.

Of the taxa listed as statistically significant, *Pinus* is the only one that has a statistically significant positive correlation with contemporaneous values of the fire proxy at the 0.01 level. The percent abundance of pine is tightly correlated with the amount of large charcoal particles in the same samples, with an associated Pearson's *r*=+0.783 at a significance of $p \leq 0.0001$. Of the remaining reliable minor taxa, several are significantly negatively correlated with the fire proxy; *Betula*, Cheopodiaceae, *Artemesia*, *Ambrosia*, and *Aster* all show a negative relationship (all with *r* ranging from -0.723 to -0.770 and all with a $p \leq 0.0001$). All nonarboreal taxa (NAP), taken together, also show a statistically significant inverse relationship with contemporaneous values of charcoal influx (with an *r* = -0.764 and $p \leq 0.0001$).

Times of high pine domination, then, correlate with outbreaks of fire in the area. Either ponderosa pine dominated vegetation encourages the outbreak and spread of fire, or the same conditions that promote the growth and dominance of pine trees is also promoting the outbreak of fires. It is highly unlikely that the statistical correlation indicates that fire promotes pines since each sample represents approximately a ten-year period of deposition and it takes longer than 10 years for pines to establish new seedlings and for these new trees to mature. Whatever the mechanism of causation behind this statistical relationship, fire has been more common in pine-dominated vegetation by far than in any other type of vegetation over the past thousand years in this area. Likewise, fire has been rare in times when nonarboreal taxa have been relatively common; fire has been unlikely on the landscape whenever taxa like *Betula*, Chenopodiaceae and Asteraceae (*Artemesia*, *Ambrosia*, *Aster* and Ligulaflorae) are enjoying times of relative abundance.

How do these relationships change once lags are introduced into the model? Do certain taxa or vegetation types lead to future fires? Lagged correlations between the charcoal variable and the pollen from different taxa reveals significant positive and negative relationships as summarized in Table 9.6 (insignificant correlations are listed in Table 9.7). As Table 9.6 indicates, episodes of fire can be statistically predicted from the values of various taxa during previous time periods.

Statistically significant positive relationships exist between the percentage of *Pinus* pollen in samples and the influx of charcoal at 50, 100, 150, or 200 years later. Unlike *Pinus*, *Picea* was not significantly correlated with contemporaneous charcoal values, yet *Picea* also shows a positive relationship with charcoal influx when greater time depth is added. As Table 9.6 indicates, *Picea* is significantly correlated with charcoal at 4, 5, or 6 lags (200, 250 or 300 years).

Significant negative relationships exist for many of the minor taxa, primarily for *Betula*, Chenopodiaceae, Poaceae and Asteraceae (*Aster*, *Ambrosia, Artemesia,* and Liguliflorae). The significant relationships hold for several successive lags; significant negative correlations occur for *Betula* at 1, 2, and 3 lags, for Poaceae at 2, 3 and 4 lags, for Chenopodiaceae at 1 and 2 lags, and for members of the Asteraceae family at 1, 2, 3, 4, 5, and 6 lags. Most of these significant leading taxa (all but Poaceae) were significantly negatively correlated with contemporaneous charcoal values as well (Table 9.4). This indicates that the same general relationships exist between past vegetation and the likelihood of fire as indicated by the analysis of contemporaneous variables. In a bivariate model, fire is associated with high percentages of past and present pine trees, and fire is inversely related with the abundance of typical "disturbance" species such as *Betula*, Asteraceae and Chenopodiaceae.

Which variables influence fire most? How do these conditioning variables interact?

Contemporaneous and lagged bivariate analyses have helped to identify the variables that relate to the influx of charcoal as fire proxy. Identified as significant influences in bivariate tests are: prior human population levels (with a 0, 50, 100, and 150 year lead), prior oxygen isotope values (with a 250 or 300 year lead), and the present and past abundances of taxa like *Pinus*, *Betula*, Chenopodiaceae and Asteraceae.

Which of these variables are most important in determining fire frequency? Answering this question requires a simultaneous comparison of the various inputs, best addressed with multivariate statistics. Granger causality is a multivariate technique that can be used to assess the unique contribution each conditioning variable makes to the fire proxy. Granger causality identifies those leading factors that add to a predictive model, taking other independent variables as well as the dependent variable (and it's own feedback potential) into account. Like multiple regression, Granger causality requires that a given variable, X, be correlated with the predicted variable Y, and that X not be highly correlated with other potential explanatory variables. Unlike multiple regressions, however, Granger causality also requires that past values of both Y and X not be correlated with X. When tests of Granger causality are run on the potential predictor variables identified from the bivariate tests, several variables are identified as having statistically significant predictive "causal" value.

Table 9.8 lists all leading variables that pass the test for Granger causality (output containing results for all variables is given in Appendix J). Again, variable pairs in bold are of interest and those in normal typeface involve rare taxonomic types (and rare types will be ignored in this discussion of results). To simplify the list somewhat, the list of interactions is narrowed to just those involving oxygen isotopes, charcoal, and/or population and this shorter list is presented in Table 9.9.

Table 9.10 lists the significant Granger causal relationships that involve fire. Leading fire by fifty years are values of *Pinus* and human population. Also identified as important via Granger causality (Table 9.10) is the previous oxygen isotope values 300 years prior to the outbreak of fire. Although the bivariate tests indicated that *Pinus*, population, and oxygen isotopes were significant at other lag-intervals as well, once the influence and interaction of other variables such as taxonomic abundances were taken into account, only the fifty year lags remain as significant. Granger causality, then, removes those variables that suffer from multicollinearity and helps solve the problem of equifinality.

Again, this method identifies past climate, the most abundant and ubiquitous taxon (*Pinus*), and human population as the primary determinants of the incidence of fire. Based on this information, paired with the sign of the bivariate correlation coefficient (Table 9.10), fire is most likely to occur 300 years after an arid period, and 50 years after vegetation is high in pine and low in herbs and shrubs, and 50 years after a rise in human population. When multiple variables are examined simultaneously, then, patterning of fire is not determined by solely by one factor (such as human population), but by a combination of factors interacting on several different temporal magnitudes.

What factors influence vegetation?

The factors influencing vegetation can be examined using the same logic as outlined above for identifying variables that determine the incidence of fire. Bivariate analyses followed by multivariate evaluations identify and tease apart interrelationships within the dataset. This, in turn, clarifies the interactions between variables in the system over time.

Is vegetation influenced by humans?

If humans cause vegetation change, it is logical to assume that the greater the number of humans on the landscape, the greater their impact on the landscape and its vegetation. Also central to this argument is that human activity will favor seral or "disturbance" vegetation, and cause a reduction in species that are typical of later-successional vegetation stages. This can be tested by comparing the human population proxy with the changing taxonomic composition of the pollen record. If human presence always leads to disturbance and clearance, then we would expect the population proxy to be significantly positively correlated with the classic disturbance species -- *Alnus*, *Betula*, and weedy herbaceous taxa like Chenopodiaceae, Poaceae, and Asteraceae. At the same time, if humans disturb the vegetation, the population proxy should significantly negatively correlated with this area's climax vegetation, dominated by ponderosa pine (*Pinus*).

Table 9.11 shows the significant correlations between the population proxy and coeval pollen types (Table 9.12 lists the insignificant correlations). The proxy records do not show a significant positive relationship between human population levels and classic "disturbance" taxa such as Poaceae, Chenopodiaceae, Asteraceae, *Betula*, and *Alnus*. In fact, surprisingly, there is a significant and strong *negative* relationship between humans and "disturbance" taxa. In contrast, the dominant and climax taxon (*Pinus*) is significantly positively correlated with contemporaneous values of human population, which contributes to the argument against humans acting as disturbance agents in this case.

What could account for this set of relationships? Perhaps human action does, as predicted, result in the increase of "weedy," early-seral vegetation, but it takes time for the effects to manifest themselves. To explore this possibility, lags can be introduced and correlations run for different time scales. Table 9.13 summaries the significant results of such lagged bivariate models involving plant abundances and human population size (with insignificant results listed in Table 9.14).

When human population size is allowed to be in a lead position, many of the same relationships as seen between contemporaneous values are repeated. Again, human population is significantly positively related to values of climax taxa and inversely related to seral vegetation. Human population is significantly negatively correlated with future amounts of herbaceous taxa like Chenopodiaceae (at lags of 50-150 years) or Asteraceae (at lags of 50 to 150 years), and with future abundances of early successional tree types (like *Alnus* and *Betula*) with longer lags. Human population, then, is correlated significantly and negatively with both contemporaneous and future values of disturbance taxa, in direct conflict with the expectation that human action encourages the growth of seral vegetation.

Does fire influence vegetation type?

Given that human population does not have the expected effect on vegetation, one can ask -- what does pattern future vegetation? Does the dataset reveal any relationships between fire and resulting plant communities? Again, interrelationships can be explored by first examining the bivariate relationships between fire and different plant taxa. Correlations between contemporaneous values of charcoal and the abundances of different kinds of plants indicates that fire is significantly positively correlated with coeval values of

Pinus (climax vegetation) and significantly negatively correlated with coeval values of seral taxa (such as *Betula*, Chenopodiaceae, and Asteraceae).

Next, the fire proxy was put into a leading role in a series of bivariate correlations over different time scales. The significant results are listed in Table 9.15 (and the insignificant ones in Table 9.16). Significant relationships seen over the shorter time intervals are similar to those seen for contemporaneous values. As with the coeval correlations, *Pinus* is significant and positively correlated with fire, in a lead position at intervals of 50, 100, and 150 years. *Betula*, Chenopodiaceae and Asteraceae, again, are significantly negatively correlated with charcoal, but the relationships disappear after 50 to 150 years (Table 9.15). The only surprise is *Alnus*, which is significantly negatively correlated with charcoal, but the relationship only shows up when longer lags (of 100 to 300 years) are introduced. In sum, increases in charcoal values correlate with coeval and future values of *Pinus*. This is in keeping with modern observations, which indicate that many species of pine are fire-dependent, not just fire-tolerant (Rauw 1980). The fire proxy is inversely related to most of the other taxa, with *Betula*, Chenopodiaceae and Asteraceae repressed by fire on short time scales and the spread of *Alnus* retarded at longer time scales.

Does climate influence vegetation type?

Given that there is a complex feedback going on between vegetation and fire in the study area over the past millennium, what is the role of climate in this system? One would expect climate to respond to global processes and therefore to not be intricately interdependent with local factors. Compared to fire and vegetation, climate should be acting statistically independently when used as a lagged variable in bivariate statistical procedures. Climate should also be identified as a significant factor when multivariate time series are run and Granger causalities evaluated.

It is logical to begin by examining the bivariate relationship in this system that has not yet been examined, the one between contemporaneous values of oxygen isotope values and taxonomic abundances. Tables 9.17 and 9.18 list the significant and insignificant correlations between these two variables, respectively. Very few taxa are significantly correlated with contemporaneous oxygen isotope values. Three taxa -- *Alnus*, Poaceae and *Artemesia* -- are negatively correlated with the isotope values. Only one taxon, *Picea*, shows a significant and positive relationship. Based on these statistics, one would expect to find proportionately more Poaceae, *Alnus*, and *Artemesia* to be more abundant during times of greater relative moisture (when oxygen isotope values are relatively more negative), and more *Picea* during periods of aridity. Most taxa (i.e. *Pinus*, Chenopodiaceae, *Betula*, *Ambrosia*, *Aster* and Ligulaflorae), however, show no significant relationship with contemporary climate conditions.

Again, climate is a variable that one would expect to be a leading variable, with effects that would not necessarily manifest themselves for years, decades or centuries. Introducing lags into the bivariate models and calculating correlations produces interesting results, which are presented in Tables 9.19 and 9.20.

Expectably, most of the taxa that were significant in the coeval comparisons (*Alnus*, Poaceae, and *Artemesia* but not *Picea*) remained significant over the shorter time intervals in the lagged model.

Additionally, when vegetation is allowed to further lag climate, a few additional significant relationships emerge, as expected. *Pinus*, for instance, shows no significant relationship with the climate proxy until greater lags are introduced into the bivariate model. After 250 to 300 years, pine is significantly and positively correlated with oxygen isotopes, showing that a change to more arid climatic conditions promotes an expansion of pines on the landscape a few centuries later. This, of course, follows from the fact that pines require many years to both establish seedlings and have those individuals mature. This also makes sense since pines are the climax taxon in the area; it often takes time to pass through generations of lower-successional types before the climax taxon of this area (pine) can establish itself.

According to the results in Table 9.19, more negative oxygen isotope values, indicative of moist conditions, promote future growth of a wide range of nonarboreal taxa including Poaceae, *Artemesia*, *Aster*, *Ambrosia*, and Chenopodiaceae. Table 9.19 also shows that there are statistically significant negative relationships between oxygen isotope values and other taxa that do not show up until lags are introduced into the model -- three of the taxa listed above (*Aster*, *Ambrosia*, and Chenopodiaceae) showed no significant contemporaneous relationship with the climate proxy.

These bivariate analyses indicate that vegetation does respond to climate, but many types of plants remain unaffected until tens to hundreds of years have passed. What happens when all factors are considered together in a multivariate procedure? Fire proxy, climate proxy, population proxy and vegetation proxies were submitted together in a time series analysis. Table 9.8 shows the resulting significant Granger causalities, and Appendix J lists the unedited output on all possible relationships, for reference.

Looking at Table 9.8, it is obvious that most of the unique significant predictors of future taxonomic abundances are the past values of other plant taxa. This occurs in 23 of the significant cases listed. In only 7 cases are non-vegetative factors identified as significant contributors in this multivariate analysis. For the most part, past vegetation is the primary factor controlling future vegetation.

Outside variables identified as significantly controlling future vegetation are (1) charcoal, with a 50-year lead on Chenopodiaceae (2) population with a 50-year lead on *Betula* and a 100-year lead on Chenopodiaceae, and (3) oxygen isotope values, with a 50-year lead on *Betula* and *Picea*, a 100-year lead on *Aster* and both a 250- and 300-year lead on Chenopodiaceae. It is interesting to note that so few taxa are identified by the algorithm as being influenced by fire or people. Climate influences a number of taxa, but is still not singled out as the most important factor determining plant types and their abundances on the landscape; historical constraints from past vegetation, fire, and population also shape plant communities.

Assessing Interactions: Comparing Bivariate and Multivariate Results

A theme that keeps repeating itself in these statistical results is that bivariate assessments of significance consistently identify more significant correlations between variables than do the multivariate Granger causality tests. This is because many of the factors that appear significant in the bivariate case become disqualified once other competing explanatory variables are simultaneously considered. It is the case that many of the variables in this analysis are intricately related to one another and multicollinearity runs through a large portion of the dataset.

Another repeating trend is that many significant relationships exist between variables when lags are introduced into statistical models, and some significant relationships between variables only appear once lags are included. Historical constraints, then, are important. Taken together, these analyses show that the variables -- taxonomic abundances, charcoal, population, and oxygen isotopes -- all interact with one another on many different timescales. Variables are highly intertwined with one another, pointing to a system of feedbacks in which all components are linked together in complex ways. This demonstrates that humans, for example, are an integral part of the system, not an external force imposing change on a "natural" system. Of all the variables considered, the climate proxy is the closest to being an external forcing mechanism on the system, as one would logically expect. Looking at Table 9.9, population and charcoal are listed as both leading and lagging variables; the climate proxy only shows up in a leading role (never as a result of the change in another variable).

Table 9.1. Bivariate Correlations between Contemporary Values of Population, Oxygen Isotopes and Charcoal

Variable Pairs	Correlation (Pearson's *r*)	Significance (*p*)
Charcoal-Oxygen Isotope	+0.110	< 0.645
Population-Oxygen Isotope	+0.308	< 0.187
Charcoal-Population	+0.772	< 0.0001

Table 9.2. Bivariate Correlations between Population (Leading) and Lagged Charcoal

Significant Correlations

	Pearson's *r*	Significance (2-tailed)
1 lag (50 years)	+0.840	< 0.0001
2 lags (100 years)	+0.713	< 0.001
3 lags (150 years)	+0.614	< 0.009

Insignificant Correlations

	Pearson's *r*	Significance (2-tailed)
4 lags (200 years)	+0.533	< 0.033
5 lags (250 years)	+0.394	< 0.147
6 lags (300 years)	+0.312	< 0.277

Table 9.3. Correlations between Oxygen Isotope (Leading) and Lagged Charcoal Influx

Significant Correlations

	Pearson's *r*	Significance (2-tailed)
5 lags (250 years)	+0.704	< 0.003
6 lags (300 years)	+0.791	< 0.001

Insignificant Correlations

	Pearson's *r*	Significance (2-tailed)
1 lag (50 years)	+0.218	< 0.371
2 lags (100 years)	+0.240	< 0.337
3 lags (150 years)	+0.376	< 0.137
4 lags (200 years)	+0.586	< 0.017

Table 9.4. Significant Correlations between the Percentage of Pollen Types and Contemporaneous Charcoal Influx

Positive Correlations

	Pearson's *r*	Significance (2-tailed)
Pinus	**+0.783**	**< 0.0001**
AP	+0.764	< 0.0001

Negative Correlations

	Pearson's *r*	Significance (2-tailed)
Betula	**-0.770**	**< 0.0001**
Quercus	-0.748	< 0.0001
Chenopodiaceae	**-0.723**	**< 0.0001**
Artemesia	**-0.740**	**< 0.0001**
Ambrosia	**-0.768**	**< 0.0001**
Aster	**-0.743**	**< 0.0001**
NAP	-0.764	< 0.0001

Items in bold are major and minor taxa. Items not in bold are rare taxa (whose abundance cannot be estimated with statistical reliability) and synthetic categories (NAP and AP).

Table 9.5. Insignificant Correlations between the Percentage of Pollen Types and Contemporaneous Charcoal Influx

Positive Correlations

	Pearson's *r*	Significance (2-tailed)
Tsuga	+0.101	< 0.671
Picea	**+0.176**	**< 0.458**

Negative Correlations

	Pearson's *r*	Significance (2-tailed)
Larix/Pseudotsuga	-0.423	< 0.063
Acer	-0.543	< 0.013
Alnus	**-0.437**	**< 0.054**
Abies	-0.414	< 0.070
Poaceae	**-0.419**	**< 0.066**
Polygonaceae	-0.429	< 0.059
Liguliflorae	**-0.557**	**< 0.011**
Apiaceae	-0.438	< 0.053

Items in bold are major and minor taxa. Items not in bold are rare taxa (whose abundance cannot be estimated with statistical reliability) and synthetic categories (NAP and AP).

Table 9.6. Significant Correlations between the Percentage of Pollen Types (Leading) and Lagged Charcoal Influx

Positive Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Pinus	**1**	**50**	**+0.841**	**< 0.0001**
AP	1	50	+0.833	< 0.0001
Pinus	**2**	**100**	**+0.858**	**< 0.0001**
AP	2	100	+0.875	< 0.0001
Pinus	**3**	**150**	**+0.829**	**< 0.0001**
Picea	**3**	**150**	**+0.638**	**< 0.006**
AP	3	150	+0.866	< 0.0001
Pinus	**4**	**200**	**+0.758**	**< 0.001**
Picea	**4**	**200**	**+0.751**	**< 0.001**
AP	4	200	+0.810	< 0.0001
Picea	**5**	**250**	**+0.832**	**< 0.0001**
Picea	**6**	**300**	**+0.817**	**< 0.0001**

Table 9.6. Significant Correlations between the Percentage of Pollen Types (Leading) and Lagged Charcoal Influx (cont.)

Negative Correlations

	# Lags	Years	Pearson's r	Significance (2-tailed)
Betula	**1**	**50**	**-0.776**	**< 0.0001**
Quercus	1	50	-0.784	< 0.0001
Chenopodiaceae	**1**	**50**	**-0.684**	**< 0.001**
Artemesia	**1**	**50**	**-0.817**	**< 0.0001**
Ambrosia	**1**	**50**	**-0.790**	**< 0.0001**
Aster	**1**	**50**	**-0.759**	**< 0.0001**
NAP	1	50	-0.833	< 0.0001
Acer	2	100	-0.663	< 0.005
Betula	**2**	**100**	**-0.764**	**< 0.0001**
Quercus	2	100	-0.732	< 0.001
Chenopodiaceae	**2**	**100**	**-0.700**	**< 0.001**
Poaceae	**2**	**100**	**-0.757**	**< 0.0001**
Artemesia	**2**	**100**	**-0.832**	**< 0.0001**
Ambrosia	**2**	**100**	**-0.796**	**< 0.0001**
Aster	**2**	**100**	**-0.676**	**< 0.002**
NAP	2	100	-0.875	< 0.0001
Acer	3	150	-0.707	< 0.001
Betula	**3**	**150**	**-0.682**	**< 0.003**
Poaceae	**3**	**150**	**-0.862**	**< 0.0001**
Artemesia	**3**	**150**	**-0.838**	**< 0.0001**
Ambrosia	**3**	**150**	**-0.764**	**< 0.0001**
Aster	**3**	**150**	**-0.673**	**< 0.003**
Apiaceae	3	150	-0.622	< 0.008
NAP	3	150	-0.866	< 0.0001
Acer	4	200	-0.673	< 0.004
Poaceae	**4**	**200**	**-0.787**	**< 0.0001**
Artemesia	**4**	**200**	**-0.847**	**< 0.0001**
Ambrosia	**4**	**200**	**-0.723**	**< 0.002**
Aster	**4**	**200**	**-0.709**	**< 0.003**
NAP	4	200	-0.810	< 0.0001
Artemesia	**5**	**250**	**-0.752**	**< 0.001**
Aster	**5**	**250**	**-0.665**	**< 0.007**
NAP	5	250	-0.641	< 0.010
Artemesia	**6**	**300**	**-0.694**	**< 0.006**

Table 9.7. Insignificant Correlations between the Percentage of Pollen Types (Leading) and Lagged Charcoal Influx

Positive Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Picea	**1**	**50**	**+0.417**	**< 0.076**
Tsuga	2	100	+0.111	< 0.660
Picea	**2**	**100**	**+0.513**	**< 0.029**
Tsuga	3	150	+0.227	< 0.381
Tsuga	4	200	+0.428	< 0.098
Pinus	**5**	**250**	**+0.612**	**< 0.015**
Tsuga	5	250	+0.367	< 0.179
Pinus	**6**	**300**	**+0.500**	**< 0.069**
Tsuga	6	300	+0.283	< 0.327
Chenopodiaceae	**6**	**300**	**+0.104**	**< 0.724**
AP	6	300	+0.542	< 0.045

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Larix/Pseudotsuga	1	50	-0.529	< 0.020
Acer	1	50	-0.569	< 0.011
Alnus	**1**	**50**	**-0.478**	**< 0.038**
Tsuga	1	50	-0.046	< 0.852
Abies	1	50	-0.341	< 0.154
Poaceae	**1**	**50**	**-0.563**	**< 0.012**
Polygonaceae	1	50	-0.427	< 0.068
Liguliflorae	**1**	**50**	**-0.565**	**< 0.012**
Apiaceae	1	50	-0.552	< 0.014
Alnus	**2**	**100**	**-0.521**	**< 0.027**
Abies	2	100	-0.211	< 0.402
Polygonaceae	**2**	**100**	**-0.408**	**< 0.093**
Liguliflorae	**2**	**100**	**-0.475**	**< 0.047**
Apiaceae	2	100	-0.511	< 0.030

Table 9.7. Insignificant Correlations between the Percentage of Pollen Types (Leading) and Lagged Charcoal Influx (cont.)

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Larix/Pseudotsuga	3	150	-0.449	< 0.070
Alnus	**3**	**150**	**-0.573**	**< 0.016**
Abies	3	150	-0.130	< 0.620
Quercus	3	150	-0.601	< 0.011
Chenopodiaceae	**3**	**150**	**-0.590**	**< 0.013**
Polygonaceae	3	150	-0.423	< 0.091
Ligulaflorae	**3**	**150**	**-0.108**	**< 0.679**
Larix/Pseudotsuga	4	200	-0.383	< 0.143
Betula	**4**	**200**	**-0.564**	**< 0.023**
Alnus	**4**	**200**	**-0.395**	**< 0.129**
Abies	4	200	-0.190	< 0.480
Quercus	4	200	-0.530	< 0.035
Chenopodiaceae	**4**	**200**	**-0.414**	**< 0.111**
Polygonaceae	**4**	**200**	**-0.431**	**< 0.095**
Ligulaflorae	**4**	**200**	**-0.142**	**< 0.601**
Apiaceae	4	200	-0.581	< 0.018
Larix/Pseudotsuga	5	250	-0.398	< 0.142
Acer	5	250	-0.574	< 0.025
Betula	**5**	**250**	**-0.583**	**< 0.023**
Alnus	**5**	**250**	**-0.347**	**< 0.205**
Abies	5	250	-0.201	< 0.471
Quercus	5	250	-0.410	< 0.129
Chenopodiaceae	**5**	**250**	**-0.176**	**< 0.531**
Poaceae	**5**	**250**	**-0.551**	**< 0.033**
Ambrosia	**5**	**250**	**-0.629**	**< 0.012**
Polygonaceae	**5**	**250**	**-0.246**	**< 0.376**
Ligulaflorae	**5**	**250**	**-0.044**	**< 0.875**
Apiaceae	5	250	-0.477	< 0.072
Acer	6	300	-0.525	< 0.054
Betula	**6**	**300**	**-0.398**	**< 0.159**
Alnus	**6**	**300**	**-0.271**	**< 0.350**
Abies	6	300	-0.290	< 0.315
Quercus	6	300	-0.322	< 0.261
Poaceae	**6**	**300**	**-0.431**	**< 0.124**
Ambrosia	**6**	**300**	**-0.529**	**< 0.052**
Aster	**6**	**300**	**-0.591**	**< 0.026**
Polygonaceae	**6**	**300**	**-0.203**	**< 0.486**
Ligulaflorae	**6**	**300**	**-0.039**	**< 0.895**
Apiaceae	6	300	-0.468	< 0.091
NAP	6	300	-0.542	< 0.045

Table 9.8. List of All Significant Multivariate Granger Causal Factors (Including Relationships Within Vegetation)

Leading "causal" Variable	Lagging "responding" Variable	# of lags	lag (years)
Abies	> *Alnus*	1	50
Abies	> oxygen isotope	1	50
Aster	> *Acer*	1	50
Acer	> *Quercus*	1	50
Polygonaceae	> *Alnus*	1	50
Artemesia	> ***Betula***	**1**	**50**
Artemesia	> **Chenopodiaceae**	**1**	**50**
Artemesia	> ***Pinus***	**1**	**50**
Aster	> **Chenopodiaceae**	**1**	**50**
Aster	> **Ligulaflorae**	**1**	**50**
Aster	> *Quercus*	1	50
population	> ***Betula***	**1**	**50**
Pinus	> ***Betula***	**1**	**50**
charcoal	> **Chenopodiaceae**	**1**	**50**
population	> **charcoal**	**1**	**50**
Pinus	> **charcoal**	**1**	**50**
Ligulaflorae	> Polygonaceae	1	50
oxygen isotope	> ***Picea***	**1**	**50**
Pinus	> *Quercus*	1	50
Tsuga	> *Quercus*	1	50
Acer	> *Quercus*	2	100
Apiaceae	> *Acer*	2	100
Alnus	> **population**	**2**	**100**
Chenopodiaceae	> ***Ambrosia***	**2**	**100**
Ambrosia	> **Chenopodiaceae**	**2**	**100**
Artemesia	> **Ligulaflorae**	**2**	**100**
Aster	> **Chenopodiaceae**	**2**	**100**
Aster	> *Larix/Pseudotsuga*	2	100
oxygen isotope	> ***Aster***	**2**	**100**
Picea	> ***Aster***	**2**	**100**
Aster	> *Quercus*	2	100
Aster	> *Tsuga*	2	100
Betula	> **Ligulaflorae**	**2**	**100**
Pinus	> ***Betula***	**2**	**100**
Apiaceae	> *Betula*	2	100
Chenopodiaceae	> *Larix/Pseudotsuga*	2	100
population	> **Chenopodiaceae**	**2**	**100**
Apiaceae	> *Larix/Pseudotsuga*	2	100
Pinus	> **Ligulaflorae**	**2**	**100**
Ligulaflorae	> Polygonaceae	2	100
Quercus	> Ligulaflorae	2	100
population	> *Quercus*	2	100
Pinus	> *Quercus*	2	100
Tsuga	> *Quercus*	2	100

Table 9.8. List of All Significant Multivariate Granger Causal Factors(Including Relationships Within Vegetation) (cont.)

Leading "causal" Variable	Lagging "responding" Variable	# of lags	lag (years)
Abies	> *Artemesia*	3	150
population	> *Abies*	3	150
Acer	> *Quercus*	3	150
Alnus	> **population**	**3**	**150**
Artemesia	> ***Pinus***	**3**	**150**
Aster	> **Chenopodiaceae**	**3**	**150**
Aster	> *Larix/Pseudotsuga*	3	150
Aster	> *Tsuga*	3	150
Chenopodiaceae	> *Larix/Pseudotsuga*	3	150
Larix/Pseudotsuga	> *Quercus*	3	150
Quercus	> Liguliflorae	3	150
Polygonaceae	> population	3	150
Tsuga	> *Quercus*	3	150
Abies	> *Artemesia*	4	200
Acer	> *Quercus*	4	200
Alnus	> **population**	**4**	**200**
Artemesia	> ***Ambrosia***	**4**	**200**
Ambrosia	> **Liguliflorae**	**4**	**200**
Ambrosia	> *Quercus*	4	200
Aster	> **Chenopodiaceae**	**4**	**200**
Aster	> *Larix/Pseudotsuga*	4	200
Apiaceae	> *Betula*	4	200
charcoal	> **population**	**4**	**200**
oxygen isotope	> **Chenopodiaceae**	**4**	**200**
Chenopodiaceae	> *Quercus*	4	200
Apiaceae	> Chenopodiaceae	4	200
Apiaceae	> Polygonaceae	4	200
Tsuga	> *Quercus*	4	200
Chenopodiaceae	> *Larix/Pseudotsuga*	5	250
Chenopodiaceae	> **Liguliflorae**	**5**	**250**
oxygen isotope	> **Chenopodiaceae**	**5**	**250**
Chenopodiaceae	> ***Pinus***	**5**	**250**
Polygonaceae	> Chenopodiaceae	5	250
Quercus	> Chenopodiaceae	5	250
oxygen isotope	> *Larix/Pseudotsuga*	5	250
oxygen isotope	> Apiaceae	5	250
Pinus	> ***Picea***	**5**	**250**
Apiaceae	> Polygonaceae	5	250
oxygen isotope	> **charcoal**	**6**	**300**
Tsuga	> *Pinus*	6	300

Table 9.9. Granger Causality -- All* Significant Results Involving Population, Charcoal, and/or Oxygen Isotope Values

Leading "causal" Variable	Lagging "responding" Variable	# of lags	years
population	**> *Betula***	**1**	**50**
charcoal	**> Chenopodiaceae**	**1**	**50**
population	**> charcoal**	**1**	**50**
Pinus	**> charcoal**	**1**	**50**
oxygen isotope	**> *Picea***	**1**	**50**
Alnus	**> population**	**2**	**100**
oxygen isotope	**> *Aster***	**2**	**100**
population	**> Chenopodiaceae**	**2**	**100**
Alnus	**> population**	**3**	**150**
Alnus	**> population**	**4**	**200**
charcoal	**> population**	**4**	**200**
oxygen isotope	**> Chenopodiaceae**	**4**	**200**
oxygen isotope	**> Chenopodiaceae**	**5**	**250**
oxygen isotope	**> charcoal**	**6**	**300**

*except for those involving rare pollen types

Table 9.10. List of Significant Multivariate Granger Causal Factors Involving Charcoal, with Corresponding Lagged Bivariate Correlations

Charcoal in Leading Position

Leading "causal" Variable	Lagging "responding" Variable	# of lags	lag (years)	Bivariate Correlation Pearson's r	Significance of correlation
charcoal ------------------>	Chenopodiaceae	1	50	-0.823	< 0.0001
charcoal ------------------>	population	4	200	+0.791	< 0.001

Charcoal in Lagging Position

Leading "causal" Variable	Lagging "responding" Variable	# of lags	lag (years)	Bivariate Correlation Pearson's r	Significance of correlation
population ---------------->	charcoal	1	50	+0.840	< 0.0001
Pinus ---------------------->	charcoal	1	50	+0.841	< 0.0001
oxygen isotope----------->	charcoal	6	300	+0.791	< 0.001

Table 9.11. Significant Correlations between Pollen Percentages and Human Population

Positive Correlations

	correlation Pearson's *r*	significance (two tailed)
Pinus	**+0.868**	**< 0.0001**
AP	+0.881	< 0.0001

Negative Correlations

	correlation Pearson's *r*	significance (two tailed)
Betula	**-0.780**	**< 0.0001**
Alnus	**-0.581**	**< 0.007**
Quercus	-0.646	< 0.002
Chenopodiaceae	**-0.694**	**< 0.001**
Poaceae	**-0.691**	**< 0.001**
Artemesia	**-0.887**	**< 0.0001**
Ambrosia	**-0.681**	**< 0.001**
Aster	**-0.788**	**< 0.0001**
Polygonaceae	-0.677	< 0.001
Liguliflorae	**-0.598**	**< 0.005**
Apiaceae	-0.621	< 0.003
NAP	-0.881	< 0.0001

Table 9.12. Insignificant Correlations between Pollen Percentages and Human Population

Positive Correlations

	correlation Pearson's r	significance (two tailed)
Tsuga	+0.359	< 0.120
Picea	**+0.257**	**< 0.274**

Negative Correlations

	correlation Pearson's r	significance (two tailed)
Larix/Pseudotsuga	-0.477	< 0.033
Acer	-0.526	< 0.017
Abies	-0.437	< 0.054

Table 9.13. Significant Correlations between the Population (Leading) and Lagged Values of Taxonomic Abundance

Positive Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Pinus	**1**	**50**	**+0.837**	**< 0.0001**
AP	1	50	+0.816	< 0.0001
Pinus	**2**	**100**	**+0.743**	**< 0.0001**
AP	2	100	+0.689	< 0.002
Pinus	**3**	**150**	**+0.735**	**< 0.001**
AP	3	150	+0.665	< 0.004
Pinus	**4**	**200**	**+0.674**	**< 0.004**
Polygonaceae	4	200	+0.707	< 0.002
Polygonaceae	5	250	+0.756	< 0.001
Polygonaceae	6	300	+0.759	< 0.002

Table 9.13. Significant Correlations between the Population (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Acer	1	50	-0.583	< 0.009
Betula	**1**	**50**	**-0.828**	**< 0.0001**
Quercus	1	50	-0.817	< 0.0001
Chenopodiaceae	**1**	**50**	**-0.795**	**< 0.0001**
Artemesia	**1**	**50**	**-0.757**	**< 0.0001**
Ambrosia	**1**	**50**	**-0.760**	**< 0.0001**
Aster	**1**	**50**	**-0.742**	**< 0.0001**
NAP	1	50	-0.816	< 0.0001
Betula	**2**	**100**	**-0.739**	**< 0.0001**
Abies	2	100	-0.590	< 0.010
Quercus	2	100	-0.823	< 0.0001
Chenopodiaceae	**2**	**100**	**-0.841**	**< 0.0001**
Ambrosia	**2**	**100**	**-0.817**	**< 0.0001**
Aster	**2**	**100**	**-0.616**	**< 0.006**
NAP	2	100	-0.689	< 0.002
Betula	**3**	**150**	**-0.746**	**< 0.001**
Alnus	**3**	**150**	**-0.603**	**< 0.010**
Abies	3	150	-0.762	< 0.0001
Quercus	3	150	-0.768	< 0.0001
Chenopodiaceae	**3**	**150**	**-0.721**	**< 0.001**
Ambrosia	**3**	**150**	**-0.680**	**< 0.003**
Ligulaflorae	**3**	**150**	**-0.627**	**< 0.007**
NAP	3	150	-0.665	< 0.004
Betula	**4**	**200**	**-0.739**	**< 0.001**
Alnus	**4**	**200**	**-0.807**	**< 0.0001**
Abies	4	200	-0.733	< 0.001
Quercus	4	200	-0.636	< 0.008
Ligulaflorae	**4**	**200**	**-0.620**	**< 0.010**
Alnus	**5**	**250**	**-0.889**	**< 0.0001**
Abies	5	250	-0.676	< 0.006
Poaceae	**5**	**250**	**-0.678**	**< 0.006**
Alnus	**6**	**300**	**-0.801**	**< 0.001**
Poaceae	**6**	**300**	**-0.658**	**< 0.010**

Table 9.14. Insignificant Correlations between the Population (Leading) and Lagged Values of Taxonomic Abundance

Positive Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Tsuga	1	50	+0.241	< 0.321
Picea	**1**	**50**	**+0.120**	**< 0.626**
Picea	**2**	**100**	**+0.041**	**< 0.871**
Picea	**3**	**150**	**+0.150**	**< 0.566**
Acer	4	200	+0.017	< 0.950
Picea	**4**	**200**	**+0.262**	**< 0.327**
Apiaceae	4	200	+0.130	< 0.632
AP	4	200	+0.584	< 0.017
Pinus	**5**	**250**	**+0.585**	**< 0.022**
Larix	5	250	+0.025	< 0.931
Acer	5	250	+0.142	< 0.614
Picea	**5**	**250**	**+0.335**	**< 0.222**
Aster	**5**	**250**	**+0.024**	**< 0.932**
Apiaceae	5	250	+0.179	< 0.522
AP	5	250	+0.512	< 0.051
Pinus	**6**	**300**	**+0.469**	**< 0.091**
Larix	6	300	+0.222	< 0.445
Acer	6	300	+0.288	< 0.318
Tsuga	6	300	+0.002	< 0.994
Picea	**6**	**300**	**+0.409**	**< 0.147**
Aster	**6**	**300**	**+0.051**	**< 0.863**
AP	6	300	+0.441	< 0.114

Table 9.14. Insignificant Correlations between the Population (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Larix	1	50	-0.556	< 0.013
Alnus	**1**	**50**	**-0.478**	**< 0.039**
Abies	1	50	-0.357	< 0.133
Poaceae	**1**	**50**	**-0.529**	**< 0.020**
Polygonaceae	1	50	-0.561	< 0.012
Ligulaflorae	**1**	**50**	**-0.383**	**< 0.106**
Apiaceae	1	50	-0.537	< 0.018
Larix	2	100	-0.561	< 0.015
Acer	2	100	-0.563	< 0.015
Alnus	**2**	**100**	**-0.445**	**< 0.064**
Tsuga	2	100	-0.019	< 0.940
Poaceae	**2**	**100**	**-0.407**	**< 0.094**
Artemesia	**2**	**100**	**-0.525**	**< 0.025**
Polygonaceae	2	100	-0.312	< 0.208
Ligulaflorae	**2**	**100**	**-0.548**	**< 0.019**
Apiaceae	2	100	-0.195	< 0.438
Larix	3	150	-0.481	< 0.051
Acer	3	150	-0.318	< 0.214
Tsuga	3	150	-0.185	< 0.477
Poaceae	**3**	**150**	**-0.504**	**< 0.039**
Artemesia	**3**	**150**	**-0.568**	**< 0.017**
Aster	**3**	**150**	**-0.432**	**< 0.083**
Polygonaceae	3	150	-0.518	< 0.033
Apiaceae	3	150	-0.148	< 0.571
Larix	4	200	-0.125	< 0.646
Tsuga	4	200	-0.307	< 0.247
Chenopodiaceae	**4**	**200**	**-0.569**	**< 0.022**
Poaceae	**4**	**200**	**-0.561**	**< 0.024**
Artemesia	**4**	**200**	**-0.568**	**< 0.022**
Ambrosia	**4**	**200**	**-0.468**	**< 0.067**
Aster	**4**	**200**	**-0.164**	**< 0.544**
NAP	4	200	-0.584	< 0.017

Table 9.14. Insignificant Correlations between the Population (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Tsuga	5	250	-0.301	< 0.276
Picea	**5**	**250**	**+0.335**	**< 0.222**
Quercus	5	250	-0.401	< 0.138
Chenopodiaceae	**5**	**250**	**-0.388**	**< 0.153**
Artemesia	**5**	**250**	**-0.531**	**< 0.041**
Ambrosia	**5**	**250**	**-0.311**	**< 0.259**
Ligulaflorae	**5**	**250**	**-0.606**	**< 0.017**
NAP	5	250	-0.512	< 0.051
Betula	**6**	**300**	**-0.455**	**< 0.102**
Abies	6	300	-0.630	< 0.016
Quercus	6	300	-0.125	< 0.669
Chenopodiaceae	**6**	**300**	**-0.103**	**< 0.725**
Poaceae	**6**	**300**	**-0.658**	**< 0.010**
Artemesia	**6**	**300**	**-0.637**	**< 0.014**
Ambrosia	**6**	**300**	**-0.051**	**< 0.862**
Ligulaflorae	**6**	**300**	**-0.633**	**< 0.015**
Apiaceae	6	300	-0.046	< 0.875
NAP	6	300	-0.441	< 0.114

Table 9.15. Significant Correlations between the Charcoal (Leading) and Lagged Values of Taxonomic Abundance

Positive Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Pinus	**1**	**50**	**+0.816**	**< 0.0001**
AP	1	50	+0.799	< 0.0001
Pinus	**2**	**100**	**+0.769**	**< 0.0001**
AP	2	100	+0.714	< 0.001
Pinus	**3**	**150**	**+0.660**	**< 0.004**

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Betula	**1**	**50**	**-0.736**	**< 0.0001**
Quercus	1	50	-0.737	< 0.0001
Chenopodiaceae	**1**	**50**	**-0.823**	**< 0.0001**
Artemesia	**1**	**50**	**-0.698**	**< 0.001**
Ambrosia	**1**	**50**	**-0.753**	**< 0.0001**
Aster	**1**	**50**	**-0.696**	**< 0.001**
NAP	1	50	-0.799	< 0.0001
Betula	**2**	**100**	**-0.756**	**< 0.0001**
Alnus	**2**	**100**	**-0.626**	**< 0.005**
Abies	2	100	-0.627	< 0.005
Quercus	2	100	-0.700	< 0.001
Chenopodiaceae	**2**	**100**	**-0.785**	**< 0.0001**
Artemesia	**2**	**100**	**-0.595**	**< 0.009**
Ambrosia	**2**	**100**	**-0.675**	**< 0.002**
Ligulaflorae	**2**	**100**	**-0.590**	**< 0.010**
NAP	2	100	-0.714	< 0.001

Table 9.15. Significant Correlations between the Charcoal (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

# Lags Years	Pearson's *r*			Significance (2-tailed)
Alnus	**3**	**150**	**-0.633**	**< 0.006**
Abies	3	150	-0.662	< 0.004
Quercus	3	150	-0.684	< 0.002
Chenopodiaceae	**3**	**150**	**-0.661**	**< 0.004**
Polygonaceae	3	150	-0.632	< 0.007
Ligulaflorae	**3**	**150**	**-0.694**	**< 0.002**
Alnus	**4**	**200**	**-0.684**	**< 0.003**
Poaceae	**4**	**200**	**-0.441**	**< 0.087**
Polygonaceae	4	200	-0.653	< 0.006
Alnus	**5**	**250**	**-0.653**	**< 0.008**
Abies	5	250	-0.743	< 0.001
Alnus	**6**	**300**	**-0.827**	**< 0.0001**
Polygonaceae	6	300	-0.662	< 0.010

Table 9.16. Insignificant Correlations between the Charcoal (Leading) and Lagged Values of Taxonomic Abundance

Positive Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Tsuga	1	50	+0.225	< 0.354
Picea	**1**	**50**	**+0.011**	**< 0.964**
Tsuga	2	100	+0.135	< 0.595
Picea	**2**	**100**	**+0.020**	**< 0.939**
Picea	**3**	**150**	**+0.093**	**< 0.722**
Apiaceae	3	150	+0.009	< 0.973
AP	3	150	+0.577	< 0.015
Pinus	**4**	**200**	**+0.515**	**< 0.041**
Acer	4	200	+0.131	< 0.630
Picea	**4**	**200**	**+0.173**	**< 0.521**
Apiaceae	4	200	+0.114	< 0.674
AP	4	200	+0.421	< 0.104
Pinus	**5**	**250**	**+0.363**	**< 0.184**
Larix	5	250	+0.256	< 0.358
Acer	5	250	+0.252	< 0.364
Picea	**5**	**250**	**+0.160**	**< 0.570**
Aster	**5**	**250**	**+0.125**	**< 0.658**
Apiaceae	5	250	+0.244	< 0.381
AP	5	250	+0.300	< 0.277
Pinus	**6**	**300**	**+0.338**	**< 0.237**
Larix	6	300	+0.312	< 0.277
Acer	6	300	+0.361	< 0.205
Tsuga	6	300	+0.081	< 0.784
Picea	**6**	**300**	**+0.253**	**< 0.382**
Quercus	6	300	+0.049	< 0.868
Ambrosia	**6**	**300**	**+0.170**	**< 0.562**
Aster	**6**	**300**	**+0.148**	**< 0.613**
Apiaceae	6	300	+0.195	< 0.504
AP	6	300	+0.305	< 0.288

Table 9.16. Insignificant Correlations between the Charcoal (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Larix	1	50	-0.460	< 0.047
Acer	1	50	-0.547	< 0.015
Alnus	**1**	**50**	**-0.537**	**< 0.018**
Abies	1	50	-0.516	< 0.024
Poaceae	**1**	**50**	**-0.562**	**< 0.012**
Polygonaceae	1	50	-0.490	< 0.033
Liguliflorae	**1**	**50**	**-0.519**	**< 0.023**
Apiaceae	1	50	-0.328	< 0.170
Larix	2	100	-0.570	< 0.014
Acer	2	100	-0.434	< 0.072
Poaceae	**2**	**100**	**-0.553**	**< 0.017**
Artemesia	**2**	**100**	**-0.595**	**< 0.009**
Ambrosia	**2**	**100**	**-0.675**	**< 0.002**
Aster	**2**	**100**	**-0.526**	**< 0.025**
Polygonaceae	2	100	-0.541	< 0.020
Apiaceae	2	100	-0.256	< 0.306
Larix	3	150	-0.308	< 0.229
Acer	3	150	-0.092	< 0.727
Alnus	**3**	**150**	**-0.633**	**< 0.006**
Tsuga	3	150	-0.171	< 0.511
Poaceae	**3**	**150**	**-0.465**	**< 0.060**
Artemesia	**3**	**150**	**-0.511**	**< 0.036**
Ambrosia	**3**	**150**	**-0.505**	**< 0.039**
Aster	**3**	**150**	**-0.245**	**< 0.343**
Polygonaceae	3	150	-0.632	< 0.007
NAP	3	150	-0.577	< 0.015

Table 9.16. Insignificant Correlations between the Charcoal (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Betula	**4**	**200**	**-0.586**	**< 0.017**
Tsuga	4	200	-0.477	< 0.062
Abies	4	200	-0.551	< 0.027
Quercus	4	200	-0.549	< 0.028
Chenopodiaceae	**4**	**200**	**-0.415**	**< 0.110**
Poaceae	**4**	**200**	**-0.441**	**< 0.087**
Artemesia	**4**	**200**	**-0.411**	**< 0.114**
Ambrosia	**4**	**200**	**-0.350**	**< 0.184**
Aster	**4**	**200**	**-0.010**	**< 0.970**
Ligulaflorae	**4**	**200**	**-0.435**	**< 0.092**
NAP	4	200	-0.421	< 0.104
Betula	**5**	**250**	**-0.379**	**< 0.164**
Tsuga	5	250	-0.281	< 0.310
Quercus	5	250	-0.197	< 0.482
Chenopodiaceae	**5**	**250**	**-0.145**	**< 0.606**
Poaceae	**5**	**250**	**-0.432**	**< 0.108**
Artemesia	**5**	**250**	**-0.413**	**< 0.126**
Ambrosia	**5**	**250**	**-0.099**	**< 0.725**
Polygonaceae	5	250	-0.625	< 0.013
Ligulaflorae	**5**	**250**	**-0.502**	**< 0.056**
NAP	5	250	-0.300	< 0.277
Betula	**6**	**300**	**-0.323**	**< 0.259**
Abies	6	300	-0.565	< 0.035
Chenopodiaceae	**6**	**300**	**-0.041**	**< 0.889**
Poaceae	**6**	**300**	**-0.606**	**< 0.021**
Artemesia	**6**	**300**	**-0.475**	**< 0.086**
Ligulaflorae	**6**	**300**	**-0.537**	**< 0.048**
NAP	6	300	-0.305	< 0.288

Table 9.17. Significant Correlations between the Percentage of Different Taxa and Contemporaneous Oxygen Isotope Values

Positive Correlations

	correlation Pearson's *r*	significance (two tailed)
Picea	**+0.867**	**< 0.0001**

Negative Correlations

	correlation Pearson's *r*	significance (two tailed)
Alnus	**-0.581**	**< 0.007**
Poaceae	**-0.615**	**< 0.004**
Artemesia	**-0.588**	**< 0.006**
Polygonaceae	-0.594	< 0.006

Table 9.18. Insignificant Correlations between the Percentage of Different Taxa and Contemporaneous Oxygen Isotope Values

Positive Correlations

	correlation Pearson's *r*	significance (two tailed)
Pinus	**+0.424**	**< 0.063**
Larix/Pseudotsuga	+0.001	< 0.998
Chenopodiaceae	**+0.003**	**< 0.989**
AP	+0.442	< 0.051

Negative Correlations

	correlation Pearson's *r*	significance (two tailed)
Acer	-0.097	< 0.686
Betula	**-0.359**	**< 0.120**
Tsuga	-0.046	< 0.848
Abies	-0.525	< 0.017
Quercus	-0.186	< 0.432
Ambrosia	**-0.247**	**< 0.293**
Aster	**-0.257**	**< 0.274**
Ligulaflorae	**-0.314**	**< 0.177**
Apiaceae	-0.220	< 0.351
NAP	-0.442	< 0.051

Table 9.19. Significant Correlations between the Oxygen Isotope (Leading) and Lagged Values of Taxonomic Abundance

Positive Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Picea	**1**	**50**	**+0.910**	**< 0.0001**
Picea	**2**	**100**	**+0.811**	**< 0.0001**
AP	4	200	+0.658	< 0.006
Pinus	**5**	**250**	**+0.654**	**< 0.008**
AP	5	250	+0.713	< 0.003
Pinus	**6**	**300**	**+0.715**	**< 0.004**
AP	6	300	+0.710	< 0.004

Table 9.19. Significant Correlations between the Oxygen Isotope (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Poaceae	**1**	**50**	**-0.587**	**< 0.008**
Artemesia	**1**	**50**	**-0.598**	**< 0.007**
Poaceae	**2**	**100**	**-0.599**	**< 0.009**
Artemesia	**3**	**150**	**-0.624**	**< 0.007**
Aster	**3**	**150**	**-0.708**	**< 0.001**
Acer	4	200	-0.740	< 0.001
Ambrosia	**4**	**200**	**-0.683**	**< 0.004**
Aster	**4**	**200**	**-0.849**	**< 0.0001**
NAP	4	200	-0.658	< 0.006
Larix	5	250	-0.717	< 0.003
Acer	5	250	-0.864	< 0.0001
Quercus	5	250	-0.672	< 0.006
Chenopodiaceae	**5**	**250**	**-0.775**	**< 0.001**
Poaceae	**5**	**250**	**-0.365**	**< 0.182**
Ambrosia	**5**	**250**	**-0.845**	**< 0.0001**
Aster	**5**	**250**	**-0.864**	**< 0.0001**
Apiaceae	5	250	-0.692	< 0.004
NAP	5	250	-0.713	< 0.003
Acer	6	300	-0.730	< 0.003
Quercus	6	300	-0.854	< 0.0001
Chenopodiaceae	**6**	**300**	**-0.859**	**< 0.0001**
Ambrosia	**6**	**300**	**-0.883**	**< 0.0001**
Aster	**6**	**300**	**-0.712**	**< 0.004**
NAP	6	300	-0.710	< 0.004

Table 9.20. Insignificant Correlations between the Oxygen Isotope (Leading) and Lagged Values of Taxonomic Abundance

Positive Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Pinus	**1**	**50**	**+0.397**	**< 0.092**
Larix	1	50	+0.088	< 0.721
Tsuga	1	50	+0.184	< 0.451
Chenopodiaceae	**1**	**50**	**+0.029**	**< 0.906**
AP	1	50	+0.436	< 0.062
Pinus	**2**	**100**	**+0.431**	**< 0.074**
Tsuga	2	100	+0.486	< 0.041
AP	2	100	+0.510	< 0.031
Pinus	**3**	**150**	**+0.491**	**< 0.045**
Tsuga	3	150	+0.577	< 0.015
Abies	3	150	+0.136	< 0.603
Picea	**3**	**150**	**+0.590**	**< 0.013**
Ligulaflorae	**3**	**150**	**+0.026**	**< 0.921**
AP	3	150	+0.580	< 0.015
Pinus	**4**	**200**	**+0.572**	**< 0.021**
Tsuga	4	200	+0.522	< 0.038
Abies	4	200	+0.216	< 0.423
Picea	**4**	**200**	**+0.264**	**< 0.322**
Alnus	**5**	**250**	**+0.005**	**< 0.986**
Tsuga	5	250	+0.286	< 0.301
Abies	5	250	+0.188	< 0.503
Polygonaceae	5	250	+0.028	< 0.992
Tsuga	6	300	+0.011	< 0.969

Table 9.20. Insignificant Correlations between the Oxygen Isotope (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

	# Lags	Years	Pearson's r	Significance (2-tailed)
Acer	1	50	-0.161	< 0.511
Betula	**1**	**50**	**-0.363**	**< 0.127**
Alnus	**1**	**50**	**-0.533**	**< 0.019**
Abies	1	50	-0.286	< 0.235
Quercus	1	50	-0.085	< 0.728
Ambrosia	**1**	**50**	**-0.262**	**< 0.278**
Aster	**1**	**50**	**-0.294**	**< 0.222**
Polygonaceae	1	50	-0.457	< 0.049
Ligulaflorae	**1**	**50**	**-0.197**	**< 0.420**
Apiaceae	1	50	-0.277	< 0.250
NAP	1	50	-0.436	< 0.062
Larix	2	100	-0.023	< 0.928
Acer	2	100	-0.309	< 0.212
Betula	**2**	**100**	**-0.332**	**< 0.178**
Alnus	**2**	**100**	**-0.389**	**< 0.111**
Abies	2	100	-0.038	< 0.881
Quercus	2	100	-0.113	< 0.656
Chenopodiaceae	**2**	**100**	**-0.090**	**< 0.722**
Ambrosia	**2**	**100**	**-0.367**	**< 0.134**
Aster	**2**	**100**	**-0.479**	**< 0.044**
Polygonaceae	2	100	-0.280	< 0.261
Ligulaflorae	**2**	**100**	**-0.068**	**< 0.787**
Apiaceae	2	100	-0.443	< 0.066
NAP	2	100	-0.510	< 0.031
Larix	3	150	-0.302	< 0.239
Acer	3	150	-0.509	< 0.037
Betula	**3**	**150**	**-0.359**	**< 0.157**
Alnus	**3**	**150**	**-0.264**	**< 0.307**
Quercus	3	150	-0.229	< 0.377
Chenopodiaceae	**3**	**150**	**-0.289**	**< 0.260**
Poaceae	**3**	**150**	**-0.512**	**< 0.036**
Ambrosia	**3**	**150**	**-0.500**	**< 0.041**
Polygonaceae	**3**	**150**	**-0.112**	**< 0.668**
Apiaceae	3	150	-0.553	< 0.021
NAP	3	150	-0.580	< 0.015

Table 9.20. Insignificant Correlations between the Oxygen Isotope (Leading) and Lagged Values of Taxonomic Abundance (cont.)

Negative Correlations

	# Lags	Years	Pearson's *r*	Significance (2-tailed)
Betula	**4**	**200**	**-0.403**	**< 0.122**
Alnus	**4**	**200**	**-0.083**	**< 0.759**
Quercus	4	200	-0.440	< 0.088
Chenopodiaceae	**4**	**200**	**-0.579**	**< 0.019**
Poaceae	**4**	**200**	**-0.433**	**< 0.094**
Artemesia	**4**	**200**	**-0.560**	**< 0.024**
Polygonaceae	**4**	**200**	**-0.002**	**< 0.995**
Liguliflorae	**4**	**200**	**-0.090**	**< 0.741**
Apiaceae	4	200	-0.581	< 0.018
Betula	**5**	**250**	**-0.492**	**< 0.063**
Picea	**5**	**250**	**-0.071**	**< 0.800**
Poaceae	**5**	**250**	**-0.365**	**< 0.182**
Artemesia	**5**	**250**	**-0.503**	**< 0.056**
Liguliflorae	**5**	**250**	**-0.159**	**< 0.572**
Larix	6	300	-0.597	< 0.024
Betula	**6**	**300**	**-0.657**	**< 0.011**
Alnus	**6**	**300**	**-0.053**	**< 0.856**
Abies	6	300	-0.169	< 0.565
Picea	**6**	**300**	**-0.412**	**< 0.143**
Poaceae	**6**	**300**	**-0.258**	**< 0.374**
Artemesia	**6**	**300**	**-0.475**	**< 0.086**
Aster	**6**	**300**	**-0.712**	**< 0.004**
Polygonaceae	6	300	-0.051	< 0.862
Liguliflorae	**6**	**300**	**-0.330**	**< 0.249**
Apiaceae	6	300	-0.483	< 0.080

Chapter 10. Conclusions

The goal of this dissertation has been to examine the interaction between people, climate and the landscape over a decadal to centennial time-scale. This time-scale was chosen for study because few research projects have dealt with interactions and change in landscapes on this temporal scale, although this is the scale at which succession, global climate, and human impact primarily operate. Modern ecological studies have examined interactions on annual to decadal-scales. Paleoecological studies have mainly dealt with processes on a millennial-scale, leaving a gap in our understanding of the important processes that operate across the intermediate time scales between these two major approaches.

This study focuses on the interactions of a natural and cultural system over the past thousand years in eastern Washington as one example for evaluating the processes interacting at decadal to centennial scales. In order to test and evaluate ideas about how people, vegetation, climate, and fire all affect each other, I first had to find or create proxy variables to cover the necessary range of data. An existing population proxy, drawn from area archaeology, was used in this study. New variables covering taxonomic plant abundances over time (pollen), local climate (oxygen isotope records of aridity), and local incidence of vegetation fires (charcoal deposition) were generated, and matched to the resolution, scale, and extent of the pre-existing population proxy.

Using statistical analyses to explore the resulting dataset has yielded information on local environmental history, which is of use to people living in the area today, archaeologists, and paleoecologists who wish to understand both the historic and prehistoric record of human behavioral ecologists in this part of the world. Additionally, statistical analyses have provided information on the general nature of landscape processes that operate on the decadal to centennial scale in this area. This is important for understanding past processes in other areas of our world and for understanding the probable changes and interactions that could take place in the next 50 to 250 years, given the events occurring now.

History of the Chief Joseph Dam area of eastern Washington

Area Vegetation History

This study has revealed several trends that are of regional or local interest and increased our knowledge of the ecological history of this particular area. Such paleovegetation data provide a finer scale than previous work, yielding a more suitable backdrop for understanding and evaluating human. It was known, for instance, that this area had undergone changes in vegetation over the past few thousand years, but the details and timing of these vegetation changes were not as finely resolved as the archaeological record.

The relatively high-resolution vegetation reconstruction generated by this study extends back 1,525 years, and is based on counts of pollen of different taxa recovered from samples of lake mud from Five Lakes, a basin located approximately 13 kilometers north of Grand Coulee Dam and 6 kilometers southeast of the modern town of Nespelem. Lake mud was sampled at 5 cm (approximately 53-year) intervals, and the resulting reconstruction of vegetation reveals a general trend over time towards decreased amounts of pine and increased amounts of early-seral taxa such as alder, birch, chenopods, and composites.

Previous pollen studies found that modern vegetation was established by 2,000 years ago (Chatters 1998) with a recent rise in Chenopodiaceae imposed upon this pollen zone about 100 years ago (Dalan 1985, Davis et al. 1977). Examining the pollen diagram created for this study, the past 1,000 to 2,000 years of vegetation history can be described in finer terms than to simply call it "modern" in nature. The vegetation record can be further divided into two smaller pollen zones. The earliest subdivision from about 1,525 to 580 B.P. is a time of high and constant amounts of pine pollen, indicating that vegetation a thousand years ago was less diverse, that pine woodlands were more extensive than today, and that vegetation was more stable and unchanging than it is today.

Beginning about 580 B.P., vegetation becomes less stable, with individual taxa varying more in abundance from sample to sample. Overall, the recent portion of the vegetation record has been characterized by a dominance by pine, but at a lower and more fluctuating abundance than before. The upper, or more recent, part of the vegetation record is characterized by a larger contribution from nonarboreal pollen (herbs and shrubs) and a greater proportion of early-seral taxa as part of a more diverse and dynamic vegetation than before.

As predicted by other researchers, the recent portion of the record shows a growing abundance of Chenopodiceae. This spread of Chenopodiaceae was predicted based on the introduction of Euro-American land-use practices, primarily the introduction of large numbers of domestic grazing animals into eastern Washington starting around 1850 A.D. (Davis et al. 1977). Although a recent rise in chenopods is seen in this study, the magnitude of this rise is much lower than that documented in other records and the timing does not coincide with a date of A.D. 1850 but occurs in this pollen diagram much earlier -- at approximately 580 B.P.

Area Fire History

Fire history in the area was investigated using the influx of charcoal particles into the same lake sediments used for pollen analysis. Using charcoal as a proxy for local vegetation fires, a 1,525-year history of area fire was reconstructed. Whether charcoal was measured in terms of the total influx of all sizes of particles, or simply the influx of large particles, results remained unchanged. The record shows that charcoal influx was greatest from 1,525 to 500 B.P., roughly the same time period as the early and stable pine-dominated vegetation described above.

When examining spikes in the influx of large charcoal particles (measured by $\#/cm^2/yr$ of charcoal < 125 μm), dates of individual fire events could be determined and return intervals between fire events reconstructed. During the earlier part of the record (1,525 to 500 B.P.), fire occurred, on average, every 148 years and individual return intervals ranged from 94 to 232 years. These return rates are longer than those observed in modern ecological studies and historic documents, but correspond well to the resulting return intervals that are recognizable in other palynological records. The return rates of 94 to 232, as determined by this study, indicate that this area was burning at the same rate as other areas in prehistory and that proxies are less sensitive than historic records and modern fire-scar studies. Comparing results at Five Lakes with other palynological studies, the length of the average return intern interval at Five Lakes (148 years) corresponds to returns seen for natural, rather than cultural, fire regimes (Chatters 1998).

During the later part of this record (the past 500 years), charcoal influx was greatly reduced. This could signal a reduction in the size of fires in the area. Although a decrease in vegetation fires was expected during the era of active fire suppression in this area (from about 150 to 30 years ago [Martin et al. 1977]), it was a surprise to find that charcoal influx was low even before the advent of human fire suppression.

Area Climate History

As part of this study, oxygen isotope assays from lake carbonates were used to reconstruct local climate. The oxygen isotope record provided a reconstruction of relative aridity for the area, and could not be resolved into separate records for temperature and precipitation. The results from this analysis show that, overall, conditions were more arid in the study area at 1,000

B.P. than they are today. From 1,000 to about 600 B.P., conditions became progressively more mesic and reached a relative maximum of moisture about 600 B.P. This indicates that corresponding global period known as the Medieval Warm Period was expressed locally as an increase in precipitation, a decrease in evaporation, or both. After 600 B.P., local conditions became more arid. This drying episode, which peaked about 400 B.P. corresponds temporally with the global phenomenon known as the Little Ice Age. Results show that the LIA was expressed in the study area as a period of relative aridity rather than a period of cooler and moister conditions.

Processes Operating on Decadal to Centennial Scales

Interactions on the Landscape

One finding was that many of the statistically significant bivariate correlations between variables were shown to be unimportant once all variables were simultaneously considered in a multivariate procedure. Variables that promised to have potential explanatory value when examined in isolation turned out to be linearly dependent on other factors when competing potential explanatory factors and time lags were entered into the analysis. This was one indication that human population, taxonomic abundances, fire, and climate participate in a highly complex set of interrelated feedback systems. In addition, many of the interrelationships were not apparent until lags of 50, 100, or even 300 years were entered into the model.

Once the dataset was evaluated using multivariate time series techniques, significant leading factors could be identified. Vegetation, for instance, was patterned mainly by past taxonomic abundances and oxygen isotope values. Of these two, past vegetation had a greater relative influence on future plant communities. History, then, constrains vegetation type more than fire, humans or climate -- a surprising finding given that human activities and climate are thought of as primary determinants of landscape change.

Although not in a primary role, population and fire did have some influence on future taxonomic abundances on short time-scales. The nature of the relationship between plants and humans was surprising, however. Times of high population were not, as expected, associated with relative increases in disturbance taxa. In fact, the opposite trend was observed. In bivariate models, human population sizes were significantly negatively correlated with disturbance taxa and positively correlated with climax taxa at several time scales.

Tests run on the charcoal proxy indicated that fire was also part of a densely interwoven pattern of relationships with population, vegetation, past fires, and climate. In multivariate models, fire was seen to be significantly patterned over the short term by human population sizes and over the long term by climate. Time series analysis and Granger causation tests indicated that, while population conditioned charcoal influx 50 years in the future, charcoal influxes likewise predicted population values 200 years in the future. Again, this demonstrates that the variables are complexly interrelated with one another, neither one clearly "causing" the other. Like vegetation, fire was also historically constrained by past values of itself (with significant autocorrelations).

By running and comparing bivariate and multivariate statistical analyses, significant interrelationships could be discovered and variables identified as leading or lagging in these interactions. Results indicated that no variables could be considered in isolation; human population, vegetation, and fire could not be considered extrinsic, independent factors imposing change on a system. Humans, for instance, influence fire, but fire regimes are seen to pattern population sizes in return. Of all the factors analyzed, oxygen isotope was identified most often as a linearly independent leading factor, showing that climate is the closest to being an "outside" factor in the past millennium in the study area. This analysis also showed the importance of historical constraints on this ecological system, which exert significant control on future conditions.

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Appendix A. Abbreviations, Symbols, and Conventions Used

Table A.1. Abbreviations, Symbols, and Conventions Used

Notation	Meaning/Use
A.D.	Annos Dominae, also know as the Common Era (C.E.) These are calendar years from historic records. (The sole exception is the date of A.D. 1479/1480 given for the Mt St Helens Wn eruption on p. 68, which was determined via tree ring records).
cSt	Centistokes
Local	areas within 20 m of a basin (Jacobson and Bradshaw 1981)
Extralocal	areas between 20 and several hundred m of a basin (roughly within a km)
Regional	areas more than a few hundred m of a basin (usually several tens of km)
cal. A.D.	calibrated radiocarbon dates, obtained by using dendro-calibration curves to convert radiocarbon dates to A.D. dates (using the CALIB. v.4.3 program, Dataset 2, after correcting for $\delta^{13}C$).
cal. B.C.	Before Christ, also know as Before the Common Era (B.C.E.) These are calibrated radiocarbon dates obtained by using dendro-calibration curves to convert radiocarbon dates to B.C. dates (using the CALIB v.4.3 program, Dataset 2, after correcting for $\delta^{13}C$).
AP	Arboreal Pollen -- the sum of all tree pollen
NAP	Non-Arboreal Pollen -- the sum of all herb and shrub (but not aquatic) pollen
LOI	Loss On Ignition analysis, in which the percent composition of organics and carbonates are determined via weight loss when samples are oxidized at two different temperatures in a muffle furnace (see Dean 1974 or Appendix C for procedures)
SEM	Scanning Electron Microscope The SEM and EDS used in this study were a JEOL 840A
EDS	Energy Dispersive Spectrometry A detection system on an SEM which collects x-rays produced by materials when under the electron beam. X-ray counts for different energy levels are made, and x-ray "fingerprints" for different elements are used to identify the elemental composition of the material under the beam. This is similar to WDS, Wavelength Dispersive Spectrometry, a collector that counts the incidence of x-rays of different wavelengths.

Table A.1. Abbreviations, Symbols, and Conventions Used

Notation	Meaning/Use
AMS	Accelerator Mass Spectrometer AMS dates in this manuscript are those ^{14}C dates calculated from measurements of ^{14}C made using the accelerator at University of Arizona.
B.P.	Before Present -- dates of B.P. reported here are measured in terms of uncalibrated ^{14}C years before present, where present is A.D. 1950, and ^{14}C dates have been corrected for $\delta^{13}C$ by the lab.
cm bi	centimeters below sediment-water interface
m asl	meters above sea level (modern elevation)
µm	microns, micrometers
$\delta^{13}C$	carbon isotope value, reported in permil (‰) $\delta^{13}C=1000(R_{sample}/R_{standard}-1)$, where $R={}^{13}C/{}^{12}C$ and the $R_{standard}$ is PDB-CO_2, with a $\delta^{13}C=0$
$\delta^{18}O$	oxygen isotope value, reported in permil (‰) $\delta^{18}O=1000(R_{sample}/R_{standard}-1)$, where $R={}^{18}O/{}^{16}O$ and the $R_{standard}$ is VSMOW-CO_2, with a $\delta^{18}O=0$

Appendix B. Paleodemographic Data

Table B.1. Paleodemographic Record -- Population Surrogates Used

Temporal Interval cal A.D.	Interval Midpoint cal A.D.	# of Components	Total Area m^2	Average Bone $\#/m^2/yr$	Average Bone $g/m^2/yr$	Average Shell $g/m^2/yr$	Average Features $\#/m^2/yr$
1875-1925	1900	8.00	11202.00	71.19	13.49	0.06	0.00
1825-1875	1850	9.00	30402.00	77.26	14.56	0.70	0.00
1775-1825	1800	13.00	37902.00	122.71	39.31	50.66	0.01
1725-1775	1750	17.00	47239.00	104.57	38.46	32.22	0.00
1675-1725	1700	14.00	42729.00	66.93	32.55	24.31	0.01
1625-1675	1650	17.00	57903.00	62.07	21.46	18.32	0.00
1575-1625	1600	17.00	57903.00	62.07	21.46	18.32	0.00
1525-1575	1550	17.00	57903.00	62.07	21.46	18.32	0.00
1475-1525	1500	18.00	61975.00	132.27	47.31	3.13	0.00
1425-1475	1450	26.00	76111.00	159.49	49.91	14.93	0.01
1375-1425	1400	20.00	66404.00	237.79	53.47	18.63	0.01
1325-1375	1350	22.00	49790.00	207.44	54.06	20.25	0.05
1275-1325	1300	27.00	79655.00	234.71	57.87	21.31	0.05
1225-1275	1250	23.00	74609.00	155.53	37.92	21.31	0.03
1175-1225	1200	22.00	75014.00	185.63	54.12	21.31	0.04
1125-1175	1150	18.00	56662.00	148.35	49.31	14.93	0.04
1075-1125	1110	18.00	53020.00	130.60	86.60	14.93	0.02
1025-1075	1050	21.00	55732.00	153.05	87.12	11.80	0.02
975-1025	1000	23.00	64324.00	196.43	77.76	10.73	0.04
925-975	950	31.00	101437.00	129.08	43.72	13.03	0.02
		$\bar{x}$ =19.05	$\bar{x}$ =57895.80	$\bar{x}$ =134.96	$\bar{x}$ =45.10	$\bar{x}$ =17.46	$\bar{x}$ =0.02
		s_x = 5.68	s_x = 19438.24	s_x = 57.47	s_x = 21.63	s_x = 11.07	s_x = 0.02

Data are taken from Campbell 1989:166

Interval midpoints, averages, and standard deviations added later

Table B.2. Paleodemographic Record -- Z-scores and Composite Population Index

Temporal Interval cal A.D.	Interval Midpoint cal A.D.	z-score # Components	z-score of area	z-score of bone ($\#/m^2/yr$)	z-score of bone ($gm/m^2/yr$)	z-score of shell	z-score of features	Composite Population Index*
1875-1925	1900	-1.95	-2.40	-1.11	-1.46	-1.57	-0.97	-1.11
1825-1875	1850	-1.77	-1.41	-1.00	-1.41	-1.51	-0.97	-1.00
1775-1825	1800	-1.07	-1.03	-0.21	-0.27	3.00	-0.42	-0.21
1725-1775	1750	-0.36	-0.55	-0.53	-0.31	1.33	-0.97	-0.53
1675-1725	1700	-0.89	-0.78	-1.18	-0.58	0.62	-0.42	-1.18
1625-1675	1650	-0.36	0.00	-1.27	-1.09	0.08	-0.97	-1.27
1575-1625	1600	-0.36	0.00	-1.27	-1.09	0.08	-0.97	-1.27
1525-1575	1550	-0.36	0.00	-1.27	-1.09	0.08	-0.97	-1.27
1475-1525	1500	-0.18	0.21	-0.05	0.10	-1.29	-0.97	-0.05
1425-1475	1450	1.22	0.94	0.43	0.22	-0.23	-0.42	0.43
1375-1425	1400	0.17	0.44	1.79	0.39	0.11	-0.42	1.79
1325-1375	1350	0.52	-0.42	1.26	0.41	0.25	1.80	1.26
1275-1325	1300	1.40	1.12	1.74	0.59	0.35	1.80	1.74
1225-1275	1250	0.70	0.86	0.36	-0.33	0.35	0.69	0.36
1175-1225	1200	0.52	0.88	0.88	0.42	0.35	1.25	0.88
1125-1175	1150	-0.18	-0.06	0.23	0.19	-0.23	1.25	0.23
1075-1125	1110	-0.18	-0.25	-0.08	1.92	-0.23	0.14	-0.08
1025-1075	1050	0.34	-0.11	0.31	1.94	-0.51	0.14	0.31
975-1025	1000	0.70	0.33	1.07	1.51	-0.61	1.25	1.07
925-975	950	2.10	2.24	-0.10	-0.06	-0.40	0.14	-0.10

*average of all z-scores for six potential population surrogates

Appendix C. Lake Locations

Table C.1. Location Information for lakes discussed in the text

Lake Name	County in Washington State	Latitude	Longitude	UTM (The principle point is 11 for all lakes listed)	Elevation asl *	USGS 7.5' Quad (1:24000 scale map)
Bedard Lake North	Okanogan	48° 07' 13"N	119° 31' 05"W	312603E 5332517N	747 m (2,450ft)	BRIDGEPORT POINT 1980
Bovy Bog	Okanogan	48° 08' 16"N	119° 20' 36"W	325669E 5334041N	503 m (1,650 ft)	BOOT MOUNTAIN 1980
Duley Lake	Okanogan	48° 09' 57"N	119° 29' 37"W	314594E 5337515N	736 m (2,414 ft)	JOE LAKE 1990
Five Lakes	Okanogan	48° 04' 55"N	118° 55' 46"W	356291E 5326990N	780 m (2,560 ft)	BELVEDERE 1990
Goose Lake	Okanogan	48° 10' 16"N	119° 20' 32"W	325852E 5337759N	372 m (1,220 ft)	BOOT MOUNTAIN 1980
Hidden Lake	Okanogan	48° 08' 10"N	119° 20' 03"W	326339E 5333858N	573 m (1,880 ft)	BOOT MOUNTAIN 1980
Murphy Lake	Douglas	48° 01' 00"N	119° 27' 24"W	316809E 5320873N	563 m (2,144 ft)	STUBBLEFIELD POINT 1990
Rebecca Lake	Okanogan	48° 03' 21"N	118° 55' 53"W	356088E 5324104N	579 m (1,900 ft)	BELVEDERE 1990
Rex Grange Lake	Douglas	48° 03' 27"N	119° 07' 27"W	341721E 5324653N	771 m (2,530 ft)	SANDERSON CREEK 1990
Rinker's Lake	Douglas	48° 00' 30"N	119° 17' 01"W	329672E 5319512N	704 m (2,310 ft)	TREFRY CANYON 1980

*asl = above modern sea level

Appendix D. Details of Laboratory Procedures

Table D.1. Loss-on-Ignition Analysis

Procedural Steps
Empty clean crucibles weighed
Crucibles filled with approximately 2 cm^3 wet sediment
Crucibles and wet sediment placed in 80 °C drying oven for 12 hours
Crucibles and dry sediment allowed to cool to room temperature
Crucibles and dry sediment weighed
Crucibles and dry sediment put in 550 °C muffle furnace for 90 minutes
Crucibles and 550-°C burned sediment allowed to cool to room temperature
Crucibles and 550-°C burned sediment weighed
Crucibles and 550-°C burned sediment put in 1,000 °C muffle furnace for 90 minutes
Crucibles and 1,000-°C burned sediment allowed to cool to room temperature
Crucibles and 1,000-°C burned sediment weighed
Residue scanned under 40x binocular dissecting scope for tephra & inorganic sediment identification
Residue put in labeled coin envelopes for storage and crucibles cleaned

Table D.2 -- Pollen Processing

Procedural Steps
One cm^3 of sediment was taken from a 1-cm span of stratigraphic depth within the core
Sediment placed in a 50 ml Nalgene centrifuge tube
2 *Lycopodium* aliquot tablets added to tube (lot #124961)*
3 ml 10% HCl added to dissolved aliquot tablets -- allowed to stand overnight
50 ml 10% HCl added, centrifuged, decanted
50 ml concentrated HCl in hot** water bath for 10 minutes, centrifuged, decanted
water wash -- 50 ml distilled water, centrifuged, decanted
50 ml 10% KOH in hot water bath for 10 minutes, centrifuged, decanted
50 ml water, centrifuged, decanted
(repeated about six times until decant was clear and pH neutral)
50 ml 10% HCl, centrifuged, decanted
sieved through sterilized metal window screen to remove large particles
filtered through 8 μm nylon mesh (a.k.a hematology screen or "Nytex") using a motorized vacuum pump
filtrate discarded and 8 μm and larger particles washed into test tubes with distilled water
25 ml concentrated HF in hot water bath for 30 minutes, centrifuged, decanted
50 ml distilled water, centrifuged, decanted (twice)
prep slides made from all samples to assess processing efficacy and possible damage to pollen
optional step for samples with sulfides: 50 ml H_2NO_3, centrifuged and decanted followed by a distilled water wash
optional step for flocculated samples: 50 ml 5% sodium hexametaphosphate and 10 seconds of sonification, centrifuged, decanted, followed by a distilled water wash)
optional step for siliceous samples: 50 ml HF in hot water bath for 30 minutes, centrifuged, decanted, followed by two distilled water washes
50 ml concentrated glacial acetic acid, centrifuged and decanted (twice)
25 ml acetolysis mixture, in hot water bath for 7 minutes
50 ml concentrated glacial acetic acid, centrifuged and decanted (twice)
50 ml distilled water, centrifuged, decanted
prep slides of all samples made and evaluated under microscope
50 ml ethanol, centrifuged, decanted
50 ml tert-butanol (TBA) centrifuged, decanted
samples pipetted into vials with silicon oil (10,000 cSt) and TBA allowed to evaporate

*for batch #124961 Lycopodium spore tables, the average number of spores per tablet was 12,542

**hot=80°C

Appendix E. LOI Results

Table E.1. LOI Results for Bedard Lake North

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
0	8.2420	10.1748	9.9360	9.8814	12.36	6.42	81.22
1	8.3897	9.4335	9.3399	9.3041	8.97	7.79	83.24
2	8.3743	9.1103	9.0511	9.0234	8.04	8.55	83.40
3	8.2906	9.2216	9.1555	9.1093	7.10	11.28	81.62
4	8.3146	9.3520	9.2688	9.2249	8.02	9.62	82.36
5	8.6660	9.4760	9.4060	9.3733	8.64	9.18	82.18
6	8.5017	10.9675	10.7671	10.6620	8.13	9.69	82.19
7	8.5046	9.6191	9.5346	9.4838	7.58	10.36	82.06
8	8.8672	9.5252	9.4806	9.4476	6.78	11.40	81.82
9	8.2234	9.9210	9.8051	9.7093	6.83	12.83	80.35
10	8.3818	9.8000	9.7071	9.6324	6.55	11.97	81.48
11	8.0085	9.5521	9.4762	9.3962	4.92	11.78	83.30
12	8.3670	10.2678	10.1721	10.0726	5.03	11.90	83.07
13	8.5170	9.9507	9.8594	9.7626	6.37	15.34	78.29
14	8.5463	10.1722	10.0722	9.9618	6.15	15.43	78.42
15	8.5081	10.3199	10.2262	10.0851	5.17	17.70	77.13
16	8.3577	10.2742	10.1739	10.0289	5.23	17.20	77.57
17	8.4627	10.5419	10.4252	10.2773	5.61	16.17	78.22
18	9.2696	11.5450	11.4114	11.2504	5.87	16.08	78.05
19	8.2063	9.7630	9.6763	9.5600	5.57	16.98	77.45
20	8.4791	10.1641	10.0742	9.9441	5.34	17.55	77.12
21	8.1782	10.6910	10.5806	10.3587	4.39	20.07	75.54
22	7.7497	11.2165	11.0620	10.7658	4.46	19.42	76.13
23	8.5155	10.6902	10.5853	10.4097	4.82	18.35	76.82
24	8.6887	10.7291	10.6300	10.4669	4.86	18.17	76.98
25	8.4743	11.0186	10.9016	10.6933	4.60	18.61	76.79
26	8.3046	10.6914	10.5911	10.3958	4.20	18.60	77.20
27	8.3854	9.9390	9.8797	9.7441	3.82	19.84	76.35
28	9.0068	12.4369	12.2921	12.0200	4.22	18.03	77.75
29	8.5693	10.9067	10.8077	10.6211	4.24	18.14	77.62
30	8.9860	11.9613	11.8191	11.6134	4.78	15.71	79.51
31	8.2273	10.2615	10.1636	10.0193	4.81	16.12	79.07
32	8.4241	10.5812	10.4850	10.3273	4.46	16.62	78.92
33	8.6041	10.1763	10.1200	9.9925	3.58	18.43	77.99
34	8.3564	11.6520	11.5300	11.2566	3.70	18.85	77.44
35	8.2290	11.2921	11.1671	10.9361	4.08	17.14	78.78
36	7.8852	8.9264	8.8827	8.8114	4.20	15.56	80.24
37	8.3171	9.2947	9.2564	9.1975	3.92	13.69	82.39
38	8.2362	10.3052	10.2358	10.1180	3.35	12.94	83.71
39	8.2379	10.0251	9.9713	9.8669	3.01	13.28	83.71
40	8.5912	10.0548	10.0025	9.9086	3.57	14.58	81.85
41	8.3806	12.2080	12.0770	11.7505	3.42	19.39	77.19

Table E.1. LOI Results for Bedard Lake North (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
42	7.9574	10.0246	9.9444	9.6772	3.88	29.38	66.74
43	8.4475	10.6684	10.5843	10.2643	3.79	32.75	63.47
44	8.4121	10.9163	10.8306	10.4927	3.42	30.67	65.91
45	8.3641	9.1771	9.1480	9.0300	3.58	32.99	63.43
46	8.4667	9.7760	9.7254	9.5463	3.86	31.09	65.05
47	8.5260	10.0130	9.9502	9.7537	4.22	30.03	65.74
48	8.2434	10.3834	10.2968	10.0169	4.05	29.73	66.23
49	8.3909	9.9292	9.8672	9.6290	4.03	35.19	60.78
50	8.3747	10.1710	10.1040	9.8234	3.73	35.50	60.77
51	8.2906	9.2872	9.2475	9.1040	3.98	32.72	63.29
52	8.3145	10.1804	10.0937	9.7997	4.65	35.81	59.54
53	8.6657	10.6171	10.4728	10.1105	7.39	42.20	50.41

*% Other = 100-%organics-%carbonates = the index of terrigenous input

Table E.2. LOI Results for Bovy Bog

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
70	8.3639	8.7632	8.6872	8.6679	19.03	10.99	69.98
71	8.4662	8.8022	8.7173	8.7028	25.27	9.81	64.92
72	8.5255	8.9239	8.8266	8.8106	24.42	9.13	66.45
73	8.2415	8.6769	8.6291	8.6158	10.98	6.94	82.08
74	8.3893	8.7768	8.7550	8.7406	5.63	8.45	85.93
75	8.3736	8.6454	8.6304	8.6199	5.52	8.78	85.70
76	8.2900	9.1118	9.0660	9.0297	5.57	10.04	84.39
77	8.3141	8.7068	8.6826	8.6657	6.16	9.78	84.06
78	8.6650	9.5634	9.5125	9.4770	5.67	8.98	85.35
79	8.5018	8.9342	8.9079	8.8919	6.08	8.41	85.51
80	8.5042	9.3099	9.2555	9.2286	6.75	7.59	85.66
81	8.8668	9.5789	9.5243	9.4965	7.67	8.87	83.46
82	8.2234	8.6741	8.6455	8.6256	6.35	10.03	83.62
83	8.3816	8.9343	8.9005	8.8726	6.12	11.47	82.41
84	8.0094	8.9882	8.9290	8.8940	6.05	8.13	85.82
85	8.3667	9.0983	9.0585	9.0304	5.44	8.73	85.83
86	8.5169	9.1577	9.1238	9.1044	5.29	6.88	87.83
87	8.5467	9.6816	9.6201	9.5777	5.42	8.49	86.09
88	8.5089	9.2219	9.1777	9.1448	6.20	10.49	83.31
89	8.3580	9.0389	8.9783	8.9438	8.90	11.52	79.58
90	8.4631	9.0794	9.0186	8.9933	9.87	9.33	80.80
91	9.2700	9.8264	9.7859	9.7622	7.28	9.68	83.04
92	8.2065	8.8547	8.8055	8.7814	7.59	8.45	83.96
93	8.4799	9.6500	9.5296	9.4903	10.29	7.63	82.08
94	8.1786	8.8053	8.7466	8.7227	9.37	8.67	81.97
95	7.7499	8.6010	8.5030	8.4769	11.51	6.97	81.52
96	8.5156	9.0054	8.9606	8.9475	9.15	6.08	84.77
97	8.6891	9.3182	9.2523	9.2284	10.48	8.63	80.89
98	8.4744	9.3659	9.1978	9.1626	18.86	8.97	72.17
99	8.3048	8.8790	8.8000	8.7814	13.76	7.36	78.88
100	8.3857	9.2324	9.0663	9.0298	19.62	9.80	70.59
101	9.0069	9.6925	9.5968	9.5684	13.96	9.41	76.63
102	8.5696	9.0634	8.9616	8.9416	20.62	9.21	70.18
103	8.9849	9.8187	9.6667	9.6326	18.23	9.29	72.48
104	8.2276	8.6569	8.5917	8.5736	15.19	9.58	75.23
105	8.4239	8.7513	8.6946	8.6811	17.32	9.37	73.31
106	8.6038	8.9617	8.8918	8.8757	19.53	10.22	70.25
107	8.3565	8.7346	8.6528	8.6372	21.63	9.38	68.99
108	8.2287	8.6069	8.5064	8.4921	26.57	8.59	64.83
109	7.8848	8.4174	8.2704	8.2507	27.60	8.41	63.99
110	8.3162	8.7408	8.6256	8.6088	27.13	8.99	63.88
111	8.2362	8.5782	8.4860	8.4707	26.96	10.17	62.87

Table E.2. LOI Results for Bovy Bog (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
112	8.2375	8.7496	8.5984	8.5730	29.53	11.27	59.20
113	8.5913	8.9446	8.8113	8.7945	37.73	10.81	51.46
114	8.3805	8.6624	8.5704	8.5555	32.64	12.01	55.35
115	7.9570	8.2717	8.1663	8.1493	33.49	12.28	54.23
116	8.4474	8.7288	8.6273	8.6143	36.07	10.50	53.43
117	8.4116	8.7735	8.6274	8.6106	40.37	10.55	49.08
118	8.3642	8.7712	8.6072	8.5893	40.29	10.00	49.71
119	8.4667	8.9145	8.7376	8.7193	39.50	9.29	51.21
120	8.5263	8.9037	8.7953	8.7806	28.72	8.85	62.42

*% Other = 100-%organics-%carbonates = the index of terrigenous input

Table E.3. LOI Results for Rebecca Lake

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
58.3	8.1783	8.2149	8.1922	8.1906	61.97	9.95	33.65
58.8	8.1140	8.1648	8.1336	8.1322	61.42	6.26	35.83
59.2	8.3153	8.3917	8.3457	8.3445	60.18	3.57	38.24
59.7	8.5918	8.6736	8.6246	8.6215	59.94	8.48	36.33
60.1	8.3791	8.4534	8.4074	8.4050	61.87	7.34	34.90
60.6	7.8833	7.9445	7.9059	7.9044	63.04	5.76	34.42
61.0	8.3088	8.3788	8.3331	8.3317	65.24	4.70	32.69
61.5	8.9856	9.0631	9.0145	9.0128	62.71	4.99	35.10
61.9	8.4738	8.5579	8.5050	8.5031	62.88	5.14	34.86
62.4	8.8659	8.9479	8.8964	8.8944	62.74	5.54	34.82
62.8	8.4109	8.4723	8.4353	8.4345	60.34	2.96	38.36
63.3	8.3127	8.3803	8.3401	8.3384	59.47	5.72	38.02
63.7	8.4786	8.5463	8.5052	8.5036	60.68	5.38	36.95
64.2	8.3037	8.3922	8.3404	8.3384	58.59	5.01	39.21
64.6	8.2263	8.2865	8.2538	8.2519	54.40	6.98	42.52
65.1	8.4231	8.4924	8.4545	8.4530	54.72	4.92	43.11
65.5	8.5029	8.5841	8.5407	8.5384	53.45	6.58	43.66
65.9	8.6641	8.7258	8.6929	8.6908	53.32	7.92	43.19
66.4	8.3731	8.4361	8.4034	8.4013	51.95	7.58	44.72
66.8	8.3882	8.4722	8.4301	8.4272	50.15	7.84	46.40
67.3	8.2399	8.3185	8.2824	8.2807	45.93	5.06	51.84
67.7	8.5241	8.6211	8.5747	8.5722	47.81	5.86	49.61
68.2	8.4652	8.5419	8.5048	8.5024	48.40	6.96	48.53
68.6	8.3628	8.4348	8.4006	8.3979	47.46	8.69	48.71
69.1	8.5455	8.6261	8.5861	8.5850	49.60	3.24	48.98
69.5	7.7490	7.7743	7.7621	7.7615	48.32	5.40	49.31
70.0	8.5147	8.6010	8.5576	8.5565	50.32	2.76	48.47
70.4	8.5683	8.6492	8.6083	8.6077	50.62	1.55	48.70
70.9	8.3555	8.4179	8.3849	8.3844	52.80	1.82	46.39
71.3	8.5001	8.5998	8.5500	8.5481	49.92	4.44	48.12
71.8	8.4618	8.5343	8.4969	8.4955	51.62	4.23	46.51
72.2	8.5150	8.6022	8.5573	8.5567	51.49	1.69	47.76
72.7	8.3658	8.4637	8.4137	8.4131	51.02	1.51	48.31
73.1	9.2687	9.3601	9.3123	9.3107	52.33	3.86	45.98
73.6	8.6877	8.8223	8.7518	8.7499	52.36	3.21	46.23
74.0	8.3576	8.4206	8.3893	8.3885	49.64	3.07	49.01
74.4	8.4453	8.5159	8.4787	8.4771	52.73	5.15	45.00
74.9	8.6025	8.6533	8.6269	8.6261	51.92	3.58	46.51
75.3	8.5073	8.5858	8.5448	8.5436	52.23	3.33	46.31
75.8	8.2370	8.3237	8.2792	8.2765	51.30	7.07	45.59
76.2	8.2246	8.3124	8.2658	8.2647	53.02	2.85	45.73
76.7	8.2272	8.2922	8.2585	8.2570	51.92	5.24	45.77

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
77.1	8.2365	8.2966	8.2655	8.2643	51.75	4.54	46.26
77.6	8.3805	8.4471	8.4121	8.4112	52.52	3.24	46.06
78.0	8.0076	8.0567	8.0304	8.0298	53.61	2.77	45.17
78.5	8.2056	8.2643	8.2337	8.2328	52.04	3.48	46.42
78.9	8.3846	8.4367	8.4097	8.4090	51.82	3.27	46.74
79.4	9.0062	9.0537	9.0295	9.0287	51.05	3.83	47.26
79.8	8.1783	8.2308	8.2053	8.2033	48.57	8.87	47.52
80.3	8.1140	8.1634	8.1397	8.1367	48.03	13.79	45.90
80.7	8.3153	8.3748	8.3464	8.3432	47.69	12.23	46.93
81.2	8.5918	8.6700	8.6329	8.6293	47.41	10.47	47.98
81.6	8.3791	8.4427	8.4136	8.4098	45.68	13.76	48.27
82.1	7.8833	7.9384	7.9127	7.9102	46.73	10.11	48.82
82.5	8.3088	8.3855	8.3514	8.3477	44.46	10.96	50.72
82.9	8.9856	9.0647	9.0294	9.0258	44.69	10.34	50.76
83.4	8.4738	8.5418	8.5117	8.5087	44.30	9.87	51.36
83.8	8.8659	8.9531	8.9108	8.9069	48.54	10.03	47.05
84.3	8.4109	8.4908	8.4531	8.4492	47.18	11.24	47.87
84.7	8.3127	8.3991	8.3576	8.3530	48.03	12.10	46.64
85.2	8.4786	8.5580	8.5205	8.5166	47.23	11.31	47.80
85.6	8.3037	8.3886	8.3453	8.3418	51.00	9.37	44.88
86.1	8.2263	8.3109	8.2697	8.2662	48.67	9.54	47.13
86.5	8.4231	8.5337	8.4776	8.4731	50.75	9.24	45.19
87.0	8.5029	8.6175	8.5582	8.5525	51.72	11.31	43.30
87.4	8.6641	8.7692	8.7159	8.7112	50.69	10.28	44.79
87.9	8.3731	8.4790	8.4244	8.4200	51.54	9.45	44.31
88.3	8.3882	8.4830	8.4347	8.4308	50.92	9.46	44.91
88.8	8.2399	8.3429	8.2895	8.2859	51.82	7.95	44.68
89.2	8.5241	8.6157	8.5685	8.5653	51.53	7.94	44.98
89.7	8.4652	8.5124	8.4891	8.4876	49.26	7.46	47.46
90.1	8.3628	8.4176	8.3885	8.3863	53.10	9.33	42.79
101.3	8.1783	8.2809	8.2241	8.2212	55.39	6.32	41.83
101.7	8.1140	8.2288	8.1658	8.1625	54.90	6.43	42.27
102.2	8.3153	8.4038	8.3565	8.3544	53.42	5.40	44.21
102.6	8.5918	8.6897	8.6352	8.6329	55.72	5.34	41.93
110.4	8.3791	8.4362	8.4042	8.4030	55.99	4.77	41.91
110.8	7.8833	7.9560	7.9172	7.9147	53.44	7.82	43.12
111.2	8.3088	8.3896	8.3469	8.3452	52.78	4.78	45.11
111.7	8.9856	9.0515	9.0158	9.0141	54.25	5.86	43.17
112.1	8.4738	8.5573	8.5115	8.5096	54.82	5.17	42.90
112.5	8.8659	8.9200	8.8914	8.8902	52.87	4.83	45.01
112.9	8.4109	8.4854	8.4459	8.4444	53.06	4.43	45.00
113.3	8.3127	8.3617	8.3351	8.3338	54.29	6.03	43.06
113.7	8.4786	8.5333	8.5064	8.5049	49.18	6.44	47.99

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
114.1	8.3037	8.3605	8.3331	8.3315	48.19	6.41	48.99
114.6	8.2263	8.2784	8.2526	8.2511	49.57	6.33	47.65
115.0	8.4231	8.4981	8.4607	8.4585	49.87	6.52	47.27
115.4	8.5029	8.5818	8.5417	8.5397	50.79	5.76	46.67
115.8	8.6641	8.7142	8.6900	8.6879	48.30	9.53	47.50
116.2	8.3731	8.4165	8.3945	8.3932	50.75	6.82	46.25
116.6	8.3882	8.4339	8.4110	8.4101	50.05	4.47	47.98
117.0	8.2399	8.2768	8.2578	8.2573	51.42	3.08	47.22
117.4	8.5241	8.5564	8.5400	8.5395	50.85	3.17	47.75
117.9	8.4652	8.5224	8.4928	8.4917	51.75	4.17	46.42
118.3	8.3628	8.4208	8.3918	8.3897	49.96	8.24	46.42
118.7	8.5455	8.6070	8.5745	8.5734	52.81	4.25	45.32
119.1	7.7490	7.8133	7.7805	7.7785	51.09	7.07	45.80
119.5	8.5147	8.5770	8.5451	8.5432	51.12	7.11	45.75
119.9	8.5683	8.6382	8.6020	8.6002	51.83	5.86	45.60
120.3	8.3555	8.4385	8.3946	8.3926	52.92	5.47	44.67
120.8	8.5001	8.5642	8.5306	8.5294	52.34	4.43	45.71
121.2	8.4618	8.5284	8.4932	8.4920	52.82	4.27	45.30
121.6	8.5150	8.5787	8.5455	8.5446	52.12	3.21	46.47
122.0	8.3658	8.4326	8.3977	8.3963	52.28	4.59	45.70
122.4	9.2687	9.3491	9.3073	9.3056	52.05	4.81	45.83
122.8	8.6877	8.7482	8.7164	8.7156	52.48	3.19	46.12
123.2	8.3576	8.4294	8.3912	8.3897	53.17	4.91	44.67
123.7	8.4453	8.5402	8.4897	8.4878	53.24	4.55	44.75
124.1	8.6025	8.6932	8.6447	8.6430	53.50	4.13	44.68
124.5	8.5073	8.5870	8.5453	8.5436	52.29	4.99	45.52
124.9	8.2370	8.3091	8.2702	8.2685	53.95	5.20	43.76
125.3	8.2246	8.3417	8.2797	8.2767	52.95	5.82	44.49
125.7	8.2272	8.3212	8.2712	8.2689	53.22	5.44	44.39
126.1	8.2365	8.2834	8.2581	8.2571	53.99	4.60	43.98
126.6	8.3805	8.4375	8.4069	8.4059	53.68	3.99	44.56
127.0	8.0076	8.0566	8.0302	8.0290	53.92	5.33	43.73
127.4	8.2056	8.2595	8.2289	8.2285	56.81	1.69	42.45
127.8	8.3846	8.4454	8.4119	8.4107	55.14	4.49	42.88
128.2	9.0062	9.0583	9.0302	9.0290	53.89	5.24	43.80
128.6	8.1783	8.2571	8.2157	8.2131	52.60	7.35	44.16
129.0	8.1140	8.2219	8.1644	8.1606	53.24	8.11	43.19
129.4	8.3153	8.4223	8.3678	8.3639	50.98	8.18	45.42
129.9	8.5918	8.6780	8.6339	8.6306	51.19	8.71	44.98
130.3	8.3791	8.4674	8.4225	8.4199	50.79	6.69	46.26
130.7	7.8833	7.9682	7.9251	7.9226	50.77	6.83	46.23
131.1	8.3088	8.4183	8.3633	8.3597	50.25	7.47	46.46
131.5	8.9856	9.0818	9.0330	9.0291	50.78	9.10	45.22

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
131.9	8.4738	8.5724	8.5229	8.5199	50.23	6.80	46.78
132.3	8.8659	8.9574	8.9144	8.9115	46.97	7.32	49.81
132.8	8.4109	8.5042	8.4573	8.4542	50.29	7.56	46.38
133.2	8.3127	8.4001	8.3560	8.3536	50.51	6.11	46.80
133.6	8.4786	8.5633	8.5210	8.5185	49.97	6.71	47.08
134.0	8.3037	8.3865	8.3449	8.3427	50.30	6.04	47.04
134.4	8.2263	8.2765	8.2517	8.2507	49.50	4.53	48.51
134.8	8.4231	8.5013	8.4619	8.4596	50.42	6.68	46.65
135.2	8.5029	8.5809	8.5419	8.5396	50.03	6.56	47.08
135.7	8.6641	8.7588	8.7101	8.7071	51.40	7.32	45.38
136.1	8.3731	8.4542	8.4111	8.4082	53.21	7.99	43.28
136.5	8.3882	8.4669	8.4238	8.4212	54.76	7.36	41.99
136.9	8.2399	8.3147	8.2744	8.2725	53.91	5.78	43.55
137.3	8.5241	8.5896	8.5537	8.5518	54.81	6.59	42.29
137.7	8.4652	8.5311	8.4948	8.4929	55.04	6.72	42.00
138.1	8.3628	8.4244	8.3915	8.3895	53.37	7.57	43.30
138.6	8.5455	8.6197	8.5781	8.5749	56.13	9.65	39.62
139.0	7.7490	7.8347	7.7845	7.7826	58.58	5.17	39.15
139.4	8.5147	8.5908	8.5469	8.5452	57.65	5.07	40.12
139.8	8.5683	8.6435	8.5995	8.5977	58.48	5.44	39.12
140.2	8.3555	8.4383	8.3887	8.3868	59.84	5.35	37.80
140.6	8.5001	8.5939	8.5382	8.5362	59.40	4.84	38.47
141.0	8.4618	8.5424	8.4935	8.4923	60.67	3.52	37.78
141.4	8.5150	8.6275	8.5593	8.5573	60.60	4.04	37.62
141.9	8.3658	8.4553	8.4002	8.3986	61.59	3.93	36.68
142.3	9.2687	9.3240	9.2908	9.2895	60.04	5.34	37.61
142.7	8.6877	8.7561	8.7151	8.7139	59.94	3.82	38.38
143.1	8.3576	8.4327	8.3889	8.3878	58.36	3.18	40.24
143.5	8.4453	8.5297	8.4787	8.4776	60.40	2.96	38.29
143.9	8.6025	8.6645	8.6268	8.6265	60.81	1.10	38.71
144.3	8.5073	8.5643	8.5289	8.5284	62.05	1.99	37.07
144.8	8.2370	8.2877	8.2561	8.2551	62.27	4.70	35.67
145.2	8.2246	8.3036	8.2536	8.2528	63.25	2.30	35.74
145.6	8.2272	8.3089	8.2590	8.2573	61.05	4.73	36.86
146.0	8.2365	8.2914	8.2578	8.2570	61.24	3.31	37.31
146.4	8.3805	8.4269	8.3977	8.3972	63.00	2.45	35.92
146.8	8.0076	8.0506	8.0239	8.0236	61.98	1.85	37.21
147.2	8.2056	8.2624	8.2276	8.2267	61.27	3.40	37.24
147.7	8.3846	8.4151	8.3965	8.3960	61.15	3.73	37.21
148.1	9.0062	9.0602	9.0277	9.0270	60.28	2.74	38.52
148.5	8.1783	8.2729	8.2165	8.2139	59.65	6.25	37.60
148.9	8.1140	8.1940	8.1443	8.1427	62.15	4.54	35.85
149.3	8.3153	8.4346	8.3619	8.3594	60.92	4.86	36.94

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
149.7	8.5918	8.6824	8.6269	8.6253	61.29	4.02	36.94
150.1	8.3791	8.5053	8.4269	8.4245	62.12	4.32	35.97
150.6	7.8833	7.9679	7.9139	7.9127	63.83	3.36	34.69
151.0	8.3088	8.3917	8.3407	8.3391	61.46	4.39	36.61
151.4	8.9856	9.0533	9.0133	9.0119	59.05	4.70	38.88
151.8	8.4738	8.5529	8.5049	8.5035	60.72	4.03	37.51
152.2	8.8659	8.9369	8.8954	8.8943	58.41	3.68	39.97
152.6	8.4109	8.5118	8.4539	8.4524	57.43	3.38	41.08
153.0	8.3127	8.3894	8.3459	8.3448	56.78	3.11	41.85
153.4	8.4786	8.5683	8.5175	8.5153	56.61	5.58	40.94
153.9	8.3037	8.3866	8.3403	8.3384	55.88	5.07	41.88
154.3	8.2263	8.3124	8.2662	8.2642	53.72	5.28	43.96
154.7	8.4231	8.5110	8.4637	8.4613	53.84	6.20	43.43
155.1	8.5029	8.5870	8.5389	8.5371	57.19	5.00	40.61
155.5	8.6641	8.7784	8.7169	8.7137	53.85	6.36	43.35
155.9	8.3731	8.4577	8.4114	8.4092	54.70	6.05	42.64
156.3	8.3882	8.4577	8.4169	8.4158	58.71	3.60	39.71
156.8	8.2399	8.3081	8.2704	8.2691	55.35	4.17	42.82
157.2	8.5241	8.6079	8.5619	8.5601	54.93	4.75	42.99
157.6	8.4652	8.5474	8.5050	8.5028	51.61	5.94	45.78
158.0	8.3628	8.4548	8.4075	8.4057	51.39	4.57	46.60
158.4	8.5455	8.6450	8.5930	8.5900	52.31	6.85	44.67
158.8	7.7490	7.8364	7.7918	7.7897	51.00	5.46	46.59
159.2	8.5147	8.5999	8.5548	8.5527	52.93	5.60	44.60
159.7	8.5683	8.6352	8.5995	8.5978	53.40	5.78	44.05
160.1	8.3555	8.4326	8.3911	8.3887	53.76	7.07	43.13
160.5	8.5001	8.5722	8.5339	8.5322	53.08	5.51	44.49
160.9	8.4618	8.5254	8.4915	8.4900	53.30	5.36	44.34
161.3	8.5150	8.5843	8.5462	8.5448	54.95	4.59	43.03
161.7	8.3658	8.4477	8.4044	8.4025	52.87	5.13	44.87
162.1	9.2687	9.3576	9.3094	9.3072	54.19	5.76	43.28
162.6	8.6877	8.7658	8.7245	8.7225	52.91	5.82	44.53
163.0	8.3576	8.4172	8.3870	8.3852	50.63	7.06	46.26
163.4	8.4453	8.5039	8.4739	8.4723	51.19	6.21	46.08
163.8	8.6025	8.6725	8.6363	8.6347	51.68	5.35	45.97
164.2	8.5073	8.5689	8.5381	8.5361	50.04	7.19	46.80
164.6	8.2370	8.3280	8.2810	8.2787	51.59	5.87	45.82
165.0	8.2246	8.3039	8.2628	8.2605	51.86	6.59	45.24
165.4	8.2272	8.2976	8.2622	8.2602	50.25	6.46	46.91
165.9	8.2365	8.2987	8.2668	8.2650	51.24	6.75	45.78
166.3	8.3805	8.4530	8.4162	8.4145	50.79	5.33	46.86
166.7	8.0076	8.0877	8.0471	8.0448	50.62	6.67	46.44
167.1	8.2056	8.2691	8.2364	8.2353	51.46	3.93	46.81

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
167.5	8.3846	8.4800	8.4307	8.4279	51.65	6.79	45.36
167.9	9.0062	9.1525	9.0777	9.0731	51.15	7.15	45.71
168.3	8.1783	8.2628	8.2209	8.2168	49.56	11.17	45.53
168.8	8.1140	8.2208	8.1672	8.1622	50.16	10.74	45.11
169.2	8.3153	8.4340	8.3754	8.3701	49.35	10.25	46.14
169.6	8.5918	8.7085	8.6497	8.6441	50.41	10.91	44.79
170.0	8.3791	8.4360	8.4072	8.4043	50.57	11.57	44.34
170.4	7.8833	7.9947	7.9396	7.9346	49.44	10.31	46.03
170.8	8.3088	8.3927	8.3510	8.3467	49.64	11.78	45.17
171.2	8.9856	9.1102	9.0487	9.0426	49.36	11.22	45.71
171.7	8.4738	8.5716	8.5227	8.5179	50.05	11.04	45.09
172.1	8.8659	8.9735	8.9202	8.9150	49.49	10.98	45.68
172.5	8.4109	8.5162	8.4637	8.4588	49.88	10.58	45.46
172.9	8.3127	8.4236	8.3691	8.3639	49.17	10.66	46.14
173.3	8.4786	8.5834	8.5315	8.5265	49.57	10.84	45.66
173.7	8.3037	8.4140	8.3591	8.3540	49.77	10.51	45.60
174.1	8.2263	8.3188	8.2737	8.2693	48.81	10.81	46.43
174.6	8.4231	8.5454	8.4859	8.4798	48.67	11.24	46.38
175.0	8.5029	8.5905	8.5479	8.5435	48.69	11.42	46.29
175.4	8.6641	8.7847	8.7253	8.7192	49.30	11.50	45.65
175.8	8.3731	8.4747	8.4239	8.4190	50.00	10.96	45.18
176.2	8.3882	8.4798	8.4348	8.4301	49.07	11.79	45.74
176.6	8.2399	8.3461	8.2941	8.2892	49.01	10.49	46.37
177.0	8.5241	8.6279	8.5767	8.5716	49.37	11.06	45.76
177.4	8.4652	8.5917	8.5292	8.5231	49.39	11.04	45.75
177.9	8.3628	8.4639	8.4141	8.4089	49.23	11.81	45.57
178.3	8.5455	8.6318	8.5885	8.5843	50.14	11.07	44.99
178.7	7.7490	7.8452	7.7974	7.7925	49.69	11.58	45.22
179.1	8.5147	8.6011	8.5582	8.5538	49.62	11.57	45.29
179.5	8.5683	8.6627	8.6152	8.6106	50.34	10.96	44.83
179.9	8.3555	8.4520	8.4023	8.3979	51.53	10.36	43.92
180.3	8.5001	8.5974	8.5457	8.5413	53.11	10.39	42.32
180.8	8.4618	8.5334	8.4962	8.4934	51.92	9.05	44.10
181.2	8.5150	8.5892	8.5515	8.5478	50.84	11.19	44.23
181.6	8.3658	8.4331	8.3989	8.3960	50.85	9.79	44.84
182.0	9.2687	9.3641	9.3156	9.3112	50.89	10.36	44.55
182.4	8.6877	8.7639	8.7244	8.7211	51.77	9.99	43.83
182.8	8.3576	8.4451	8.3995	8.3958	52.11	9.61	43.66
183.2	8.4453	8.5245	8.4826	8.4790	52.94	10.34	42.51
183.7	8.6025	8.6746	8.6365	8.6333	52.81	10.24	42.69
184.1	8.5073	8.5800	8.5415	8.5382	52.89	10.32	42.57
184.5	8.2370	8.3091	8.2694	8.2661	55.06	10.40	40.36
184.9	8.2246	8.2839	8.2518	8.2489	54.17	11.11	40.94

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
185.3	8.2272	8.2812	8.2517	8.2491	54.59	10.95	40.59
185.7	8.2365	8.3093	8.2688	8.2653	55.63	10.77	39.63
186.1	8.3805	8.4825	8.4289	8.4237	52.55	11.70	42.30
186.6	8.0076	8.0832	8.0447	8.0409	50.86	11.57	44.05
187.0	8.2056	8.3195	8.2618	8.2560	50.61	11.67	44.25
187.4	8.3846	8.4744	8.4274	8.4229	52.39	11.39	42.59
187.8	9.0062	9.1111	9.0592	9.0535	49.50	12.25	45.11
188.2	8.1783	8.2845	8.2306	8.2273	50.78	7.07	46.11
188.6	8.1140	8.2310	8.1724	8.1693	50.11	6.02	47.24
189.0	8.3153	8.4663	8.3910	8.3868	49.90	6.25	47.35
189.4	8.5918	8.7132	8.6520	8.6484	50.39	6.84	46.60
189.9	8.3791	8.5551	8.4667	8.4621	50.21	6.00	47.15
190.3	7.8833	8.0083	7.9457	7.9426	50.06	5.73	47.42
190.7	8.3088	8.4294	8.3685	8.3653	50.48	6.03	46.87
191.1	8.9856	9.1249	9.0545	9.0511	50.52	5.55	47.04
191.5	8.4738	8.5778	8.5242	8.5220	51.52	4.81	46.37
191.9	8.8659	8.9744	8.9175	8.9153	52.44	4.61	45.53
192.3	8.4109	8.5196	8.4620	8.4602	53.01	3.66	45.38
192.8	8.3127	8.4409	8.3728	8.3701	53.10	4.88	44.75
193.2	8.4786	8.5807	8.5282	8.5259	51.47	5.01	46.33
193.6	8.3037	8.4595	8.3757	8.3722	53.77	5.11	43.98
194.0	8.2263	8.3191	8.2696	8.2677	53.39	4.65	44.56
194.4	8.4231	8.5073	8.4619	8.4599	53.95	5.40	43.68
194.8	8.5029	8.6013	8.5486	8.5461	53.53	5.89	43.87
195.2	8.6641	8.7782	8.7175	8.7146	53.20	5.88	44.22
195.7	8.3731	8.4593	8.4128	8.4109	53.98	4.88	43.88
196.1	8.3882	8.4688	8.4248	8.4233	54.56	4.37	43.52
196.5	8.2399	8.3480	8.2899	8.2874	53.79	5.15	43.94
196.9	8.5241	8.6040	8.5606	8.5591	54.38	4.12	43.80
197.3	8.4652	8.5567	8.5072	8.5053	54.04	4.72	43.88
197.7	8.3628	8.4455	8.4015	8.3993	53.26	6.05	44.07
198.1	8.5455	8.6380	8.5900	8.5861	51.89	9.71	43.84
198.6	7.7490	7.8513	7.7981	7.7948	51.98	7.45	44.74
199.0	8.5147	8.6330	8.5708	8.5672	52.56	7.01	44.36
199.4	8.5683	8.7001	8.6309	8.6267	52.50	7.24	44.31
199.8	8.3555	8.5424	8.4432	8.4372	53.08	7.24	43.74
200.0	8.5001	8.7175	8.6017	8.5946	53.28	7.37	43.48
190.4	8.4618	8.6539	8.5562	8.5499	50.86	7.51	45.84
190.7	8.5150	8.6223	8.5663	8.5628	52.17	7.42	44.57
191.1	8.3658	8.5028	8.4327	8.4281	51.15	7.63	45.49
191.5	9.2687	9.3855	9.3223	9.3185	54.13	7.40	42.61
191.9	8.6877	8.8001	8.7426	8.7386	51.11	8.09	45.33
192.2	8.3576	8.4705	8.4096	8.4054	53.97	8.46	42.31

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
192.6	8.4453	8.5680	8.5015	8.4973	54.20	7.87	42.34
193.0	8.6025	8.7008	8.6471	8.6440	54.58	7.17	42.27
193.3	8.5073	8.6663	8.5813	8.5762	53.44	7.36	43.32
193.7	8.2370	8.3724	8.2950	8.2908	57.18	6.96	39.76
194.1	8.2246	8.3447	8.2789	8.2749	54.81	7.47	41.91
194.5	8.2272	8.4259	8.3207	8.3139	52.96	7.78	43.62
194.8	8.2365	8.3840	8.3043	8.2993	54.03	7.70	42.58
195.2	8.3805	8.5321	8.4497	8.4450	54.35	7.12	42.51
195.6	8.0076	8.1967	8.0934	8.0876	54.64	6.91	42.32
195.9	8.2056	8.4072	8.2963	8.2904	54.99	6.65	42.09
196.3	8.3846	8.5440	8.4546	8.4498	56.07	6.85	40.92
196.7	9.0062	9.1830	9.0849	9.0793	55.50	7.14	41.36
197.1	8.1783	8.3256	8.2432	8.2377	55.96	8.41	40.34
197.4	8.1140	8.2632	8.1736	8.1691	60.07	6.85	36.92
197.8	8.3153	8.4678	8.3825	8.3781	55.93	6.63	41.15
198.2	8.5918	8.7895	8.6767	8.6696	57.07	8.16	39.34
198.5	8.3791	8.5271	8.4424	8.4371	57.20	8.22	39.19
198.9	7.8833	8.0577	7.9565	7.9496	58.06	8.99	37.99
199.3	8.3088	8.4499	8.3662	8.3609	59.32	8.46	36.96
199.6	8.9856	9.1241	9.0384	9.0337	61.86	7.72	34.74
200.0	8.4738	8.6354	8.5375	8.5320	60.61	7.66	36.01
200.4	8.8659	9.0110	8.9215	8.9167	61.69	7.44	35.03
200.8	8.4109	8.6109	8.4874	8.4802	61.78	8.12	34.65
201.1	8.3127	8.4666	8.3718	8.3659	61.62	8.64	34.58
201.5	8.4786	8.6169	8.5316	8.5276	61.68	6.57	35.43
201.9	8.3037	8.4442	8.3688	8.3557	53.70	21.19	36.98
202.2	8.2263	8.3853	8.2985	8.2852	54.58	19.02	37.06
202.6	8.4231	8.5607	8.4771	8.4747	60.72	3.96	37.54
203.0	8.5029	8.6566	8.5631	8.5591	60.87	5.84	36.56
203.4	8.6641	8.8276	8.7254	8.7205	60.77	7.20	36.06
203.7	8.3731	8.5152	8.4278	8.4237	61.54	6.56	35.57
204.1	8.3882	8.5083	8.4344	8.4319	61.51	4.73	36.41
204.5	8.2399	8.3717	8.2911	8.2884	61.18	4.66	36.77
204.8	8.5241	8.6610	8.5770	8.5732	61.38	6.31	35.84
205.2	8.4652	8.6044	8.5186	8.5148	61.64	6.20	35.63
205.6	8.3628	8.5448	8.4327	8.4263	61.61	7.99	34.87
206.0	8.5455	8.6371	8.5804	8.5781	61.95	5.71	35.53
206.3	7.7490	7.8424	7.7850	7.7825	61.46	6.20	35.81
206.7	8.5147	8.5960	8.5458	8.5438	61.69	5.73	35.79
207.1	8.5683	8.6682	8.6061	8.6035	62.14	6.03	35.20
207.4	8.3555	8.4785	8.4017	8.3986	62.44	5.64	35.08
207.8	8.5001	8.5947	8.5374	8.5348	60.59	6.24	36.66
208.2	8.4618	8.6041	8.5160	8.5123	61.91	5.91	35.49

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
208.6	8.5150	8.6163	8.5542	8.5519	61.30	5.16	36.43
208.9	8.3658	8.4536	8.3993	8.3975	61.85	4.66	36.10
209.3	9.2687	9.4079	9.3244	9.3212	59.97	5.31	37.69
209.7	8.6877	8.8351	8.7475	8.7443	59.44	4.93	38.39
210.0	8.3576	8.5285	8.4300	8.4257	57.65	5.65	39.86
210.4	8.4453	8.6045	8.5124	8.5081	57.88	6.14	39.42
210.8	8.6025	8.7255	8.6522	8.6498	59.55	4.53	38.46
211.2	8.5073	8.6359	8.5619	8.5586	57.54	5.83	39.89
211.5	8.2370	8.3871	8.2981	8.2945	59.26	5.53	38.31
211.9	8.2246	8.3764	8.2886	8.2853	57.81	5.02	39.99
212.3	8.2272	8.3213	8.2648	8.2626	60.02	5.44	37.59
212.6	8.2365	8.3599	8.2859	8.2828	59.94	5.71	37.55
213.0	8.3805	8.4574	8.4134	8.4112	57.28	6.50	39.86
213.4	8.0076	8.1115	8.0476	8.0453	61.52	5.03	36.27
213.8	8.2056	8.3048	8.2435	8.2410	61.79	5.61	35.74
214.1	8.3846	8.4668	8.4158	8.4138	62.04	5.53	35.52
214.5	9.0062	9.1305	9.0556	9.0527	60.26	5.30	37.41
214.9	8.1783	8.2822	8.2172	8.2150	62.54	4.81	35.34
215.2	8.1140	8.2544	8.1645	8.1618	64.00	4.37	34.08
215.6	8.3153	8.4747	8.3739	8.3705	63.26	4.78	34.64
216.0	8.5918	8.7157	8.6375	8.6350	63.16	4.49	34.87
216.4	8.3791	8.4984	8.4294	8.4263	57.84	5.91	39.56
216.7	7.8833	8.0199	7.9383	7.9347	59.74	5.99	37.63
217.1	8.3088	8.3355	8.3196	8.3191	59.63	3.82	38.69
217.5	8.9856	9.1211	9.0390	9.0359	60.61	5.20	37.10
217.8	8.4738	8.6071	8.5267	8.5237	60.32	5.11	37.43
218.2	8.8659	8.9977	8.9202	8.9170	58.82	5.43	38.79
218.6	8.4109	8.4978	8.4465	8.4444	59.09	5.49	38.49
218.9	8.3127	8.4243	8.3598	8.3563	57.78	7.23	39.04
219.3	8.4786	8.5681	8.5160	8.5138	58.27	5.59	39.27
219.7	8.3037	8.4274	8.3565	8.3534	57.30	5.70	40.19
220.1	8.2263	8.2852	8.2519	8.2511	56.54	3.28	42.02
220.4	8.4231	8.5233	8.4669	8.4648	56.26	4.76	41.65
220.8	8.5029	8.6279	8.5559	8.5528	57.64	5.55	39.92
221.2	8.6641	8.7894	8.7181	8.7148	56.93	5.99	40.44
221.5	8.3731	8.4651	8.4128	8.4103	56.82	6.30	40.40
221.9	8.3882	8.5563	8.4588	8.4549	58.00	5.27	39.68
222.3	8.2399	8.3488	8.2860	8.2836	57.65	5.01	40.15
222.7	8.5241	8.6644	8.5830	8.5794	58.05	5.75	39.42
223.0	8.4652	8.6079	8.5235	8.5201	59.12	5.49	38.46
223.4	8.3628	8.5043	8.4220	8.4180	58.16	6.42	39.01
223.8	8.5455	8.7090	8.6148	8.6109	57.65	5.42	39.97
224.1	7.7490	7.8446	7.7891	7.7871	58.11	4.75	39.80

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
224.5	8.5147	8.5955	8.5485	8.5469	58.11	4.64	39.85
224.9	8.5683	8.6972	8.6219	8.6190	58.42	5.11	39.33
225.3	8.3555	8.5046	8.4172	8.4136	58.60	5.49	38.99
225.6	8.5001	8.6326	8.5546	8.5515	58.85	5.32	38.82
226.0	8.4618	8.6085	8.5215	8.5187	59.34	4.34	38.75
226.4	8.5150	8.7000	8.5906	8.5869	59.15	4.49	38.88
226.7	8.3658	8.5412	8.4380	8.4346	58.82	4.47	39.21
227.1	9.2687	9.4416	9.3381	9.3351	59.88	3.88	38.41
227.5	8.6877	8.8234	8.7414	8.7391	60.41	3.93	37.86
227.9	8.3576	8.4828	8.4072	8.4045	60.38	4.90	37.46
228.2	8.4453	8.5442	8.4837	8.4820	61.17	3.91	37.11
228.6	8.6025	8.6955	8.6380	8.6366	61.77	3.42	36.72
229.0	8.5073	8.6329	8.5550	8.5529	61.98	3.80	36.35
229.3	8.2370	8.3267	8.2695	8.2682	63.71	3.42	34.78
229.7	8.2246	8.3135	8.2558	8.2544	64.92	3.58	33.50
230.1	8.2272	8.3481	8.2699	8.2681	64.68	3.48	33.79
230.5	8.2365	8.3936	8.2912	8.2891	65.15	3.04	33.51
230.8	8.3805	8.4849	8.4174	8.4159	64.70	3.16	33.91
231.2	8.0076	8.1545	8.0589	8.0567	65.06	3.40	33.45
231.6	8.2056	8.3326	8.2497	8.2479	65.25	3.31	33.29
231.9	8.3846	8.5103	8.4285	8.4268	65.08	3.16	33.53
232.3	9.0062	9.1422	9.0540	9.0518	64.89	3.68	33.49
232.7	8.1783	8.2381	8.2001	8.1981	63.60	7.61	33.05
233.1	8.1140	8.1892	8.1404	8.1385	64.85	5.89	32.56
233.4	8.3153	8.4071	8.3487	8.3461	63.65	6.32	33.57
233.8	8.5918	8.6897	8.6266	8.6241	64.50	5.69	32.99
234.2	8.3791	8.4975	8.4233	8.4193	62.64	7.77	33.94
234.5	7.8833	7.9961	7.9246	7.9217	63.37	5.85	34.06
234.9	8.3088	8.3845	8.3364	8.3344	63.47	6.15	33.82
235.3	8.9856	9.0569	9.0119	9.0101	63.18	5.58	34.36
235.6	8.4738	8.5850	8.5139	8.5113	63.98	5.21	33.72
236.0	8.8659	9.0306	8.9249	8.9210	64.16	5.38	33.47
236.4	8.4109	8.4944	8.4413	8.4392	63.63	5.58	33.91
236.8	8.5455	8.6464	8.5841	8.5807	61.79	7.55	34.89
237.1	7.7490	7.8731	7.7937	7.7899	63.97	7.05	32.93
237.5	8.5147	8.6354	8.5570	8.5537	64.93	6.21	32.34
237.9	8.5683	8.6533	8.6002	8.5973	62.45	7.76	34.14
238.2	8.3555	8.4804	8.3997	8.3958	64.61	7.01	32.31
238.6	8.5001	8.5910	8.5351	8.5320	61.50	7.75	35.09
239.0	8.4618	8.5556	8.4942	8.4917	65.49	6.06	31.84
239.4	8.5150	8.6281	8.5549	8.5523	64.72	5.33	32.94
239.7	8.3658	8.4767	8.4066	8.4039	63.23	5.43	34.38
240.1	9.2687	9.3256	9.2906	9.2889	61.60	6.79	35.41

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
240.5	8.6877	8.8184	8.7366	8.7330	62.55	6.26	34.70
240.8	8.3576	8.4805	8.4053	8.4017	61.23	6.66	35.84
241.2	8.4453	8.5683	8.4912	8.4877	62.72	6.47	34.43
241.6	8.6025	8.7077	8.6387	8.6359	65.54	6.05	31.80
242.0	8.5073	8.6096	8.5433	8.5407	64.81	5.78	32.65
242.3	8.2370	8.3316	8.2708	8.2681	64.22	6.61	32.88
242.7	8.2246	8.3042	8.2523	8.2504	65.16	5.56	32.39
243.1	8.2272	8.2953	8.2521	8.2504	63.44	5.84	33.99
243.4	8.2365	8.3137	8.2632	8.2615	65.35	5.15	32.38
243.8	8.3805	8.4918	8.4186	8.4159	65.75	5.62	31.78
244.2	8.0076	8.1157	8.0444	8.0413	65.91	6.52	31.22
244.6	8.2056	8.3186	8.2404	8.2380	69.22	4.82	28.66
244.9	8.3846	8.5068	8.4234	8.4204	68.24	5.58	29.31
245.3	9.0062	9.1254	9.0446	9.0420	67.77	4.96	30.05
245.7	8.1783	8.2355	8.1966	8.1954	67.98	4.97	29.83
246.0	8.1140	8.2740	8.1725	8.1680	63.45	6.32	33.77
246.4	8.3153	8.3738	8.3350	8.3340	66.41	3.69	31.97
246.8	8.5918	8.6677	8.6171	8.6151	66.64	6.14	30.65
247.2	8.3791	8.4775	8.4148	8.4120	63.67	6.58	33.43
247.5	7.8833	7.9782	7.9160	7.9135	65.54	5.99	31.82
247.9	8.3088	8.4153	8.3457	8.3429	65.35	5.98	32.02
248.3	8.9856	9.0677	9.0161	9.0136	62.89	6.92	34.06
248.6	8.4738	8.5798	8.5134	8.5104	62.69	6.43	34.48
249.0	8.8659	8.9809	8.9092	8.9061	62.32	6.12	34.98
249.4	8.4109	8.4929	8.4410	8.4391	63.27	5.27	34.41
249.8	8.3127	8.4102	8.3489	8.3459	62.90	6.88	34.07
250.1	8.4786	8.5523	8.5063	8.5043	62.46	6.02	34.89
250.5	8.3037	8.3813	8.3335	8.3315	61.66	5.71	35.82
250.9	8.2263	8.3287	8.2676	8.2647	59.65	6.55	37.47
251.2	8.4231	8.5093	8.4560	8.4541	61.77	5.14	35.96
251.6	8.5029	8.5354	8.5162	8.5157	59.08	3.85	39.23
252.0	8.6641	8.7933	8.7179	8.7135	58.40	7.74	38.20
252.4	8.3731	8.4767	8.4165	8.4131	58.09	7.57	38.58
252.7	8.3882	8.4830	8.4278	8.4252	58.25	6.23	39.01
253.1	8.2399	8.3223	8.2739	8.2718	58.71	5.80	38.74
253.5	8.5241	8.6011	8.5563	8.5542	58.40	6.31	38.82
253.8	8.4652	8.5350	8.4943	8.4923	58.27	6.51	38.87
254.2	8.3628	8.4543	8.4013	8.3984	57.96	7.08	38.93
254.6	8.5455	8.6847	8.6042	8.6009	57.83	5.39	39.80
254.9	7.7490	7.9231	7.8177	7.8140	60.54	4.90	37.31
255.3	8.5147	8.6334	8.5595	8.5573	62.26	4.21	35.89
255.7	8.5683	8.7351	8.6279	8.6246	64.30	4.50	33.72

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
256.1	8.3555	8.4548	8.3918	8.3898	63.41	4.69	34.52
256.4	8.5001	8.6038	8.5355	8.5336	65.81	4.27	32.30
256.8	8.4618	8.5772	8.4993	8.4976	67.53	3.35	30.99
257.2	8.5150	8.6211	8.5507	8.5490	66.40	3.53	32.05
257.5	8.3658	8.4952	8.4075	8.4056	67.75	3.34	30.78
257.9	9.2687	9.4009	9.3086	9.3064	69.86	3.70	28.52
258.3	8.6877	8.7955	8.7216	8.7200	68.57	3.37	29.95
258.7	8.3576	8.4568	8.3891	8.3872	68.30	4.35	29.79
259.0	8.4453	8.5243	8.4707	8.4692	67.89	4.32	30.21
259.4	8.6025	8.6977	8.6320	8.6304	69.03	3.70	29.34
259.8	8.5073	8.6124	8.5396	8.5378	69.27	3.78	29.07
260.1	8.2370	8.3371	8.2648	8.2630	72.24	3.97	26.01
260.5	8.2246	8.3240	8.2534	8.2517	71.04	3.89	27.25
260.9	8.2272	8.3174	8.2538	8.2524	70.49	3.66	27.90
261.3	8.2365	8.3320	8.2663	8.2646	68.76	4.16	29.41
261.6	8.3805	8.4760	8.4115	8.4099	67.59	3.69	30.79
262.0	8.0076	8.0866	8.0353	8.0338	64.87	4.46	33.16
262.4	8.2056	8.3115	8.2392	8.2374	68.24	3.86	30.06
262.7	8.3846	8.4848	8.4178	8.4158	66.87	4.65	31.09
263.1	9.0062	9.1112	9.0426	9.0406	65.36	4.33	32.73
263.5	8.1783	8.2795	8.2186	8.2152	60.21	7.64	36.43
263.9	8.1140	8.1765	8.1392	8.1372	59.63	7.45	37.09
264.2	8.3153	8.3530	8.3321	8.3309	55.38	7.55	41.30
264.6	8.5918	8.6595	8.6201	8.6178	58.17	7.89	38.36
265.0	8.3791	8.4424	8.4071	8.4048	55.69	8.44	40.60
265.3	7.8833	7.9632	7.9196	7.9161	54.63	9.81	41.05
265.7	8.3088	8.3442	8.3238	8.3225	57.49	8.35	38.84
266.1	8.9856	9.0468	9.0115	9.0094	57.76	7.61	38.89
266.5	8.4738	8.5460	8.5038	8.5013	58.42	7.88	38.12
266.8	8.8659	8.9142	8.8855	8.8837	59.46	8.23	36.92
267.2	8.4109	8.4682	8.4336	8.4314	60.35	8.73	35.81
267.6	8.3154	8.3726	8.3376	8.3351	61.24	9.74	34.47
267.9	8.4786	8.5563	8.5095	8.5069	60.30	7.61	36.36
268.3	8.3037	8.3672	8.3306	8.3289	57.72	5.91	39.69
268.7	8.2263	8.3087	8.2627	8.2602	55.89	6.76	41.14
269.1	8.4231	8.5005	8.4549	8.4530	58.94	5.58	38.61
269.4	8.5029	8.5709	8.5326	8.5308	56.40	5.85	41.03
269.8	8.6641	8.7283	8.6917	8.6895	57.05	7.79	39.52
270.2	8.3731	8.4390	8.4019	8.3995	56.37	8.28	39.98
270.5	8.3882	8.4786	8.4287	8.4261	55.14	6.66	41.92
270.9	8.2399	8.3520	8.2909	8.2875	54.48	7.00	42.44
271.3	8.5241	8.6656	8.5878	8.5829	55.02	7.87	41.52
271.6	8.4652	8.5785	8.5152	8.5110	55.87	8.32	40.47

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
272.0	8.3628	8.5007	8.4246	8.4187	55.17	9.81	40.52
272.4	8.5455	8.6284	8.5821	8.5778	55.88	11.66	38.99
272.8	7.7490	7.8213	7.7801	7.7770	56.96	9.91	38.69
273.1	8.5147	8.6037	8.5520	8.5483	58.09	9.32	37.81
273.5	8.5683	8.6450	8.6011	8.5975	57.30	10.52	38.07
273.9	8.3555	8.4190	8.3820	8.3791	58.30	10.19	37.21
274.2	8.5001	8.5646	8.5187	8.5093	57.47	2.12	14.33
274.6	8.4618	8.5237	8.4868	8.4843	59.58	9.19	36.38
275.0	8.5150	8.6060	8.5510	8.5478	60.44	8.12	35.99
275.4	8.3658	8.4366	8.3926	8.3903	62.08	7.38	34.68
275.7	9.2687	9.3497	9.2987	9.2963	62.96	6.73	34.07
276.1	8.6877	8.7388	8.7066	8.7051	62.92	6.89	34.05
276.5	8.3576	8.4117	8.3787	8.3767	60.96	8.41	35.34
276.8	8.4453	8.5556	8.4944	8.4904	55.46	8.35	40.86
277.2	8.6025	8.6659	8.6296	8.6274	57.21	8.06	39.24
277.6	8.5073	8.5731	8.5366	8.5344	55.43	7.77	41.15
278.0	8.2370	8.3428	8.2837	8.2800	55.81	7.95	40.69
278.3	8.2246	8.3217	8.2695	8.2659	53.78	8.42	42.51
278.7	8.2272	8.4192	8.3239	8.3162	49.65	9.12	46.34
279.1	8.2365	8.4831	8.3645	8.3542	48.10	9.44	47.74
279.4	8.3805	8.5817	8.4856	8.4772	47.71	9.50	48.11
279.8	8.0076	8.1717	8.0954	8.0884	46.50	9.69	49.24
280.0	8.2056	8.4278	8.3251	8.3157	46.23	9.56	49.56
270.4	8.1783	8.2350	8.2054	8.2031	52.20	9.22	43.74
270.8	8.1140	8.1825	8.1464	8.1437	52.70	8.79	43.43
271.2	8.3153	8.4042	8.3579	8.3544	52.11	8.82	44.01
271.6	8.5918	8.6729	8.6297	8.6265	53.33	8.97	42.73
272.0	8.3791	8.4512	8.4130	8.4098	52.95	10.08	42.62
272.4	7.8833	7.9908	7.9353	7.9307	51.65	9.73	44.07
272.8	8.3088	8.3791	8.3432	8.3400	51.07	10.35	44.38
273.2	8.9856	9.0362	9.0107	9.0087	50.40	8.98	45.65
273.6	8.4738	8.5471	8.5090	8.5060	52.05	9.30	43.86
274.0	8.8659	8.9297	8.8958	8.8933	53.09	8.90	42.99
274.4	8.4109	8.4814	8.4441	8.4410	52.98	9.99	42.62
274.8	8.3127	8.3978	8.3523	8.3485	53.53	10.15	42.01
275.2	8.4786	8.5559	8.5146	8.5117	53.40	8.53	42.85
275.6	8.3037	8.3741	8.3351	8.3331	55.47	6.46	41.69
276.0	8.2263	8.3202	8.2683	8.2658	55.27	6.17	42.01
276.4	8.4231	8.4976	8.4563	8.4546	55.40	5.34	42.25
276.8	8.5029	8.5861	8.5413	8.5388	53.91	6.83	43.09
277.2	8.6641	8.7375	8.6977	8.6952	54.19	7.75	42.40
277.6	8.3731	8.4600	8.4133	8.4105	53.71	7.33	43.06
278.0	8.3882	8.4916	8.4349	8.4322	54.79	6.04	42.55

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
278.4	8.2399	8.3473	8.2888	8.2861	54.52	5.61	43.02
278.8	8.5241	8.6111	8.5635	8.5614	54.74	5.49	42.84
279.2	8.4652	8.5691	8.5160	8.5123	51.13	8.09	45.31
279.6	8.3628	8.4921	8.4198	8.4150	55.90	8.53	40.35
280.0	8.5455	8.6411	8.5894	8.5856	54.13	9.03	41.89
280.4	7.7490	7.8302	7.7862	7.7829	54.22	9.10	41.77
280.8	8.5147	8.6010	8.5557	8.5521	52.46	9.48	43.37
281.2	8.5683	8.6965	8.6301	8.6247	51.79	9.66	43.95
281.6	8.3555	8.5126	8.4361	8.4287	48.68	10.77	46.58
282.0	8.5001	8.6314	8.5654	8.5599	50.23	9.52	45.58
282.4	8.4618	8.5554	8.5157	8.5108	42.47	11.78	52.35
282.8	8.5150	8.5974	8.5629	8.5583	41.89	12.70	52.52
283.2	8.3658	8.4698	8.4253	8.4200	42.74	11.58	52.16
283.6	9.2687	9.3570	9.3195	9.3150	42.49	11.46	52.46
284.0	8.6877	8.8274	8.7394	8.7347	62.96	7.65	33.68
284.4	8.3576	8.4662	8.4118	8.4071	50.14	9.84	45.53
284.8	8.4453	8.5417	8.4960	8.4920	47.46	9.43	48.39
285.2	8.6025	8.6658	8.6344	8.6317	49.53	9.87	46.13
285.6	8.5073	8.5537	8.5308	8.5289	49.41	9.05	46.61
286.0	8.2370	8.2904	8.2649	8.2621	47.71	12.12	46.96
286.4	8.2246	8.2864	8.2598	8.2564	42.96	12.69	51.46
286.8	8.2272	8.2843	8.2617	8.2587	39.53	12.15	55.13
287.2	8.2365	8.2817	8.2655	8.2628	35.73	13.83	58.19
287.6	8.3805	8.4451	8.4193	8.4157	39.89	12.85	54.45
288.0	8.0076	8.1168	8.0714	8.0660	41.53	11.34	53.48
288.4	8.2056	8.3058	8.2653	8.2603	40.37	11.34	54.64
288.8	8.3846	8.5086	8.4594	8.4532	39.65	11.46	55.30
289.2	9.0062	9.1449	9.0904	9.0831	39.31	11.88	55.46
289.6	8.1779	8.2520	8.2230	8.2195	39.07	10.89	56.14
290.0	8.1122	8.1825	8.1571	8.1539	36.09	10.51	59.29
290.4	8.3151	8.4154	8.3796	8.3749	35.71	10.66	59.60
290.8	8.5903	8.6650	8.6386	8.6351	35.34	10.65	59.97
291.2	8.3791	8.4801	8.4459	8.4409	33.86	11.36	61.14
291.6	7.8836	8.0104	7.9658	7.9611	35.16	11.46	61.14
292.0	8.3089	8.3646	8.3456	8.3425	34.20	12.44	60.32
292.4	8.9855	9.0555	9.0303	9.0271	36.00	10.23	59.50
292.8	8.4737	8.5428	8.5182	8.5150	35.65	10.35	59.80
293.2	8.8663	8.9305	8.9073	8.9045	36.06	10.09	59.50
293.6	8.4109	8.4657	8.4465	8.4439	35.04	10.78	60.22
294.0	8.3130	8.4068	8.3739	8.3692	35.07	11.39	59.91
294.4	8.4787	8.5622	8.5347	8.5308	32.93	10.62	62.40
294.8	8.3040	8.3579	8.3371	8.3352	38.59	7.80	57.98
295.2	8.2268	8.2989	8.2707	8.2684	39.18	7.25	57.63

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
295.6	8.4230	8.4900	8.4637	8.4618	39.25	6.61	57.84
296.0	8.5032	8.5777	8.5481	8.5455	39.66	8.08	56.78
296.4	8.6521	8.7587	8.7226	8.7182	33.86	9.49	61.96
296.8	8.3731	8.4584	8.4291	8.4249	34.35	11.19	60.73
297.2	8.3881	8.4627	8.4364	8.4334	35.23	9.13	60.75
297.6	8.2407	8.2992	8.2759	8.2741	39.83	6.80	57.18
298.0	8.5244	8.5862	8.5606	8.5588	41.39	6.80	55.62
298.4	8.4651	8.5422	8.5085	8.5060	43.75	7.36	53.01
298.8	8.3630	8.4562	8.4179	8.4139	41.04	9.75	54.67
299.2	8.5460	8.6111	8.5793	8.5770	48.85	7.86	47.70
299.6	7.7493	7.8296	7.7914	7.7882	47.60	9.05	48.41
300.0	8.5152	8.5701	8.5420	8.5404	51.18	6.62	45.90
300.4	8.5688	8.6369	8.6018	8.5995	51.47	7.68	45.15
300.8	8.3551	8.4357	8.3949	8.3918	50.65	8.74	45.51
301.2	8.5008	8.5952	8.5437	8.5405	54.53	7.70	42.09
301.6	8.4622	8.5425	8.4978	8.4956	55.67	6.23	41.59
302.0	8.5154	8.5743	8.5385	8.5374	60.78	4.24	37.35
302.4	8.3660	8.4634	8.4011	8.3993	63.93	4.31	34.17
302.8	9.2692	9.4059	9.3179	9.3146	64.37	5.57	33.17
303.2	8.6882	8.8056	8.7279	8.7254	66.23	4.84	31.64
303.6	8.3579	8.4338	8.3856	8.3841	63.55	4.49	34.48
304.0	8.4461	8.5468	8.4831	8.4809	63.31	4.97	34.51
304.4	8.6025	8.7281	8.6504	8.6474	61.90	5.34	35.75
304.8	8.5076	8.6251	8.5517	8.5489	62.44	5.41	35.18
305.2	8.2352	8.3586	8.2804	8.2777	63.35	5.06	34.43
305.6	8.2229	8.3136	8.2572	8.2552	62.16	5.01	35.63
306.0	8.2366	8.3590	8.2821	8.2792	62.81	5.48	34.78
306.4	8.2276	8.3112	8.2585	8.2566	63.00	5.30	34.67
306.8	8.3810	8.4882	8.4230	8.4202	60.84	5.93	36.55
307.2	8.0077	8.1171	8.0538	8.0510	57.86	5.92	39.53
307.6	8.2049	8.2779	8.2358	8.2341	57.70	5.13	40.04
308.0	8.3853	8.4700	8.4227	8.4206	55.81	5.77	41.65
308.4	9.0066	9.0893	9.0410	9.0391	58.34	5.36	39.30
308.8	8.1779	8.2258	8.1965	8.1949	61.11	7.58	35.56
309.2	8.1122	8.2004	8.1467	8.1437	60.88	7.73	35.71
309.6	8.3151	8.4281	8.3625	8.3582	58.03	8.65	38.16
310.0	8.5903	8.6752	8.6328	8.6289	49.97	10.43	45.44
310.4	8.3791	8.4504	8.4181	8.4145	45.37	11.48	49.58
310.8	7.8836	7.9668	7.9274	7.9228	47.39	12.42	47.15
311.2	8.3089	8.3796	8.3507	8.3461	40.91	14.64	52.65
311.6	8.9855	9.0572	9.0296	9.0240	38.49	17.75	53.70
312.0	8.4737	8.5396	8.5138	8.5090	39.12	16.54	53.60
312.4	8.8663	8.9691	8.9308	8.9227	37.24	18.01	54.84

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
312.8	8.4109	8.5019	8.4667	8.4598	38.63	17.23	53.79
313.2	8.3130	8.4406	8.3915	8.3814	38.48	18.08	53.57
313.6	8.4787	8.6233	8.5757	8.5639	32.90	18.55	58.94
314.0	8.3040	8.4636	8.4138	8.4016	31.20	17.37	61.15
314.4	8.2268	8.3171	8.2860	8.2804	34.40	14.10	59.39
314.8	8.4230	8.5331	8.4998	8.4936	30.26	12.80	64.11
315.2	8.5032	8.6493	8.6079	8.5996	28.33	12.91	65.99
315.6	8.6521	8.7723	8.7354	8.7277	30.74	14.46	62.90
316.0	8.3731	8.4663	8.4327	8.4265	36.03	15.23	57.27
316.4	8.3881	8.4978	8.4554	8.4485	38.61	14.40	55.06
316.8	8.2407	8.3677	8.3189	8.3116	38.41	13.06	55.84
317.2	8.5244	8.6779	8.6207	8.6123	37.28	12.36	57.28
317.6	8.4651	8.5573	8.5246	8.5196	35.45	12.44	59.08
318.0	8.3630	8.4934	8.4448	8.4370	37.27	13.51	56.79
318.4	8.5460	8.7076	8.6505	8.6414	35.32	12.86	59.02
318.8	7.7493	7.9079	7.8491	7.8400	37.04	13.04	57.22
319.2	8.5152	8.6469	8.6030	8.5956	33.33	12.86	61.01
319.6	8.5688	8.7232	8.6719	8.6630	33.19	13.17	61.01
320.0	8.3551	8.5111	8.4601	8.4515	32.66	12.53	61.83
320.4	8.5008	8.6944	8.6364	8.6277	29.96	10.21	65.55
320.8	8.4622	8.6151	8.5684	8.5621	30.57	9.29	65.35
321.2	8.5154	8.7061	8.6536	8.6459	27.50	9.24	68.43
321.6	8.3660	8.5620	8.5155	8.5076	23.70	9.16	72.27
322.0	9.2692	9.4405	9.4007	9.3936	23.23	9.42	72.62
322.4	8.6882	8.8358	8.8026	8.7966	22.49	9.32	73.41
322.8	8.3579	8.5629	8.5164	8.5083	22.69	8.98	73.36
323.2	8.4461	8.5849	8.5556	8.5506	21.15	8.11	75.29
323.6	8.6025	8.6915	8.6698	8.6661	24.40	9.45	71.44
324.0	8.5076	8.6299	8.6022	8.5976	22.64	8.54	73.60
324.4	8.2352	8.3159	8.2973	8.2941	22.99	9.15	72.99
324.8	8.2229	8.2799	8.2573	8.2546	39.68	10.78	55.58
325.2	8.2366	8.3017	8.2764	8.2734	38.94	10.47	56.45
325.6	8.2276	8.3019	8.2633	8.2606	51.95	8.11	44.48
326.0	8.3810	8.4566	8.4154	8.4126	54.46	8.41	41.84
326.4	8.0077	8.0732	8.0382	8.0357	53.48	8.51	42.78
326.8	8.2049	8.2709	8.2341	8.2317	55.79	8.26	40.58
327.2	8.3853	8.4487	8.4154	8.4131	52.48	8.42	43.81
327.6	9.0066	9.0537	9.0317	9.0296	46.77	10.12	48.78
328.0	8.1779	8.2764	8.2243	8.2222	52.87	4.96	44.95
328.4	8.1122	8.2171	8.1593	8.1568	55.15	5.42	42.47
328.8	8.3151	8.4006	8.3489	8.3473	60.47	4.25	37.66
329.2	8.5903	8.6804	8.6296	8.6274	56.35	5.67	41.15
329.6	8.3791	8.4752	8.4206	8.4185	56.82	4.97	41.00

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
330.0	7.8836	8.0241	7.9526	7.9468	50.87	9.46	44.97
330.4	8.3089	8.4251	8.3694	8.3631	47.93	12.42	46.60
330.8	8.9855	9.0774	9.0315	9.0267	49.92	11.86	44.86
331.2	8.4737	8.5652	8.5202	8.5139	49.21	15.64	43.91
331.6	8.8663	8.9377	8.9048	8.8994	46.08	17.03	46.43
332.0	8.4109	8.4821	8.4503	8.4452	44.59	16.44	48.17
332.4	8.3130	8.4080	8.3662	8.3605	44.00	13.76	49.95
332.8	8.4787	8.5540	8.5213	8.5189	43.39	30.66	53.36
333.2	8.3040	8.3429	8.3265	8.3302	42.03	23.66	67.35
333.6	8.2268	8.2572	8.2447	8.2504	41.28	14.58	77.63
334.0	8.4230	8.4579	8.4434	8.4494	41.46	11.41	75.61
334.4	8.5032	8.5574	8.5356	8.5388	40.28	18.85	65.62
334.8	8.6521	8.7324	8.7034	8.7025	36.14	24.36	62.74
335.2	8.3731	8.4357	8.4100	8.4082	41.10	34.28	56.11
335.6	8.3881	8.4775	8.4404	8.4398	41.44	21.10	57.89
336.0	8.2407	8.3059	8.2791	8.2820	41.07	16.72	63.37
336.4	8.5244	8.6132	8.5766	8.5800	41.22	11.01	62.61
336.8	8.4651	8.5673	8.5267	8.5292	39.76	11.45	62.74
337.2	8.3630	8.4397	8.4094	8.4102	39.50	20.45	61.54
337.6	8.5460	8.6321	8.5984	8.5931	39.08	14.12	54.70
338.0	7.7493	7.8265	7.7960	7.7916	39.48	12.94	54.82
338.4	8.5152	8.6043	8.5686	8.5636	40.07	12.88	54.26
338.8	8.5688	8.6669	8.6266	8.6214	41.03	12.05	53.67
339.2	8.3551	8.4802	8.4299	8.4232	40.21	12.08	54.48
339.6	8.5008	8.6163	8.5712	8.5650	39.00	12.30	55.58
340.0	8.4622	8.5843	8.5371	8.5314	38.64	10.61	56.69
340.4	8.5154	8.6274	8.5854	8.5804	37.50	10.15	58.04
340.8	8.3660	8.5001	8.4522	8.4464	35.74	9.83	59.93
341.2	9.2692	9.3965	9.3512	9.3455	35.56	10.27	59.92
341.6	8.6882	8.7942	8.7574	8.7531	34.76	9.11	61.23
342.0	8.3579	8.4449	8.4150	8.4105	34.39	11.76	60.44
342.4	8.4461	8.5202	8.4945	8.4917	34.75	8.43	61.54
342.8	8.6025	8.6978	8.6646	8.6612	34.80	8.23	61.57
343.2	8.5076	8.6591	8.6056	8.5993	35.33	9.37	60.54
343.6	8.2352	8.3634	8.3178	8.3123	35.59	9.75	60.12
344.0	8.2229	8.3439	8.2987	8.2932	37.33	10.43	58.08
344.4	8.2366	8.3202	8.2869	8.2834	39.89	9.52	55.92
344.8	8.2276	8.3463	8.2992	8.2954	39.64	7.28	57.16
345.2	8.3810	8.4814	8.4404	8.4371	40.79	7.47	55.93
345.6	8.0077	8.1007	8.0620	8.0584	41.58	8.80	54.55
346.0	8.2049	8.2918	8.2566	8.2530	40.54	9.41	55.32
346.4	8.3853	8.4465	8.4208	8.4182	41.99	9.66	53.76
346.8	9.0066	9.0816	9.0506	9.0470	41.33	10.91	53.87

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
347.2	8.1779	8.2497	8.2202	8.2173	41.06	9.33	54.84
347.6	8.1122	8.1971	8.1622	8.1587	41.13	9.37	54.74
348.0	8.3151	8.3804	8.3535	8.3509	41.27	8.88	54.82
348.4	8.5903	8.6541	8.6278	8.6253	41.19	8.90	54.89
348.8	8.3791	8.4419	8.4159	8.4135	41.48	8.69	54.70
349.2	7.8836	7.9457	7.9201	7.9174	41.14	10.06	54.43
349.6	8.3089	8.4034	8.3627	8.3592	43.09	8.42	53.20
350.0	8.9855	9.0803	9.0406	9.0369	41.82	8.87	54.27
350.4	8.4737	8.5597	8.5244	8.5207	40.99	9.91	54.65
350.8	8.8663	8.9655	8.9243	8.9199	41.51	10.19	54.01
351.2	8.4109	8.5022	8.4648	8.4606	41.00	10.45	54.41
351.6	8.3130	8.3952	8.3613	8.3573	41.24	11.20	53.83
352.0	8.4787	8.5336	8.5115	8.5092	40.26	9.73	55.46
352.4	8.3040	8.3854	8.3517	8.3480	41.34	10.33	54.12
352.8	8.2268	8.2917	8.2659	8.2629	39.83	10.51	55.55
353.2	8.4230	8.4922	8.4647	8.4616	39.70	10.19	55.82
353.6	8.5032	8.5778	8.5480	8.5445	39.92	10.81	55.32
354.0	8.6521	8.7147	8.6937	8.6913	33.57	8.72	62.59
354.4	8.3731	8.4526	8.4198	8.4161	41.26	10.58	54.09
354.8	8.3881	8.4800	8.4417	8.4372	41.68	11.01	53.48
355.2	8.2407	8.3244	8.2911	8.2869	39.78	11.40	55.20
355.6	8.5244	8.6053	8.5726	8.5686	40.42	11.24	54.64
356.0	8.4651	8.5538	8.5185	8.5138	39.83	12.04	54.87
356.4	8.3630	8.4695	8.4320	8.4261	35.21	12.48	59.30
356.8	8.5460	8.6944	8.6386	8.6329	37.57	8.73	58.59
357.2	7.7493	7.8658	7.8223	7.8177	37.30	8.97	58.76
357.6	8.5152	8.6265	8.5826	8.5784	39.44	8.68	56.74
358.0	8.5688	8.6864	8.6384	8.6340	40.77	8.60	55.44
358.4	8.3551	8.4416	8.4076	8.4045	39.28	8.27	57.08
358.8	8.5008	8.6097	8.5667	8.5629	39.44	7.93	57.07
359.2	8.4622	8.5537	8.5180	8.5147	38.96	8.32	57.38
359.6	8.5154	8.6241	8.5811	8.5774	39.54	7.73	57.06
360.0	8.3660	8.4681	8.4271	8.4233	40.19	8.34	56.14
360.4	9.2692	9.3823	9.3362	9.3323	40.76	7.84	55.79
360.8	8.6882	8.7900	8.7483	8.7445	40.98	8.38	55.33
361.2	8.4461	8.5578	8.5132	8.5089	39.93	8.75	56.22
361.6	8.3579	8.4518	8.4149	8.4115	39.26	8.23	57.11
362.0	8.6025	8.6892	8.6561	8.6530	38.24	8.13	58.19
362.4	8.5076	8.5874	8.5574	8.5544	37.59	8.54	58.65
362.8	8.2352	8.3050	8.2790	8.2764	37.25	8.47	59.03
363.2	8.2229	8.2877	8.2638	8.2612	36.96	9.12	59.03
363.6	8.2366	8.3063	8.2812	8.2784	36.04	8.97	60.01
364.0	8.2276	8.3024	8.2768	8.2742	34.16	7.90	62.37

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
364.4	8.3810	8.4791	8.4445	8.4411	35.30	7.87	61.23
364.8	8.0077	8.1074	8.0732	8.0695	34.35	8.32	61.99
365.2	8.2049	8.2764	8.2525	8.2499	33.47	8.26	62.89
365.6	8.3853	8.4718	8.4405	8.4375	36.13	7.88	60.40
366.0	9.0066	9.0803	9.0522	9.0496	38.10	8.01	58.37
366.4	8.1779	8.2494	8.2257	8.2221	33.15	11.28	61.89
366.8	8.1122	8.1724	8.1522	8.1480	33.50	15.87	59.52
367.2	8.3151	8.4002	8.3688	8.3649	36.96	10.42	58.46
367.6	8.5903	8.6965	8.6555	8.6507	38.61	10.17	56.92
368.0	8.3791	8.4834	8.4427	8.4382	38.99	9.92	56.64
368.4	7.8836	8.0004	7.9563	7.9508	37.74	10.79	57.51
368.8	8.3089	8.3844	8.3561	8.3525	37.48	10.84	57.75
369.2	8.9855	9.0377	9.0183	9.0162	37.16	8.93	58.91
369.6	8.4737	8.5732	8.5355	8.5313	37.89	9.59	57.89
370.0	8.8663	8.9336	8.9070	8.9044	39.50	8.94	56.57
370.4	8.4109	8.4946	8.4604	8.4574	40.80	8.28	55.56
370.8	8.3130	8.4157	8.3757	8.3715	38.97	9.30	56.94
371.2	8.4787	8.5436	8.5205	8.5180	35.59	8.93	60.48
371.6	8.3040	8.4033	8.3665	8.3628	37.01	8.58	59.21
372.0	8.2268	8.3411	8.2999	8.2956	36.06	8.45	60.22
372.4	8.4230	8.5567	8.5094	8.5041	35.35	9.10	60.64
372.8	8.5032	8.6541	8.5999	8.5937	35.91	9.33	59.99
373.2	8.6521	8.7811	8.7409	8.7356	31.14	9.34	64.75
373.6	8.3731	8.5280	8.4722	8.4652	36.01	10.27	59.47
374.0	8.3881	8.5041	8.4602	8.4554	37.80	9.40	58.06
374.4	8.2407	8.3391	8.3039	8.3000	35.77	8.89	60.32
374.8	8.5244	8.6585	8.6101	8.6045	36.12	9.40	59.75
375.2	8.4651	8.5909	8.5447	8.5392	36.75	9.84	58.92
375.6	8.3628	8.4709	8.4304	8.4258	37.44	9.78	58.26
376.0	8.5460	8.6556	8.6132	8.6081	38.71	10.57	56.63
376.4	7.7493	7.8479	7.8088	7.8042	39.66	10.60	55.68
376.8	8.5152	8.6388	8.5901	8.5839	39.38	11.41	55.61
377.2	8.5688	8.6867	8.6426	8.6360	37.39	12.72	57.02
377.6	8.3551	8.4432	8.4080	8.4027	39.99	13.54	54.06
378.0	8.5008	8.5921	8.5582	8.5526	37.16	13.93	56.70
378.4	8.4622	8.5582	8.5211	8.5159	38.65	12.31	55.94
378.8	8.3660	8.4464	8.4148	8.4107	39.28	11.72	55.56
379.2	8.5154	8.6153	8.5764	8.5709	38.89	12.63	55.56
379.6	9.2692	9.3780	9.3411	9.3339	33.89	15.15	59.45
380.0	8.6882	8.8154	8.7726	8.7639	33.62	15.55	59.54
380.4	8.4461	8.5857	8.5399	8.5308	32.78	14.90	60.66
380.8	8.3579	8.4344	8.4117	8.4052	29.67	19.31	61.83
381.2	8.6025	8.7194	8.6852	8.6768	29.26	16.43	63.52

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
381.6	8.5076	8.5997	8.5737	8.5673	28.21	15.91	64.79
382.0	8.2352	8.3191	8.2955	8.2891	28.11	17.33	64.26
382.4	8.3853	8.4766	8.4525	8.4460	26.34	16.18	66.54
382.8	8.2366	8.3344	8.3126	8.3062	22.29	14.87	71.17
383.2	8.2276	8.3746	8.3415	8.3322	22.54	14.37	71.13
383.6	8.3810	8.4725	8.4496	8.4435	25.03	15.15	68.31
384.0	8.0077	8.2124	8.1739	8.1645	18.81	10.49	76.58
384.4	8.2049	8.4834	8.4434	8.4350	14.36	6.89	82.61
384.8	9.0066	9.3475	9.3036	9.2913	12.88	8.20	83.51
385.2	8.2229	8.5820	8.5410	8.5287	11.42	7.82	85.14
385.6	8.5460	8.6330	8.6115	8.6092	24.66	6.01	72.70
386.0	7.7493	7.9150	7.8764	7.8717	23.30	6.45	73.87
386.4	8.5152	8.7509	8.6912	8.6848	25.35	6.12	71.96
386.8	8.5688	8.7230	8.6751	8.6708	31.05	6.34	66.16
387.2	8.3551	8.4562	8.4216	8.4193	34.17	5.28	63.50
387.6	8.5008	8.5949	8.5580	8.5553	39.21	6.52	57.92
388.0	8.4622	8.5873	8.5373	8.5333	39.95	7.26	56.85
388.4	8.3660	8.5195	8.4530	8.4485	43.29	6.74	53.75
388.8	8.5154	8.6680	8.5978	8.5928	46.00	7.37	50.75
389.2	9.2692	9.4235	9.3639	9.3595	38.64	6.48	58.51
389.6	8.6882	8.8589	8.8023	8.7968	33.14	7.39	63.61
390.0	8.3579	8.5489	8.4715	8.4654	40.52	7.32	56.26
390.4	8.4461	8.5716	8.5305	8.5263	32.79	7.61	63.86
390.8	8.6025	8.7451	8.6986	8.6942	32.64	6.93	64.31
391.2	8.5076	8.6559	8.6091	8.6033	31.55	8.96	64.51
391.6	8.2352	8.3893	8.3406	8.3336	31.63	10.32	63.83
392.0	8.2229	8.3653	8.3182	8.3120	33.11	9.82	62.57
392.4	8.2366	8.3169	8.2858	8.2823	38.73	10.05	56.85
392.8	8.2276	8.3400	8.3069	8.3021	29.40	9.81	66.28
393.2	8.3810	8.4627	8.4294	8.4271	40.70	6.54	56.43
393.6	8.0077	8.1148	8.0719	8.0687	40.03	6.79	56.98
394.0	8.2049	8.3067	8.2657	8.2626	40.28	6.81	56.73
394.4	8.3853	8.5404	8.4791	8.4739	39.52	7.55	57.16
394.8	9.0066	9.1060	9.0666	9.0631	39.64	7.89	56.89
395.2	8.1788	8.3580	8.2974	8.2911	33.83	7.93	62.68
395.6	8.1128	8.2338	8.1916	8.1869	34.86	8.82	61.26
396.0	8.3157	8.4130	8.3774	8.3742	36.61	7.36	60.15
396.4	8.5908	8.7117	8.6688	8.6647	35.46	7.80	61.11
396.8	8.3796	8.5297	8.4765	8.4710	35.42	8.33	60.91
397.2	7.8844	8.0137	7.9681	7.9630	35.29	8.96	60.77
397.6	8.3097	8.4655	8.4125	8.4058	34.04	9.77	61.66
398.0	8.9862	9.1573	9.0986	9.0912	34.31	9.90	61.34
398.4	8.4746	8.6269	8.5756	8.5697	33.67	8.80	62.45

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
398.8	8.8669	9.0558	8.9929	8.9850	33.30	9.44	62.55
399.2	8.4116	8.5723	8.5206	8.5140	32.15	9.41	63.71
399.6	8.3136	8.4765	8.4240	8.4164	32.22	10.60	63.12
400.0	8.4794	8.6329	8.5851	8.5783	31.17	9.99	64.43
400.4	8.3048	8.4169	8.3796	8.3757	33.27	7.91	63.25
400.8	8.2275	8.3664	8.3216	8.3167	32.25	8.02	64.22
401.2	8.4238	8.5270	8.4943	8.4924	31.67	4.18	66.49
401.6	8.5041	8.6614	8.6111	8.6065	31.98	6.65	65.10
402.0	8.6648	8.7746	8.7436	8.7394	28.28	8.69	67.90
402.4	8.3738	8.5014	8.4680	8.4642	26.20	6.68	70.86
402.8	8.3892	8.5010	8.4664	8.4627	30.99	7.42	65.74
403.2	8.2414	8.3535	8.3199	8.3165	29.97	6.79	67.04
403.6	8.5254	8.6806	8.6370	8.6332	28.07	5.64	69.45
404.0	8.4662	8.6245	8.5828	8.5798	26.31	4.38	71.76
404.4	8.3640	8.5496	8.4984	8.4938	27.61	5.57	69.94
404.8	8.5463	8.6925	8.6559	8.6515	25.06	6.84	71.93
405.2	7.7500	7.8679	7.8286	7.8242	33.29	8.58	62.93
405.6	8.5154	8.6382	8.5959	8.5917	34.45	7.87	62.09
406.0	8.5694	8.6828	8.6393	8.6347	38.36	9.22	57.58
406.4	8.3556	8.4892	8.4347	8.4282	40.78	11.05	54.36
406.8	8.5011	8.6266	8.5793	8.5724	37.66	12.59	56.80
407.2	8.4626	8.5862	8.5360	8.5282	40.64	14.24	53.09
407.6	8.5159	8.6690	8.6034	8.5958	42.83	11.28	52.20
408.0	8.3666	8.4877	8.4377	8.4284	41.33	17.36	51.03
408.4	9.2697	9.3853	9.3375	9.3284	41.35	17.89	50.78
408.8	8.6890	8.8371	8.7741	8.7614	42.54	19.49	48.89
409.2	8.3583	8.4348	8.4026	8.3965	42.13	17.96	49.97
409.6	8.4468	8.5206	8.4898	8.4847	41.80	15.71	51.29
410.0	8.6033	8.6761	8.6467	8.6409	40.45	18.11	51.58
410.4	8.5081	8.7412	8.6607	8.6532	34.52	7.31	62.26
410.8	8.2355	8.3994	8.3417	8.3368	35.17	6.79	61.84
411.2	8.2233	8.4046	8.3412	8.3356	34.97	7.02	61.94
411.6	8.2284	8.3612	8.3138	8.3094	35.69	7.53	60.99
412.0	8.2371	8.3867	8.3354	8.3304	34.28	7.67	62.35
412.4	8.3815	8.5076	8.4648	8.4611	33.92	6.76	63.11
412.8	8.0081	8.1196	8.0810	8.0778	34.66	6.52	62.47
413.2	8.2062	8.3193	8.2825	8.2790	32.58	6.93	64.37
413.6	8.3856	8.4860	8.4543	8.4514	31.57	6.45	65.59
414.0	9.0069	9.1245	9.0878	9.0843	31.24	6.76	65.79
414.4	8.1788	8.2896	8.2527	8.2483	33.30	9.13	62.68
414.8	8.1128	8.2719	8.2234	8.2169	30.51	9.28	65.41
415.2	8.3157	8.4369	8.4025	8.3975	28.39	9.38	67.48
415.6	8.5908	8.7187	8.6802	8.6752	30.11	8.80	66.01

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
416.0	8.3796	8.5574	8.4982	8.4913	33.31	8.82	62.81
416.4	7.8844	7.9916	7.9599	7.9556	29.60	9.01	66.43
416.8	8.3097	8.4188	8.3845	8.3799	31.47	9.47	64.36
417.2	8.9862	9.1354	9.0887	9.0826	31.30	9.29	64.61
417.6	8.4746	8.6388	8.5880	8.5817	30.94	8.72	65.23
418.0	8.8669	8.9990	8.9578	8.9529	31.19	8.34	65.14
418.4	8.4116	8.5663	8.5166	8.5109	32.10	8.38	64.21
418.8	8.3136	8.4212	8.3872	8.3833	31.60	8.24	64.78
419.2	8.4794	8.6112	8.5682	8.5631	32.66	8.71	63.51
419.6	8.3048	8.4037	8.3712	8.3678	32.88	7.82	63.68
420.0	8.2275	8.3372	8.3009	8.2975	33.09	7.04	63.81
420.4	8.4238	8.5456	8.5056	8.5015	32.84	7.65	63.79
420.8	8.5041	8.6440	8.5981	8.5928	32.82	8.53	63.43
421.2	8.6648	8.7719	8.7366	8.7325	32.93	8.81	63.19
421.6	8.3738	8.4663	8.4334	8.4299	35.57	8.60	60.65
422.0	8.3892	8.4764	8.4439	8.4409	37.29	7.69	59.32
422.4	8.2414	8.3334	8.3025	8.2991	33.62	8.39	62.68
422.8	8.5254	8.6267	8.5912	8.5876	35.04	8.19	61.35
423.2	8.4662	8.5625	8.5293	8.5256	34.42	8.73	61.73
423.6	8.3640	8.5025	8.4566	8.4507	33.16	9.60	62.61
424.0	8.5463	8.7050	8.6498	8.6436	34.80	8.88	61.29
424.4	7.7500	7.8882	7.8399	7.8344	34.95	9.04	61.07
424.8	8.5154	8.6180	8.5804	8.5761	36.67	9.42	59.19
425.2	8.5694	8.6863	8.6447	8.6398	35.61	9.52	60.20
425.6	8.3556	8.4739	8.4313	8.4260	35.97	10.28	59.51
426.0	8.5011	8.6792	8.6141	8.6058	36.53	10.66	58.78
426.4	8.4626	8.5714	8.5313	8.5258	36.84	11.48	58.11
426.8	8.5159	8.6353	8.5912	8.5843	36.96	13.03	57.30
427.2	8.3666	8.4758	8.4344	8.4289	37.91	11.55	57.01
427.6	9.2697	9.4411	9.3760	9.3677	37.96	11.01	57.19
428.0	8.6890	8.8103	8.7656	8.7579	36.81	14.43	56.84
428.4	8.3583	8.5359	8.4704	8.4602	36.85	13.12	57.38
428.8	8.4468	8.5563	8.5154	8.5092	37.35	12.97	56.94
429.2	8.6033	8.7151	8.6728	8.6655	37.88	14.74	55.64
429.6	8.5081	8.6386	8.5900	8.5826	37.24	12.89	57.09
430.0	8.2355	8.3345	8.2981	8.2932	36.75	11.24	58.30
430.4	8.2233	8.3802	8.3220	8.3143	37.08	11.22	57.98
430.8	8.2284	8.3422	8.3005	8.2948	36.67	11.28	58.37
431.2	8.2371	8.3693	8.3205	8.3142	36.90	10.83	58.34
431.6	8.3815	8.4715	8.4384	8.4337	36.74	11.88	58.03
432.0	8.0081	8.1224	8.0797	8.0742	37.40	10.84	57.83
432.4	8.2062	8.3333	8.2852	8.2796	37.82	10.11	57.73
432.8	8.3856	8.4677	8.4368	8.4328	37.67	10.93	57.52

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
433.2	9.0069	9.1306	9.0828	9.0767	38.64	11.12	56.47
433.6	8.1788	8.2866	8.2401	8.2320	40.21	9.81	49.35
434.0	8.1128	8.1482	8.1280	8.1213	39.63	3.85	24.12
434.4	8.3157	8.4100	8.3709	8.3670	41.52	9.76	54.40
434.8	8.5908	8.6866	8.6452	8.6411	43.01	9.49	52.51
435.2	8.3796	8.4694	8.4310	8.4263	42.23	10.64	52.03
435.6	7.8844	7.9961	7.9376	7.9223	41.83	7.34	33.96
436.0	8.3097	8.3821	8.3505	8.3459	41.55	9.41	50.03
436.4	8.9862	9.0868	9.0449	9.0405	41.87	10.28	54.00
436.8	8.4746	8.5865	8.5405	8.5358	41.27	9.74	54.67
437.2	8.8669	8.9693	8.9260	8.9210	41.06	8.66	52.83
437.6	8.4116	8.5330	8.4753	8.4605	38.28	6.85	40.26
438.0	8.3136	8.4561	8.3892	8.3761	40.98	7.43	43.89
438.4	8.4794	8.6114	8.5601	8.5549	38.84	8.96	57.22
438.8	8.3048	8.4011	8.3628	8.3591	39.82	8.61	56.39
439.2	8.2275	8.3198	8.2809	8.2775	42.18	8.37	54.14
439.6	8.4238	8.5009	8.4682	8.4652	42.41	8.84	53.70
440.0	8.5041	8.5959	8.5567	8.5532	42.72	8.55	53.51
440.4	8.6648	8.7627	8.7224	8.7182	41.22	9.63	54.55
440.8	8.3738	8.5489	8.4766	8.4703	41.29	8.18	55.11
441.2	8.3892	8.5171	8.4657	8.4612	40.23	7.91	56.29
441.6	8.2414	8.3919	8.3330	8.3273	39.10	8.61	57.11
442.0	8.5254	8.6167	8.5820	8.5778	38.06	10.33	57.39
442.4	8.4662	8.5747	8.5339	8.5290	37.56	10.37	57.88
442.8	8.3640	8.4691	8.4289	8.4239	38.23	10.81	57.01
443.2	8.5463	8.6534	8.6114	8.6090	39.17	5.20	58.54
443.6	7.7500	7.8209	7.7935	7.7919	38.62	5.13	59.13
444.0	8.5154	8.6411	8.5925	8.5898	38.64	4.88	59.21
444.4	8.5694	8.6861	8.6407	8.6378	38.89	5.74	58.59
444.8	8.3556	8.5304	8.4619	8.4575	39.16	5.79	58.30
445.2	8.5011	8.6328	8.5814	8.5779	39.00	6.13	58.30
445.6	8.4626	8.5620	8.5244	8.5215	37.81	6.63	59.28
446.0	8.5159	8.6091	8.5734	8.5702	38.28	7.92	58.23
446.4	8.3666	8.4595	8.4247	8.4215	37.51	7.71	59.10
446.8	9.2697	9.3755	9.3369	9.3322	36.45	10.10	59.10
447.2	8.6890	8.8020	8.7565	8.7520	40.27	9.05	55.75
447.6	8.3583	8.5133	8.4554	8.4472	37.34	12.09	57.34
448.0	8.4468	8.5567	8.5180	8.5103	35.18	16.03	57.76
448.4	8.6033	8.6988	8.6632	8.6585	37.30	11.07	57.83
448.8	8.5081	8.6957	8.6213	8.6144	39.64	8.42	56.65
449.2	8.2355	8.3657	8.3129	8.3086	40.54	7.59	56.12
449.6	8.2233	8.3473	8.2974	8.2936	40.20	6.96	56.73

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
450.0	8.2284	8.3176	8.2820	8.2791	39.85	7.52	56.84
450.4	8.2371	8.3549	8.3088	8.3045	39.13	8.20	57.26
450.8	8.3815	8.5231	8.4664	8.4621	40.06	6.82	56.94
451.2	8.0081	8.1285	8.0817	8.0774	38.89	8.12	57.54
451.6	8.2062	8.3178	8.2789	8.2751	34.86	7.74	61.74
452.0	8.3856	8.5332	8.4792	8.4729	36.55	9.70	59.18
452.4	9.0069	9.1931	9.1253	9.1190	36.40	7.69	60.21
452.8	8.1788	8.3426	8.2896	8.2829	32.37	9.23	63.57
453.2	7.9570	8.0954	8.0506	8.0450	32.38	9.20	63.57
453.6	8.3157	8.4347	8.3949	8.3899	33.42	9.65	62.34
454.0	8.5908	8.7178	8.6761	8.6708	32.83	9.48	62.99
454.4	8.3796	8.4921	8.4562	8.4512	31.93	10.11	63.63
454.8	7.8844	7.9830	7.9500	7.9457	33.42	9.91	62.22
455.2	8.2895	8.4146	8.3719	8.3665	34.11	9.81	61.58
455.6	8.9862	9.0948	9.0571	9.0523	34.73	9.95	60.89
456.0	8.4746	8.6068	8.5568	8.5514	37.82	9.20	58.13
456.4	8.8669	8.9506	8.9187	8.9154	38.09	9.09	57.91
456.8	8.4116	8.4937	8.4587	8.4553	42.60	9.42	53.26
457.2	8.3136	8.3938	8.3628	8.3585	38.63	12.18	56.01
457.6	8.4794	8.5492	8.5208	8.5172	40.69	11.88	54.08
458.0	8.3048	8.4193	8.3758	8.3695	37.99	12.50	56.51
458.4	8.2275	8.3349	8.2966	8.2897	35.69	14.59	57.89
458.8	8.4238	8.5010	8.4737	8.4685	35.36	15.16	57.97
459.2	8.5041	8.5942	8.5607	8.5553	37.15	13.75	56.80
459.6	8.6648	8.7416	8.7148	8.7095	34.92	15.55	58.24
460.0	8.3738	8.4479	8.4229	8.4171	33.74	17.64	58.50
460.4	8.3892	8.4899	8.4534	8.4473	36.21	13.89	57.68
460.8	8.2414	8.3235	8.2938	8.2894	36.11	12.18	58.53
461.2	8.5254	8.6334	8.5937	8.5868	36.76	14.52	56.85
461.6	8.4662	8.6089	8.5568	8.5484	36.51	13.30	57.64
462.0	8.3640	8.4943	8.4459	8.4367	37.15	16.05	55.79
462.4	8.5463	8.6852	8.6339	8.6227	36.90	18.41	55.00
462.8	7.7500	7.8441	7.8095	7.8023	36.72	17.39	55.63
463.2	8.5154	8.5931	8.5639	8.5578	37.60	17.85	54.54
463.6	8.5694	8.6805	8.6376	8.6289	38.57	17.90	53.56
464.0	8.3556	8.4615	8.4208	8.4122	38.46	18.34	53.47
464.4	8.5011	8.6399	8.5850	8.5738	39.57	18.35	52.36
464.8	8.4626	8.5876	8.5391	8.5288	38.82	18.72	52.94
465.2	8.5159	8.6420	8.5904	8.5808	40.88	17.39	51.47
465.6	8.3666	8.4969	8.4444	8.4348	40.31	16.75	52.32
466.0	9.2697	9.3890	9.3411	9.3316	40.13	18.11	51.91
466.4	8.6890	8.7540	8.7320	8.7296	33.90	8.39	62.41
466.8	8.3583	8.4707	8.4324	8.4279	34.10	9.09	61.89

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
467.2	8.4468	8.5212	8.4958	8.4928	34.10	9.17	61.87
467.6	8.6033	8.6982	8.6672	8.6638	32.67	8.14	63.75
468.0	8.5081	8.5803	8.5566	8.5543	32.78	7.40	63.96
468.4	8.2355	8.3536	8.3167	8.3126	31.20	7.89	65.33
468.8	8.2233	8.3258	8.2936	8.2903	31.40	7.42	65.33
469.2	8.2284	8.3541	8.3159	8.3113	30.38	8.31	65.96
502.0	8.2371	8.3236	8.2969	8.2938	30.91	8.14	65.51
470.0	8.3815	8.5149	8.4750	8.4699	29.92	8.61	66.29
470.4	8.0081	8.1246	8.0890	8.0850	30.56	7.90	65.97
470.8	8.2062	8.3276	8.2888	8.2846	32.00	7.77	64.58
471.2	8.3856	8.5130	8.4720	8.4675	32.14	8.03	64.32
471.6	9.0069	9.2215	9.1593	9.1513	28.98	8.47	67.29
472.0	8.1788	8.2850	8.2539	8.2512	29.33	5.78	68.13
472.4	7.9570	8.1075	8.0652	8.0612	28.08	6.12	69.23
472.8	8.3157	8.5170	8.4605	8.4550	28.09	6.15	69.20
473.2	8.5908	8.7240	8.6861	8.6830	28.46	5.21	69.25
473.6	8.3796	8.4657	8.4417	8.4399	27.93	4.62	70.03
474.0	7.8844	7.9741	7.9439	7.9416	33.65	5.95	63.73
474.4	8.2895	8.3975	8.3661	8.3635	29.07	5.58	68.47
474.8	8.9862	9.0945	9.0580	9.0553	33.72	5.67	63.79
475.2	8.4746	8.5671	8.5346	8.5324	35.12	5.53	62.45
475.6	8.8669	9.0378	8.9775	8.9726	35.30	6.45	61.86
476.0	8.4116	8.5311	8.4889	8.4858	35.33	5.90	62.08
476.4	8.3136	8.3888	8.3620	8.3600	35.68	5.89	61.73
476.8	8.4794	8.5780	8.5431	8.5406	35.41	5.65	62.10
477.2	8.3048	8.4462	8.3963	8.3924	35.29	6.27	61.95
477.6	8.2275	8.4093	8.3476	8.3429	33.96	5.87	63.46
478.0	8.4238	8.5525	8.5071	8.5040	35.30	5.47	62.29
478.4	8.5041	8.7074	8.6372	8.6315	34.54	6.37	62.66
478.8	8.6648	8.8283	8.7718	8.7666	34.59	7.23	62.23
479.2	8.3738	8.5426	8.4852	8.4798	34.00	7.20	62.83
479.6	8.3892	8.5374	8.4855	8.4813	35.02	6.44	62.15
480.0	8.2414	8.3201	8.2914	8.2895	36.47	5.34	61.18
480.4	8.5254	8.6537	8.6063	8.6031	36.98	5.67	60.52
480.8	8.4662	8.5949	8.5468	8.5431	37.40	6.53	59.73
481.2	8.3640	8.5296	8.4688	8.4636	36.70	7.20	60.13
481.6	8.5463	8.6429	8.6091	8.6062	34.97	6.82	62.03
482.0	7.7500	7.8579	7.8198	7.8167	35.31	6.53	61.82
482.4	8.5154	8.6434	8.5980	8.5941	35.47	6.92	61.48
482.8	8.5694	8.6661	8.6320	8.6291	35.30	6.69	61.76
483.2	8.3556	8.4437	8.4117	8.4091	36.30	6.70	60.75
483.6	8.5011	8.5714	8.5450	8.5431	37.51	6.31	59.72
484.0	8.4626	8.5752	8.5330	8.5295	37.43	7.17	59.41

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
484.4	8.5159	8.5916	8.5632	8.5612	37.49	6.15	59.80
484.8	8.3666	8.4679	8.4296	8.4265	37.78	6.96	59.16
485.2	9.2697	9.3755	9.3368	9.3334	36.58	7.41	60.16
485.6	8.6890	8.8174	8.7703	8.7664	36.68	6.90	60.28
486.0	8.3583	8.4576	8.4214	8.4185	36.49	6.52	60.64
486.4	8.4468	8.5349	8.5026	8.5002	36.72	6.06	60.61
486.8	8.6033	8.7089	8.6704	8.6671	36.46	7.10	60.42
487.2	8.5081	8.6380	8.5907	8.5865	36.45	7.35	60.32
487.6	8.2355	8.3749	8.3246	8.3203	36.07	7.09	60.81
488.0	8.2233	8.3237	8.2869	8.2838	36.60	7.13	60.26
488.4	8.2284	8.3587	8.3120	8.3078	35.84	7.24	60.97
488.8	8.2371	8.3216	8.2909	8.2883	36.27	6.99	60.65
489.2	8.3815	8.4442	8.4204	8.4187	38.04	5.98	59.33
489.6	8.0081	8.0900	8.0585	8.0561	38.46	6.66	58.61
490.0	8.2062	8.2954	8.2608	8.2579	38.75	7.52	57.94
490.4	8.3856	8.5182	8.4675	8.4629	38.24	7.88	58.30
490.8	9.0069	9.1141	9.0725	9.0689	38.81	7.63	57.84
491.2	8.1788	8.2302	8.2103	8.2078	38.75	11.06	56.38
491.6	7.9570	8.0227	7.9965	7.9934	39.88	10.72	55.40
492.0	8.3157	8.3887	8.3603	8.3571	38.86	10.13	56.68
492.4	8.5908	8.6499	8.6269	8.6243	38.87	10.20	56.65
492.8	8.3796	8.4409	8.4174	8.4145	38.37	10.76	56.90
493.2	7.8844	7.9371	7.9166	7.9144	38.96	9.48	56.87
493.6	8.2895	8.3624	8.3362	8.3326	36.01	11.07	59.12
494.0	8.9862	9.0846	9.0472	9.0425	38.01	10.97	57.16
494.4	8.4746	8.5336	8.5110	8.5084	38.36	9.81	57.32
494.8	8.8669	8.9642	8.9275	8.9232	37.75	9.92	57.88
495.2	8.4116	8.4772	8.4522	8.4495	38.19	9.35	57.70
495.6	8.3136	8.3992	8.3670	8.3637	37.59	8.76	58.55
496.0	8.4794	8.5757	8.5407	8.5366	36.31	9.68	59.43
496.4	8.3048	8.3894	8.3592	8.3558	35.66	9.14	60.32
496.8	8.2275	8.3051	8.2775	8.2748	35.54	7.90	60.98
497.2	8.4238	8.5198	8.4868	8.4837	34.32	7.34	62.45
497.6	8.5041	8.6031	8.5710	8.5679	32.39	7.24	64.43
498.0	8.6648	8.8064	8.7615	8.7567	31.74	7.62	64.90
498.4	8.3738	8.4523	8.4260	8.4229	33.48	8.97	62.57
498.8	8.3892	8.4763	8.4458	8.4425	35.07	8.48	61.19
499.2	8.2414	8.3349	8.3024	8.2990	34.76	8.26	61.60
499.6	8.5254	8.6348	8.5975	8.5935	34.14	8.31	62.20
500.0	8.4662	8.6052	8.5597	8.5541	32.73	9.07	63.27
500.4	8.3640	8.4584	8.4267	8.4232	33.53	8.55	62.71
500.8	8.1788	8.3355	8.2886	8.2811	29.94	10.81	65.30
501.2	7.9570	8.1535	8.1040	8.0957	25.22	9.60	70.56

Table E.3. LOI Results for Rebecca Lake (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
501.6	8.3157	8.4591	8.4183	8.4122	28.46	9.67	67.28
502.0	8.5908	8.7143	8.6746	8.6690	32.19	10.31	63.28
502.4	8.3796	8.4898	8.4530	8.4475	33.44	11.24	61.62
502.8	7.8844	7.9841	7.9498	7.9450	34.39	10.94	60.80
503.2	8.2895	8.4026	8.3647	8.3589	33.52	11.66	61.34
503.6	8.9862	9.0559	9.0319	9.0284	34.43	11.58	60.47
504.0	8.4746	8.5762	8.5410	8.5362	34.60	10.85	60.63
504.4	8.8669	8.9595	8.9265	8.9221	35.64	10.68	59.67
504.8	8.4116	8.5050	8.4713	8.4667	36.08	11.31	58.94
505.2	8.3136	8.4175	8.3789	8.3735	37.18	11.70	57.67
505.6	8.4794	8.5469	8.5204	8.5170	39.29	11.46	55.67
506.0	8.3048	8.4012	8.3652	8.3604	37.31	11.44	57.65
506.4	8.2275	8.3115	8.2815	8.2772	35.75	11.63	59.13
506.8	8.4238	8.5138	8.4834	8.4789	33.76	11.36	61.24
507.2	8.5041	8.5798	8.5539	8.5498	34.24	12.17	60.41
507.6	8.6648	8.7554	8.7257	8.7206	32.80	12.68	61.62
508.0	8.3738	8.4742	8.4412	8.4360	32.90	11.77	61.92
508.4	8.3892	8.4920	8.4579	8.4528	33.19	11.28	61.85
508.8	8.2414	8.3391	8.3068	8.3021	33.04	11.04	62.10
509.2	8.5254	8.6301	8.5964	8.5914	32.20	10.86	63.02
509.6	8.4662	8.5827	8.5453	8.5395	32.10	11.22	62.96
510.0	8.3640	8.5126	8.4650	8.4576	32.00	11.32	63.02
510.4	8.5463	8.6240	8.6028	8.5991	27.33	10.67	67.97
510.8	7.7500	7.8524	7.8249	7.8206	26.89	9.54	68.91
511.2	8.5154	8.6643	8.6274	8.6209	24.79	9.92	70.84
511.6	8.5694	8.7608	8.7117	8.7028	25.67	10.51	69.70
512.0	8.3556	8.5146	8.4676	8.4602	29.53	10.65	65.79
512.4	8.5011	8.6923	8.6426	8.6340	26.00	10.23	69.50
512.8	8.4626	8.6538	8.5978	8.5889	29.29	10.52	66.08
513.2	8.5159	8.6389	8.6002	8.5948	31.46	9.89	64.19
513.6	8.3666	8.5191	8.4704	8.4634	31.97	10.36	63.48
514.0	9.2697	9.3406	9.3190	9.3157	30.42	10.59	64.93

*% Other = 100-%organics-%carbonates = the index of terrigenous input

Table E.4. LOI Results for Five Lakes

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
10	8.5031	8.9385	8.8431	8.8141	21.91	15.14	62.95
11	8.5054	8.8062	8.7470	8.7274	19.68	14.81	65.51
12	8.8678	9.1431	9.0859	9.0662	20.78	16.26	62.96
13	8.2245	8.4663	8.4160	8.3970	20.80	17.86	61.34
14	8.3830	8.5860	8.5413	8.5273	22.02	15.67	62.31
15	8.0094	8.2064	8.1640	8.1509	21.52	15.11	63.36
16	8.3680	8.5673	8.5263	8.5142	20.57	13.80	65.63
17	8.5178	8.9810	8.8842	8.8578	20.90	12.95	66.15
18	8.5478	8.8172	8.7673	8.7493	18.52	15.19	66.29
19	8.5100	8.8034	8.7516	8.7321	17.66	15.11	67.24
20	8.3596	8.6951	8.6381	8.6156	16.99	15.24	67.77
21	8.4644	8.7488	8.6994	8.6821	17.37	13.82	68.81
22	9.2716	9.5955	9.5390	9.5196	17.44	13.61	68.94
23	8.2078	8.6121	8.5427	8.5187	17.17	13.49	69.34
24	8.4810	8.8401	8.7787	8.7575	17.10	13.42	69.48
25	8.1791	8.5863	8.5253	8.4934	14.98	17.80	67.22
26	7.7511	8.1450	8.0840	8.0566	15.49	15.81	68.70
27	8.5166	8.9171	8.8495	8.8251	16.88	13.85	69.27
28	8.6897	9.2391	9.1492	9.1163	16.36	13.61	70.03
29	8.4757	8.8873	8.8157	8.7955	17.40	11.15	71.45
30	8.3056	8.7422	8.6732	8.6501	15.80	12.02	72.17
31	8.3860	8.6786	8.6359	8.6160	14.59	15.46	69.95
32	9.0077	9.4851	9.4158	9.3850	14.52	14.66	70.82
33	8.5699	9.0745	8.9996	8.9702	14.84	13.24	71.91
34	8.9870	9.4852	9.4119	9.3838	14.71	12.82	72.47
35	8.2281	8.6441	8.5788	8.5573	15.70	11.75	72.56
36	8.4250	8.7992	8.7430	8.7218	15.02	12.88	72.11
37	8.6041	9.0290	8.9643	8.9418	15.23	12.03	72.74
38	8.3570	8.8687	8.7932	8.7666	14.75	11.81	73.43
39	8.2296	8.7446	8.6654	8.6424	15.38	10.15	74.47
40	7.8852	8.4634	8.3675	8.3405	16.59	10.61	72.80
41	8.3164	8.7421	8.6620	8.6374	18.82	13.13	68.05
42	8.2363	8.7034	8.6041	8.5766	21.26	13.38	65.36
43	8.2378	8.5507	8.4707	8.4564	25.57	10.39	64.05
44	8.5913	8.8481	8.7823	8.7663	25.62	14.16	60.22
45	8.3811	8.5697	8.5075	8.4965	32.98	13.26	53.76
46	7.9573	8.2128	8.1094	8.0936	40.47	14.05	45.48
47	8.4481	8.6300	8.5480	8.5372	45.08	13.49	41.43
48	8.4132	8.5277	8.4693	8.4622	51.00	14.09	34.90
49	8.2252	8.3753	8.2961	8.2879	52.76	12.42	34.82
50	8.3835	8.5254	8.4531	8.4452	50.95	12.65	36.40
51	8.0102	8.1467	8.0817	8.0738	47.62	13.15	39.23

Table E.4. LOI Results for Five Lakes (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
52	8.3693	8.4921	8.4332	8.4264	47.96	12.59	39.45
53	8.5194	8.6791	8.5975	8.5900	51.10	10.67	38.23
54	8.5506	8.7066	8.6262	8.6186	51.54	11.07	37.39
55	8.5114	8.6882	8.6085	8.5924	45.08	20.70	34.22
56	8.3603	8.5899	8.4766	8.4666	49.35	9.90	40.75
57	8.4671	8.6053	8.5431	8.5332	45.01	16.28	38.71
58	9.2730	9.4759	9.3790	9.3678	47.76	12.55	39.70
59	8.2107	8.3922	8.3064	8.2969	47.27	11.90	40.83
60	8.4825	8.7194	8.6039	8.5920	48.75	11.42	39.83
61	8.1837	8.400	8.3072	8.2862	42.90	22.07	35.03
62	7.7536	7.9173	7.8400	7.8272	47.22	17.77	35.01
63	8.5201	8.6771	8.5971	8.5894	50.96	11.15	37.90
64	8.6933	8.8641	8.7837	8.7760	47.07	10.25	42.68
65	8.4800	8.6756	8.6043	8.5904	36.45	16.15	47.40
66	8.3112	8.6323	8.5220	8.4956	34.35	18.69	46.96
67	8.3897	8.5828	8.4983	8.4810	43.76	20.36	35.88
68	9.0109	9.2171	9.1247	9.1084	44.81	17.97	37.22
69	8.5738	8.7460	8.6676	8.6547	45.53	17.03	37.45
70	8.9893	9.1950	9.0965	9.0829	47.89	15.03	37.09
71	8.2358	8.4613	8.3610	8.3448	44.48	16.33	39.19
72	8.4261	8.6660	8.5744	8.5535	38.18	19.80	42.02
73	8.3647	8.7057	8.5914	8.5528	33.52	25.73	40.75
74	8.4675	8.7014	8.6178	8.5947	35.74	22.45	41.81
75	8.5270	8.8018	8.7054	8.6808	35.08	20.35	44.57
76	8.2440	8.7043	8.5352	8.4974	36.74	18.66	44.60
77	8.3909	8.6824	8.5632	8.5413	40.89	17.07	42.03
78	8.3753	8.5913	8.5016	8.4845	41.53	17.99	40.48
79	8.2922	8.5130	8.4228	8.4010	40.85	22.44	36.71
80	8.3176	8.5247	8.4335	8.4144	44.04	20.96	35.00
81	8.6717	8.9390	8.8559	8.8301	31.09	21.94	46.97
82	8.5036	8.7975	8.7084	8.6842	30.32	18.71	50.97
83	8.5060	8.8931	8.7812	8.7474	28.91	19.84	51.25
84	8.8685	9.4120	9.2627	9.2145	27.47	20.16	52.37
85	8.4140	8.7764	8.6801	8.6438	26.57	22.76	50.66
86	8.4493	8.7626	8.6786	8.6504	26.81	20.46	52.73
87	7.9580	8.3984	8.2814	8.2428	26.57	19.92	53.51
88	8.3817	8.7976	8.6875	8.6500	26.47	20.49	53.04
89	8.5925	8.9956	8.8864	8.8496	27.09	20.75	52.16
90	8.2400	8.7712	8.6294	8.5776	26.69	22.16	51.14
91	8.2378	8.6623	8.5531	8.5017	25.72	27.52	46.76
92	8.3180	8.6269	8.5360	8.5065	29.43	21.70	48.87
93	7.8874	8.1831	8.0972	8.0715	29.05	19.75	51.20

Table E.4. LOI Results for Five Lakes (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
94	8.2310	8.5692	8.4801	8.4490	26.35	20.90	52.76
95	8.3600	8.6988	8.6062	8.5769	27.33	19.65	53.01
96	8.6060	8.9354	8.8482	8.8193	26.47	19.94	53.59
97	8.2261	8.6374	8.5318	8.4892	25.67	23.54	50.79
98	8.3846	8.6987	8.6121	8.5847	27.57	19.83	52.60
99	8.0117	8.2051	8.1483	8.1336	29.37	17.27	53.36
100	8.3703	8.6050	8.5367	8.5185	29.10	17.62	53.27
101	8.5205	8.7917	8.7134	8.6918	28.87	18.10	53.03
102	8.5516	8.8443	8.7620	8.7345	28.12	21.35	50.53
103	8.5137	8.7597	8.6933	8.6653	26.99	25.87	47.14
104	8.3628	8.5740	8.5162	8.4923	27.37	25.72	46.91
105	8.4674	8.6574	8.6015	8.5801	29.42	25.60	44.98
106	9.2741	9.4158	9.3546	9.3435	43.19	17.80	39.01
107	8.2104	8.3530	8.2890	8.2786	44.88	16.58	38.54
108	8.4836	8.6431	8.5770	8.5606	41.44	23.37	35.19
109	8.1841	8.2930	8.2512	8.2420	38.38	19.20	42.42
110	7.7540	7.9714	7.8922	7.8775	36.43	15.37	48.20
111	8.5205	8.7692	8.6920	8.6780	31.04	12.79	56.16
112	8.6940	8.9785	8.8877	8.8708	31.92	13.50	54.58
113	8.4797	8.6709	8.6026	8.5874	35.72	18.07	46.21
114	8.3118	8.4832	8.4182	8.4044	37.92	18.30	43.78
115	8.3900	8.6373	8.5544	8.5238	33.52	28.12	38.36
116	9.0127	9.2211	9.1526	9.1300	32.87	24.65	42.48
117	8.5750	8.7896	8.7127	8.6925	35.83	21.39	42.77
118	8.9902	9.2058	9.1261	9.1071	36.97	20.03	43.00
119	8.2365	8.4583	8.3759	8.3559	37.15	20.49	42.36
120	8.4275	8.7686	8.6364	8.6063	38.76	20.06	41.19
121	8.3664	8.6286	8.5223	8.4945	40.54	24.10	35.36
122	8.4695	8.7740	8.6572	8.6292	38.36	20.90	40.74
123	8.5283	8.7600	8.6743	8.6558	36.99	18.15	44.87
124	8.2454	8.6207	8.5070	8.4789	30.30	17.02	52.69
125	8.3927	8.7222	8.6262	8.6033	29.14	15.80	55.07
126	8.3765	8.7524	8.6464	8.6189	28.20	16.63	55.17
127	8.2930	8.5872	8.5070	8.4759	27.26	24.03	48.71
128	8.3184	8.6832	8.5787	8.5515	28.65	16.95	54.41
129	8.6718	9.0672	8.9528	8.9242	28.93	16.44	54.63
130	8.5045	8.8551	8.7498	8.7244	30.03	16.47	53.50
131	8.5073	8.7952	8.7059	8.6860	31.02	15.71	53.27
132	8.8706	9.1571	9.0686	9.0480	30.89	16.34	52.77
133	8.4152	8.8119	8.7036	8.6676	27.30	20.62	52.08
134	8.4500	8.7516	8.6668	8.6405	28.12	19.82	52.06
135	7.9590	8.3356	8.2330	8.1998	27.24	20.04	52.72

Table E.4. LOI Results for Five Lakes (cont.)

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
136	8.3829	8.7017	8.6155	8.5877	27.04	19.82	53.14
137	8.5938	8.8799	8.7914	8.7625	30.93	22.96	46.11
138	8.2413	8.6498	8.5210	8.4739	31.53	26.20	42.27
139	8.2390	8.6135	8.4950	8.4518	31.64	26.22	42.14
140	8.3189	8.6196	8.5224	8.4916	32.32	23.28	44.40
141	7.8887	8.2370	8.1289	8.0944	31.04	22.51	46.45
142	8.2743	8.5305	8.4459	8.4300	33.05	14.11	52.85
143	8.3603	8.7167	8.6085	8.5633	30.36	28.82	40.82
144	8.6074	8.9652	8.8543	8.8094	30.99	28.52	40.48
145	8.2835	8.8212	8.6503	8.5813	31.78	29.16	39.05

*% Other = 100-%organics-%carbonates = the index of terrigenous input

Table E.5. LOI Results for Hidden Lake

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
0.5	8.1061	8.3113	8.2612	8.2447	24.42	18.27	57.31
1.5	8.8621	9.2799	9.2072	9.1828	17.40	13.27	69.33
2.5	8.4087	8.9551	8.8807	8.8584	13.62	9.28	77.11
3.5	8.7523	9.4400	9.3549	9.3266	12.37	9.35	78.27
4.5	8.2847	8.8583	8.7946	8.7709	11.11	9.39	79.50
5.5	8.3102	9.3628	9.2704	9.2449	8.78	5.51	85.72
6.5	8.4755	8.7668	8.6477	8.6304	40.89	13.50	45.62
7.5	8.2332	8.4871	8.3960	8.3824	35.88	12.17	51.95
8.5	8.3007	8.5836	8.4616	8.4477	43.12	11.17	45.71
9.6	8.3774	8.7611	8.6269	8.6050	34.98	12.97	52.05
10.5	8.0043	8.7675	8.6893	8.6670	10.25	6.64	83.11
11.5	8.2020	8.7100	8.6503	8.6316	11.75	8.37	79.88
12.5	8.2240	8.4982	8.3971	8.3757	36.87	17.74	45.39
13.5	8.5000	8.9524	8.8297	8.7935	27.12	18.19	54.69
14.5	8.6614	9.1866	9.1120	9.0765	14.20	15.36	70.43
25.0	8.0445	8.6108	8.5435	8.4574	11.88	34.55	53.56
50.0	7.8560	8.8880	8.7897	8.6351	9.53	34.05	56.43
56.0	8.4111	9.4906	9.3850	9.2308	9.78	32.46	57.75

*% Other = 100-%organics-%carbonates = the index of terrigenous input

Table E.6. LOI Results for Rinker's Lake

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
55	9.2222	11.1241	11.0246	10.827	5.23	23.61	71.15

*% Other = 100-%organics-%carbonates = the index of terrigenous input

Table E.7. LOI Results for Murphy Lake

Depth (cm bi)	Weight of Crucible (g)	Weight of Crucible & Dry Sediment (g)	Weight of Crucible & Sediment after 550 °C Burn (g)	Weight of Crucible & Sediment after 1,000 °C Burn (g)	% Organics	% Carbonates	% Other*
21	8.0250	9.9610	9.7264	9.4858	12.12	28.24	59.64
41	8.2540	8.8965	8.7800	8.7130	18.13	23.70	58.17

*% Other = 100-%organics-%carbonates = the index of terrigenous input

Appendix F. Oxygen Isotope Results

Table F.1. Isotope Sample Description and Results from Hidden and Rinker's Lakes

Lake	Depth (cm bi)	Age B.P.	Dry weight (g)	$\delta^{13}C$ reported by lab (‰)	$\delta^{18}O$ reported by lab (‰)
Hidden	0	0	0.2	-0.98	-5.00
Hidden	5	100	1.0	-1.08	-4.70
Hidden	20	200	0.5	-0.82	-4.69
Hidden	15	300	0.8	-0.91	-4.92
Hidden	20	400	0.6	-0.93	-4.59
Hidden	25	500	0.7	-0.82	-4.65
Hidden	30	600	0.7	-0.76	-4.96
Hidden	35	700	0.8	-0.90	-4.52
Hidden	40	800	0.5	-0.65	-3.90
Hidden	45	900	0.6	-0.92	-4.04
Hidden	50	1,000	1.7	-0.75	-3.94
Rinker's	0	0	0.4	-1.53	-9.87
Rinker's	5	157	0.6	-1.41	-8.47
Rinker's	20	313	0.5	-1.26	-6.46
Rinker's	15	470	0.5	-1.51	-6.71
Rinker's	20	626	0.7	-1.01	-8.61
Rinker's	25	783	0.9	-1.03	-8.24
Rinker's	30	939	1.1	-0.57	-6.79
Rinker's	35	1,096	1.0	-0.68	-6.75
Rinker's	40	1,252	1.2	-0.96	-7.47
Rinker's	45	1,409	1.6	-1.06	-7.06
Rinker's	50	1,570	1.1	-1.37	-7.13

Table F.2. Isotope Sample Description and Results For Rebecca Lake

Depth (cm bi)	Dry weight (g)	$\delta^{13}C$ reported by lab (‰)	$\delta^{18}O$ reported by lab (‰)	$\delta^{15}N$ reported by lab (‰)
60	0.4	-26.06	-17.96	1.60
80	0.4	NA	NA	2.24
100	0.4	NA	NA	3.03
120	0.4	NA	NA	3.27
140	0.4	-26.23	-17.56	1.93
160	0.4	-26.65	-17.07	1.56
180	0.4	NA	NA	0.90
200	0.4	-25.76	-17.98	2.32
220	0.4	-26.10	-19.30	2.00
240	0.4	-26.80	-19.42	2.51
260	0.4	-27.38	-18.47	2.15
280	0.4	-27.24	-10.03	1.90
300	0.4	NA	NA	1.55
320	0.5	-2.44	-7.77	1.58
340	0.5	-4.82	-9.45	1.90
360	0.4	NA	NA	2.19
380	0.4	-2.44	-10.40	1.56
400	0.4	-7.36	-12.09	1.71
420	0.4	-2.76	-10.28	2.00
440	0.4	-4.71	-11.15	1.42
460	0.4	-6.66	-11.66	1.88
480	0.5	NA	NA	1.97
500	0.4	NA	NA	2.14

"NA" indicates insufficient CO2 yield from sample for analysis/measurement by lab

Table F.3. Interpolated Oxygen Isotope Values for each 50-year Study Interval (from Rinker's and Hidden Lakes)

Date cal A.D.	Hidden Lake Interpolated $\delta^{18}O$	Rinker's Lake Interpolated $\delta^{18}O$	z-score for Hidden Lake Isotope Values	z-score for Rinker's Lake Isotope Values	Composite Isotope Index*
1900	-4.70	-8.98	-0.58	-1.88	-1.23
1850	-4.70	-8.45	-0.58	-1.20	-0.89
1800	-4.70	-7.92	-0.58	-0.51	-0.55
1750	-4.80	-7.28	-0.84	0.33	-0.25
1700	-4.90	-6.63	-1.09	1.17	0.04
1650	-4.75	-6.62	-0.71	1.19	0.24
1600	-4.60	-6.60	-0.33	1.21	0.44
1550	-4.65	-6.84	-0.46	0.89	0.22
1500	-4.70	-7.08	-0.58	0.58	0.00
1450	-4.85	-7.69	-0.96	-0.20	-0.58
1400	-5.00	-8.29	-1.34	-0.99	-1.16
1350	-4.75	-8.37	-0.71	-1.08	-0.90
1300	-4.50	-8.44	-0.08	-1.18	-0.63
1250	-4.20	-8.26	0.67	-0.95	-0.14
1200	-3.90	-8.08	1.43	-0.71	0.36
1150	-3.95	-7.62	1.30	-0.11	0.59
110	-4.00	-7.15	1.18	0.49	0.83
1050	-3.95	-6.96	1.30	0.74	1.02
1000	-3.90	-6.77	1.43	0.99	1.21
950	-3.85	-6.58	1.55	1.23	1.39
	$\bar{x} = -4.47$	$\bar{x} = -7.53$			
	$s_x = 0.40$	$s_x = 0.77$			

Appendix G. Pollen Data From Five Lakes

Table G.1. Raw Counts of Arboreal Pollen Grains from Five Lakes

Depth cm bl	*Lycopodium* (introduced)	*Pinus* undiff.	*Pinus* haploxylon	*Pinus* diploxylon	*Pinus* half* undiff.	*Larix/ Pseudotsuga*	*Acer*	*Betula*	*Alnus*	*Tsuga*	*Abies*	*Abies* half*	*Picea*	*Picea* Half*	*Quercus*
0.00	1,220	175	0	11	223	0	0	13	10	10	1	0	4	1	7
5.00	316	173	6	67	186	0	0	34	26	6	0	0	3	6	5
10.00	160	106	20	37	103	2	2	39	30	2	4	1	7	4	5
15.00	475	238	30	35	229	0	2	18	26	6	5	0	8	4	1
20.00	135	116	44	51	70	2	2	26	21	12	4	0	4	1	8
25.00	524	147	43	28	126	0	1	36	15	8	3	0	7	0	7
30.00	189	149	37	71	115	6	8	18	12	4	2	0	9	2	6
35.00	316	314	11	40	120	2	6	24	20	4	1	0	14	0	5
40.00	223	273	3	30	129	2	3	11	6	4	2	0	6	3	3
45.00	498	314	3	36	157	0	1	19	19	6	0	0	5	3	1
50.00	1,238	271	3	43	186	0	2	6	14	4	0	0	3	2	1
55.00	884	268	2	19	59	0	1	3	14	9	4	0	5	1	0
60.00	728	518	0	21	206	0	1	3	13	7	1	0	7	1	0
65.00	749	312	7	35	256	2	0	6	15	10	0	0	8	5	1
70.00	420	421	3	54	88	0	0	7	18	6	7	0	10	0	0
75.00	413	226	0	9	259	0	1	3	3	5	1	0	8	8	0
80.00	213	248	3	52	195	0	0	1	10	8	0	0	9	4	1
85.00	157	250	7	47	219	0	0	1	3	7	1	0	12	1	1
90.00	234	333	1	44	223	2	0	7	18	10	1	0	13	1	1
95.00	119	192	6	51	181	0	0	4	10	3	0	0	8	6	1
100.00	187	388	1	36	276	0	1	15	19	6	1	0	15	4	0
105.00	516	315	4	54	202	0	0	8	16	12	1	0	8	1	2
110.00	439	306	2	81	150	0	1	7	13	9	2	0	12	2	1
115.00	333	238	3	36	207	0	2	15	15	11	0	0	14	9	0
120.00	569	325	0	20	239	0	3	10	11	9	0	0	11	11	1
125.00	235	240	3	38	208	2	2	11	12	9	6	1	9	8	2
130.00	440	281	0	8	288	0	1	5	17	9	0	0	7	3	2
135.00	272	292	0	13	297	0	1	5	11	8	0	0	14	2	2
140.00	255	297	1	44	176	0	0	1	8	11	4	1	9	5	2
145.00	369	301	0	19	239	0	1	2	5	9	1	0	6	1	0

*Note: grains counted are whole grains except where labeled as "half"

Table G.2. Raw Counts of NonArboreal Pollen Grains from Five Lakes

Depth cm bi	Poaceae	*Artemesia*-type	*Ambrosia*-type	*Aster*-type	Liguliflorae-type	Polygonaceae	Umbelliferae
0.00	15	14	11	8	0	2	2
5.00	38	78	6	15	0	1	0
10.00	65	73	10	12	1	4	2
15.00	38	59	9	15	3	0	0
20.00	36	35	13	8	0	1	0
25.00	28	47	8	8	1	1	1
30.00	46	37	18	19	1	0	3
35.00	44	53	13	25	0	0	0
40.00	26	56	9	22	0	0	3
45.00	35	31	7	5	1	0	0
50.00	31	30	2	3	0	0	2
55.00	47	32	1	4	0	1	0
60.00	18	10	9	1	0	0	0
65.00	30	15	0	3	0	0	0
70.00	24	26	2	7	1	0	0
75.00	10	8	1	0	0	0	0
80.00	15	11	0	2	0	0	1
85.00	12	10	0	0	1	0	0
90.00	28	8	2	1	0	0	0
95.00	26	11	2	0	0	0	0
100.00	33	18	4	0	0	0	0
105.00	28	14	0	4	1	0	0
110.00	21	21	0	3	0	0	0
115.00	41	18	1	0	0	0	0
120.00	25	28	3	2	1	0	0
125.00	27	19	3	6	0	0	0
130.00	14	11	3	3	0	0	0
135.00	26	17	1	1	0	0	0
140.00	24	10	0	0	0	0	0
145.00	5	8	2	2	0	0	0

Table G.3. Raw Counts of Unidentified/Unidentifiable Pollen Grains (not included in pollen sums) from Five Lakes

Depth cm bi	Crumpled	Hidden	Corroded	Degraded	Broken	Unknown	Bacculate Inapeturate Unknown	Scabrate Inapeturate unknown	Psilate Tri-porate Unknown	Stephanoporate Annulate Unknown
0.00	4	2	5	23	1	1	0	6	0	1
5.00	1	1	0	18	0	0	0	1	0	1
10.00	5	3	2	18	0	3	0	10	0	0
15.00	1	1	1	12	0	2	0	5	0	0
20.00	3	4	2	12	1	1	0	3	3	0
25.00	7	2	1	19	0	0	0	3	0	0
30.00	5	1	2	31	0	2	0	20	0	0
35.00	2	0	0	30	0	2	0	4	0	2
40.00	5	0	0	22	0	2	0	2	0	1
45.00	2	1	0	14	0	0	0	15	0	0
50.00	0	1	0	11	0	0	0	1	0	1
55.00	2	0	0	9	0	0	0	3	0	7
60.00	0	0	0	1	0	0	0	0	0	2
65.00	0	0	1	5	0	0	0	0	0	2
70.00	0	0	1	2	0	0	0	9	0	4
75.00	0	0	0	3	0	1	0	1	0	0
80.00	0	1	1	4	0	0	0	2	0	0
85.00	1	0	0	0	0	0	0	0	0	2
90.00	0	0	0	0	0	0	0	2	0	1
95.00	0	0	0	3	0	1	0	2	0	0
100.00	0	0	0	1	0	0	0	4	0	0
105.00	0	2	0	1	0	1	0	0	0	4
110.00	0	1	0	1	0	0	0	1	0	2
115.00	0	0	0	2	0	0	0	2	0	2
120.00	0	0	0	7	0	0	0	0	0	1
125.00	0	0	0	8	0	0	0	1	0	1
130.00	0	0	0	1	0	1	0	5	0	1
135.00	0	0	0	1	0	0	0	0	0	0
140.00	0	0	0	0	0	1	0	0	0	4
145.00	0	0	0	0	0	0	0	0	0	0

Table G.4. Raw Counts of Aquatics (not included in pollen sums) from Five Lakes

Depth (cm b.l.)	*Lycopodium* Aliquot	Years B.P. (uncalibrated ^{14}C years before present)	*Carex*	*Typha*	*Pediastrum*	*Ruppia*	Cupressaceae
0.00	1,220	0	11	0	0	1	0
5.00	316	58	6	0	4	5	0
10.00	233	116	17	0	1	3	2
15.00	475	174	9	10	0	3	2
20.00	135	232	5	0	1	7	0
25.00	524	290	16	0	1	4	0
30.00	189	348	14	0	0	0	0
35.00	316	406	10	6	1	2	0
40.00	223	464	8	0	2	0	0
45.00	498	522	23	1	2	0	0
50.00	1,238	580	17	0	1	0	0
55.00	884	628	18	0	0	0	0
60.00	420	676	21	12	26	0	0
65.00	749	724	14	4	26	2	0
70.00	728	772	1	3	5	0	0
75.00	413	820	4	5	30	0	0
80.00	147	866	3	0	15	0	0
85.00	157	912	18	4	47	0	0
90.00	234	958	9	0	163	1	0
95.00	119	1,004	26	0	79	0	0
100.00	187	1,050	26	5	75	0	0
105.00	516	1,105	12	4	68	0	0
110.00	439	1,160	21	20	850	0	0
115.00	333	1,215	10	0	62	5	0
120.00	569	1,270	13	0	94	1	0
125.00	235	1,325	25	4	185	2	0
130.00	440	1,378	9	5	86	5	0
135.00	272	1,431	4	4	68	4	0
140.00	255	1,484	29	10	719	1	0
145.00	369	1,537	1	4	166	0	0

Table G.5. Percent of Arboreal Taxa in Samples from Five Lakes

Depth (cm bi)	*Pinus*	*Larix/ Pseudotsuga*	*Acer*	*Betula*	*Alnus*	*Tsuga*	*Abies*	*Picea*	*Quercus*
0.00	71.17	0.00	0.00	3.11	2.39	2.39	0.24	1.08	1.67
5.00	53.80	0.00	0.00	6.54	5.00	1.15	0.00	1.15	0.96
10.00	42.48	0.40	0.40	7.72	5.94	0.40	0.89	1.39	0.99
15.00	65.80	0.00	0.32	2.84	4.10	0.95	0.79	1.58	0.16
20.00	54.97	0.45	0.45	5.81	4.69	2.68	0.89	1.01	1.79
25.00	58.66	0.00	0.21	7.52	3.13	1.67	0.63	1.46	1.46
30.00	57.17	1.09	1.45	3.27	2.18	0.73	0.36	1.81	1.09
35.00	62.13	0.29	0.88	3.51	2.92	0.58	0.15	2.05	0.73
40.00	69.64	0.38	0.56	2.07	1.13	0.75	0.38	1.41	0.56
45.00	75.04	0.00	0.17	3.30	3.30	1.04	0.00	1.13	0.17
50.00	79.77	0.00	0.39	1.17	2.72	0.78	0.00	0.78	0.19
55.00	71.73	0.00	0.23	0.68	3.15	2.03	0.90	1.24	0.00
60.00	89.85	0.00	0.14	0.42	1.82	0.98	0.14	1.05	0.00
65.00	82.89	0.34	0.00	1.03	2.58	1.72	0.00	1.81	0.17
70.00	82.20	0.00	0.00	1.10	2.83	0.94	1.10	1.57	0.00
75.00	89.01	0.00	0.24	0.73	0.73	1.22	0.24	2.93	0.00
80.00	85.85	0.00	0.00	0.21	2.14	1.71	0.00	2.36	0.21
85.00	87.34	0.00	0.00	0.21	0.63	1.48	0.21	2.74	0.21
90.00	82.13	0.34	0.00	1.17	3.02	1.68	0.17	2.27	0.17
95.00	80.19	0.00	0.00	0.94	2.36	0.71	0.00	2.59	0.24
100.00	80.77	0.00	0.14	2.15	2.73	0.86	0.14	2.44	0.00
105.00	82.65	0.00	0.00	1.39	2.79	2.09	0.17	1.48	0.35
110.00	79.11	0.00	0.17	1.19	2.22	1.53	0.34	2.13	0.17
115.00	74.75	0.00	0.39	2.95	2.95	2.16	0.00	3.63	0.00
120.00	80.22	0.00	0.52	1.73	1.90	1.55	0.00	2.85	0.17
125.00	76.24	0.40	0.40	2.18	2.38	1.78	1.39	2.57	0.40
130.00	84.16	0.00	0.19	0.97	3.30	1.75	0.00	1.65	0.39
135.00	83.29	0.00	0.18	0.92	2.02	1.47	0.00	2.57	0.37
140.00	84.65	0.00	0.00	0.20	1.57	2.17	0.89	2.26	0.39
145.00	90.06	0.00	0.20	0.41	1.02	1.84	0.20	1.33	0.00

Table G.6. Percent of Non-arboreal Taxa in Samples from Five Lakes

Depth (cm bi)	Chenopodiaceae	Poaceae	*Artemesia*-type	*Ambrosia*-type	Polygonaceae	Umbelliferae	Other Composites (Other Asteraceae*)	Pollen Sum**
0.00	5.50	3.59	3.35	2.63	0.48	0.48	4.55	4.55
5.00	4.81	7.31	15.01	1.15	0.19	0.00	4.04	4.04
10.00	6.34	12.87	14.46	1.98	0.79	0.40	4.55	4.55
15.00	3.94	5.99	9.30	1.42	0.00	0.00	4.26	4.26
20.00	6.48	8.04	7.82	2.91	0.22	0.00	4.69	4.69
25.00	5.64	5.85	9.81	1.67	0.21	0.21	3.55	3.55
30.00	8.35	8.35	6.72	3.27	0.00	0.54	6.90	6.90
35.00	7.02	6.43	7.75	1.90	0.00	0.00	5.56	5.56
40.00	1.32	4.89	10.53	1.69	0.00	0.56	5.83	5.83
45.00	2.09	6.09	5.39	1.22	0.00	0.00	2.26	2.26
50.00	0.97	6.03	5.84	0.39	0.00	0.39	0.97	0.97
55.00	0.90	10.59	7.21	0.23	0.23	0.00	1.13	1.13
60.00	0.28	2.52	1.40	1.26	0.00	0.00	1.40	1.40
65.00	1.20	5.16	2.58	0.00	0.00	0.00	0.52	0.52
70.00	0.79	3.78	4.09	0.31	0.00	0.00	1.57	1.57
75.00	0.24	2.44	1.95	0.24	0.00	0.00	0.24	0.24
80.00	1.29	3.22	2.36	0.00	0.00	0.21	0.43	0.43
85.00	2.32	2.53	2.11	0.00	0.00	0.00	0.21	0.21
90.00	2.52	4.70	1.34	0.34	0.00	0.00	0.50	0.50
95.00	3.77	6.13	2.59	0.47	0.00	0.00	0.47	0.47
100.00	2.87	4.73	2.58	0.57	0.00	0.00	0.57	0.57
105.00	0.87	4.88	2.44	0.00	0.00	0.00	0.87	0.87
110.00	5.46	3.58	3.58	0.00	0.00	0.00	0.51	0.51
115.00	1.38	8.06	3.54	0.20	0.00	0.00	0.20	0.20
120.00	0.86	4.32	4.84	0.52	0.00	0.00	1.04	1.04
125.00	1.39	5.35	3.76	0.59	0.00	0.00	1.78	1.78
130.00	1.55	2.72	2.14	0.58	0.00	0.00	1.17	1.17
135.00	0.92	4.78	3.12	0.18	0.00	0.00	0.37	0.37
140.00	1.18	4.72	1.97	0.00	0.00	0.00	0.00	0.00
145.00	1.43	1.02	1.64	0.41	0.00	0.00	0.82	0.82

*Liguliflorae-type and *Aster*-type

**Pollen Sum is the total counts of all terrestrial pollen (AP and NAP)

Table G.7. Percent of Aquatic Taxa* in Samples from Five Lakes

Depth (cm bi)	*% Aquatics*	*% Typha*	*%Pediastrum*	*% Ruppia*	% Cupressaceae
0.00	2.79	0.00	0.00	0.23	2.56
5.00	2.83	0.00	0.77	0.94	1.12
10.00	4.00	0.00	0.20	0.57	3.23
15.00	3.35	1.52	0.00	0.46	1.37
20.00	2.83	0.00	0.22	1.52	1.09
25.00	4.21	0.00	0.21	0.80	3.20
30.00	2.48	0.00	0.00	0.00	2.48
35.00	2.71	0.85	0.15	0.28	1.42
40.00	1.85	0.00	0.38	0.00	1.48
45.00	4.34	0.17	0.35	0.00	3.83
50.00	3.39	0.00	0.19	0.00	3.20
55.00	3.90	0.00	0.00	0.00	3.90
60.00	1.25	0.41	0.70	0.00	0.14
65.00	7.66	0.64	4.47	0.32	2.23
70.00	8.85	1.73	4.09	0.00	3.03
75.00	9.55	1.11	7.33	0.00	1.11
80.00	5.73	0.00	4.72	0.00	1.01
85.00	13.97	0.74	9.92	0.00	3.31
90.00	28.65	0.00	27.35	0.13	1.17
95.00	23.55	0.00	18.63	0.00	4.91
100.00	14.50	0.50	10.76	0.00	3.24
105.00	14.29	0.61	11.86	0.00	1.83
110.00	147.70	1.35	144.93	0.00	1.42
115.00	14.74	0.00	12.18	0.85	1.71
120.00	18.27	0.00	16.23	0.15	1.89
125.00	40.93	0.55	36.63	0.28	3.47
130.00	19.78	0.81	16.72	0.81	1.45
135.00	14.41	0.64	12.49	0.64	0.64
140.00	144.69	0.79	141.54	0.08	2.29
145.00	34.78	0.61	34.02	0.00	0.15

*in keeping with established palynological protocols, % aquatics are calculated by taking the count for each aquatic taxon, dividing it by the terrestrial pollen sum, and multiplying by 100.

Table G.8. Absolute Influx (# of pollen grains per year) for Arboreal Taxa in Samples from Five Lakes

Depth (cm b.l.)	*Pinus*	*Larix*/ *Pseudotsuga*	*Acer*	*Betula*	*Alnus*	*Tsuga*	*Abies*	*Picea*	*Quercus*
0.00	527.31	0.00	0.00	23.04	17.72	17.72	1.77	7.98	12.41
5.00	1,912.64	0.00	0.00	232.66	177.92	41.06	0.00	41.06	34.22
10.00	1,990.72	18.56	18.56	361.95	278.42	18.56	41.76	64.97	46.40
15.00	1,900.65	0.00	9.10	81.94	118.36	27.31	22.76	45.52	4.55
20.00	3,940.40	32.04	32.04	416.46	336.38	192.21	64.07	72.08	128.14
25.00	1,159.62	0.00	4.13	148.56	61.90	33.01	12.38	28.89	28.89
30.00	3,604.02	68.65	91.53	205.94	137.30	45.77	22.88	114.41	68.65
35.00	2,908.31	13.69	41.06	164.23	136.86	27.37	6.84	95.80	34.22
40.00	3,592.71	19.39	29.09	106.67	58.18	38.79	19.39	72.73	29.09
45.00	1,873.66	0.00	4.34	82.50	82.50	26.05	0.00	28.22	4.34
50.00	716.15	0.00	3.49	10.48	24.45	6.99	0.00	6.99	1.75
55.00	941.42	0.00	2.45	7.34	34.25	22.02	9.78	13.45	0.00
60.00	2,304.25	0.00	2.97	8.91	38.61	20.79	2.97	22.28	0.00
65.00	1,681.48	5.77	0.00	17.32	43.31	28.87	0.00	30.31	2.89
70.00	3,247.48	0.00	0.00	36.04	92.67	30.89	36.04	51.49	0.00
75.00	2,306.07	0.00	5.24	15.71	15.71	26.18	5.24	62.83	0.00
80.00	5,126.63	0.00	0.00	10.15	101.52	81.22	0.00	111.67	10.15
85.00	7,189.68	0.00	0.00	13.77	41.32	96.41	13.77	179.05	13.77
90.00	5,703.56	18.48	0.00	64.69	166.34	92.41	9.24	124.75	9.24
95.00	7,790.06	0.00	0.00	72.69	181.72	54.51	0.00	199.89	18.17
100.00	8,208.73	0.00	11.56	173.46	219.71	69.38	11.56	196.58	0.00
105.00	2,094.75	0.00	0.00	33.53	67.05	50.29	4.19	35.62	8.38
110.00	2,410.22	0.00	4.93	34.48	64.04	44.33	9.85	61.57	4.93
115.00	2,605.64	0.00	12.99	97.41	97.41	71.43	0.00	120.13	0.00
120.00	1,861.56	0.00	11.40	38.00	41.80	34.20	0.00	62.71	3.80
125.00	3,735.91	18.40	18.40	101.22	110.42	82.82	64.41	119.62	18.40
130.00	2,244.09	0.00	4.91	24.57	83.55	44.23	0.00	41.77	9.83
135.00	3,802.00	0.00	7.95	39.75	87.45	63.60	0.00	111.30	15.90
140.00	3,845.32	0.00	0.00	8.48	67.84	93.28	38.16	97.52	16.96
145.00	2,716.04	0.00	5.86	11.72	29.30	52.74	5.86	38.09	0.00

Table G.9. Absolute Influx (# of pollen grains per year) for Nonarboreal Taxa in Samples from Five Lakes

Depth (cm bi)	Chenopodiaceae	Poaceae	*Artemesia*-type	*Ambrosia*-type	*Polygonum*	Umbelliferae	Other Composites (Other Asteraceae)
0.00	40.77	26.59	24.81	19.50	3.54	3.54	33.68
5.00	171.08	260.04	533.76	41.06	6.84	0.00	143.70
10.00	296.98	603.25	677.49	92.81	37.12	18.56	213.46
15.00	113.81	172.99	268.59	40.97	0.00	0.00	122.92
20.00	464.52	576.64	560.63	208.23	16.02	0.00	336.38
25.00	111.42	115.55	193.96	33.01	4.13	4.13	70.15
30.00	526.30	526.30	423.33	205.94	0.00	34.32	434.77
35.00	328.47	301.10	362.68	88.96	0.00	0.00	260.04
40.00	67.88	252.12	543.03	87.27	0.00	29.09	300.60
45.00	52.11	151.98	134.61	30.40	0.00	0.00	56.45
50.00	8.73	54.15	52.40	3.49	0.00	3.49	8.73
55.00	9.78	114.97	78.28	2.45	2.45	0.00	12.23
60.00	5.94	53.47	29.70	26.73	0.00	0.00	29.70
65.00	20.21	86.61	43.31	0.00	0.00	0.00	8.66
70.00	25.74	123.57	133.86	10.30	0.00	0.00	51.49
75.00	5.24	52.36	41.89	5.24	0.00	0.00	5.24
80.00	60.91	152.28	111.67	0.00	0.00	10.15	20.30
85.00	151.51	165.28	137.73	0.00	0.00	0.00	13.77
90.00	138.62	258.75	73.93	18.48	0.00	0.00	27.72
95.00	290.74	472.46	199.89	36.34	0.00	0.00	36.34
100.00	231.27	381.60	208.15	46.25	0.00	0.00	46.25
105.00	20.95	117.34	58.67	0.00	0.00	0.00	20.95
110.00	157.62	103.44	103.44	0.00	0.00	0.00	14.78
115.00	45.46	266.24	116.89	6.49	0.00	0.00	6.49
120.00	19.00	95.01	106.41	11.40	0.00	0.00	22.80
125.00	64.41	248.45	174.83	27.61	0.00	0.00	82.82
130.00	39.32	68.80	54.06	14.74	0.00	0.00	29.49
135.00	39.75	206.70	135.15	7.95	0.00	0.00	15.90
140.00	50.88	203.52	84.80	0.00	0.00	0.00	0.00
145.00	41.02	29.30	46.88	11.72	0.00	0.00	23.44

Appendix H. Charcoal Data From Five Lakes

Table H.1. Counts of Charcoal Particles for Three Size Classes

Depth (cm bi)	Approximate Age (^{14}C yr B.P.)*	# *Lycopodium* Spores (aliquot/standard)	# Charcoal Particles $\leq$ 75 µm Diameter	# Charcoal Particles between 75 and 125 µm Diameter	# Charcoal Particles $\leq$ 250 µm Diameter
0.00	0	1,220	116	11	0
5.00	58	316	17	0	0
10.00	116	160	7	3	0
15.00	174	475	13	0	0
20.00	232	135	21	1	0
25.00	290	524	70	2	0
30.00	348	189	58	5	0
35.00	406	316	31	2	0
40.00	464	223	50	1	0
45.00	522	498	65	11	0
50.00	580	1,238	63	12	0
55.00	628	884	61	19	1
60.00	676	728	44	12	0
65.00	724	749	52	16	0
70.00	772	420	46	17	3
75.00	820	413	36	7	0
80.00	866	213	83	11	2
85.00	912	157	79	5	0
90.00	958	234	83	15	1
95.00	1,004	119	91	17	1
100.00	1,050	187	60	6	1
105.00	1,105	516	85	16	1
110.00	1,160	439	73	23	2
115.00	1,215	333	79	24	1
120.00	1,270	569	121	39	2
125.00	1,325	235	134	32	2
130.00	1,378	440	30	14	0
135.00	1,431	272	27	3	0
140.00	1,484	255	41	22	0
145.00	1,537	369	48	21	4

*determined via linear interpolation from AMS dates reported in Table 5.1

Table H.2. Absolute Influx of Charcoal Particles in #/cm^2/yr

Depth (cm bi)	Approximate Age (^{14}C yr BP)*	Charcoal Particle Influx (all diameters)	Charcoal Particle Influx ≤ 75 µm Diameter	Charcoal Particle Influx between 75 and 125 µm Diameter	Charcoal Particle Influx ≤ 250 µm Diameter
0.00	0	225.10	205.61	19.50	0.00
5.00	58	30.13	30.13	0.00	0.00
10.00	116	17.72	12.41	5.32	0.00
15.00	174	23.04	23.04	0.00	0.00
20.00	232	38.99	37.22	1.77	0.00
25.00	290	127.62	124.07	3.54	0.00
30.00	348	111.67	102.80	8.86	0.00
35.00	406	58.49	54.95	3.54	0.00
40.00	464	90.40	88.62	1.77	0.00
45.00	522	134.71	115.21	19.50	0.00
50.00	580	132.94	111.67	21.27	0.00
55.00	628	143.57	108.12	33.68	1.77
60.00	676	99.26	77.99	21.27	0.00
65.00	724	120.53	92.17	28.36	0.00
70.00	772	116.98	81.53	30.13	5.32
75.00	820	76.22	63.81	12.41	0.00
80.00	866	170.16	147.12	19.50	3.54
85.00	912	148.89	140.03	8.86	0.00
90.00	958	175.47	147.12	26.59	1.77
95.00	1,004	193.20	161.29	30.13	1.77
100.00	1,050	118.76	106.35	10.63	1.77
105.00	1,105	180.79	150.66	28.36	1.77
110.00	1,160	173.70	129.39	40.77	3.54
115.00	1,215	184.34	140.03	42.54	1.77
120.00	1,270	287.14	214.47	69.13	3.54
125.00	1,325	297.78	237.51	56.72	3.54
130.00	1,378	77.99	53.17	24.81	0.00
135.00	1,431	53.17	47.86	5.32	0.00
140.00	1,484	111.67	72.67	38.99	0.00
145.00	1,537	129.39	85.08	37.22	7.09

*determined via linear interpolation from AMS dates reported in Table 5.1

Table H.3. Absolute Influx of Charcoal Particles in mm^2/cm^2/year

Depth (cm bi)	Approximate Age (^{14}C yr BP)*	Charcoal Particle Influx (all diameters)	Charcoal Particle Influx ≤ 75 µm Diameter	Charcoal Particle Influx between 75 and 125 µm Diameter	Charcoal Particle Influx ≤ 250 µm Diameter
0.00	0	2.74	2.06	0.69	0.00
5.00	58	0.30	0.30	0.00	0.00
10.00	116	0.31	0.12	0.19	0.00
15.00	174	0.23	0.23	0.00	0.00
20.00	232	0.43	0.37	0.06	0.00
25.00	290	1.37	1.24	0.12	0.00
30.00	348	1.34	1.03	0.31	0.00
35.00	406	0.67	0.55	0.12	0.00
40.00	464	0.95	0.89	0.06	0.00
45.00	522	1.84	1.15	0.69	0.00
50.00	580	1.86	1.12	0.75	0.00
55.00	628	2.51	1.08	1.18	0.25
60.00	676	1.53	0.78	0.75	0.00
65.00	724	1.92	0.92	1.00	0.00
70.00	772	2.62	0.82	1.06	0.75
75.00	820	1.07	0.64	0.44	0.00
80.00	866	2.66	1.47	0.69	0.50
85.00	912	1.71	1.40	0.31	0.00
90.00	958	2.66	1.47	0.93	0.25
95.00	1,004	2.92	1.61	1.06	0.25
100.00	1,050	1.69	1.06	0.37	0.25
105.00	1,105	2.75	1.51	1.00	0.25
110.00	1,160	3.23	1.29	1.43	0.50
115.00	1,215	3.15	1.40	1.50	0.25
120.00	1,270	5.07	2.14	2.43	0.50
125.00	1,325	4.87	2.38	1.99	0.50
130.00	1,378	1.40	0.53	0.87	0.00
135.00	1,431	0.67	0.48	0.19	0.00
140.00	1,484	2.10	0.73	1.37	0.00
145.00	1,537	3.16	0.85	1.31	1.00

*determined via linear interpolation from AMS dates reported in Table 5.1

Appendix I. Proxies Taken at 50 cal-year Intervals From cal A.D. 950 to 1900

Table I.1. Variables used in Correlations and Time Series Analysis:
Composite Isotope Index, Human Population Index, Charcoal, and Nonarboreal Pollen reported at 50 year intervals

Date A.D.	Oxygen Isotope Index	Human Population Index	Influx of Large Charcoal*	% *NAP*	% Cheno-podiaceae	% Poaceae	% *Artemesia*-type	% *Ambrosia*-type	% *Aster*-type	% Polygon-aceae	% *Liguliflorae*-type	% Umbell-iferae
A.D. 1900	-1.23	-1.58	3.85	37.19	5.92	11.34	14.61	1.75	2.52	0.63	0.14	0.29
A.D. 1850	-0.89	-1.35	2.20	30.07	4.93	8.84	11.43	1.65	2.37	0.33	0.36	0.16
A.D. 1800	-0.55	0.00	0.79	25.18	5.08	6.91	8.64	2.08	2.11	0.10	0.26	0.00
A.D. 1750	-0.25	-0.23	2.32	26.64	6.22	7.36	8.44	2.52	1.75	0.22	0.06	0.06
A.D. 1700	0.04	-0.54	4.46	26.23	6.10	6.28	9.28	1.95	1.98	0.17	0.20	0.27
A.D. 1650	0.24	-0.60	8.68	30.71	8.30	8.28	6.75	3.22	3.46	0.00	0.18	0.53
A.D. 1600	0.44	-0.60	4.10	27.18	7.16	6.63	7.64	2.04	3.63	0.00	0.02	0.06
A.D. 1550	0.22	-0.60	2.20	24.00	2.69	5.26	9.86	1.74	4.02	0.00	0.00	0.43
A.D. 1500	0.00	-0.36	12.77	18.59	1.79	5.63	7.34	1.40	2.11	0.00	0.11	0.21
A.D. 1450	-0.58	0.36	20.35	15.04	1.55	6.06	5.61	0.82	0.73	0.00	0.09	0.19
A.D. 1400	-1.16	0.41	27.18	16.64	0.94	7.93	6.41	0.32	0.72	0.09	0.00	0.23
A.D. 1350	-0.90	0.64	28.95	13.42	0.62	6.89	4.55	0.70	0.55	0.12	0.00	0.00
A.D. 1300	-0.63	1.17	24.81	7.53	0.74	3.84	1.99	0.63	0.33	0.00	0.00	0.00
A.D. 1250	-0.14	0.44	32.20	9.88	0.98	4.41	3.40	0.17	0.83	0.00	0.09	0.00
A.D. 1200	0.36	0.72	22.01	7.11	0.47	3.00	2.85	0.27	0.46	0.00	0.07	0.00
A.D. 1150	0.59	0.20	19.34	6.59	0.92	2.95	2.22	0.08	0.28	0.00	0.00	0.14
A.D. 1100	0.83	0.22	12.56	7.26	2.05	2.71	2.17	0.00	0.11	0.00	0.16	0.06
A.D. 1050	1.02	0.35	24.97	8.73	2.48	4.32	1.48	0.28	0.14	0.00	0.04	0.00
A.D. 1000	1.21	0.71	31.60	12.63	3.66	6.01	2.49	0.46	0.01	0.00	0.00	0.00
A.D. 950	1.39	0.65	12.41	10.76	2.87	4.73	2.58	0.57	0.00	0.00	0.00	0.00

*number of particles $\geq$ 150 microns in diameter deposited per square centimeter per year

Table I.2. Variables used in Correlations and Time Series Analysis: Arboreal Pollen reported at 50-year intervals

Temporal Interval A.D.	Interval Midpoint cal A.D.	% *AP*	% *Pinus*	% *Larix/ Pseudotsuga*	% *Acer*	% *Betula*	% *Alnus*	% *Tsuga*	% *Abies*	% *Picea*	% *Quercus*
1875-1925	A.D. 1900	62.81	45.60	0.29	0.29	7.40	5.68	0.61	0.65	1.32	0.98
1825-1875	A.D. 1850	69.93	56.15	0.16	0.35	4.86	4.86	0.72	0.83	1.50	0.50
1775-1825	A.D. 1800	74.82	60.95	0.20	0.37	4.17	4.36	1.72	0.84	1.32	0.89
1725-1775	A.D. 1750	73.36	56.12	0.31	0.37	6.34	4.21	2.37	0.81	1.15	1.69
1675-1725	A.D. 1700	73.77	58.41	0.19	0.42	6.78	2.97	1.51	0.58	1.52	1.40
1625-1675	A.D. 1650	69.29	57.34	1.06	1.43	3.28	2.20	0.72	0.36	1.82	1.08
1575-1625	A.D. 1600	72.82	61.62	0.37	0.94	3.48	2.85	0.60	0.17	2.02	0.77
1525-1575	A.D. 1550	76.00	67.83	0.36	0.64	2.42	1.56	0.71	0.32	1.56	0.60
1475-1525	A.D. 1500	81.41	73.00	0.14	0.32	2.84	2.48	0.93	0.14	1.24	0.32
1425-1475	A.D. 1450	84.96	77.32	0.00	0.28	2.27	3.02	0.92	0.00	0.96	0.18
1375-1425	A.D. 1400	83.36	76.42	0.00	0.32	0.96	2.90	1.30	0.38	0.97	0.11
1325-1375	A.D. 1350	86.58	80.04	0.00	0.19	0.56	2.54	1.55	0.55	1.15	0.00
1275-1325	A.D. 1300	92.47	86.37	0.17	0.07	0.73	2.20	1.35	0.07	1.43	0.09
1225-1275	A.D. 1250	90.12	82.52	0.16	0.00	1.07	2.72	1.30	0.60	1.68	0.08
1175-1225	A.D. 1200	92.89	86.18	0.00	0.14	0.89	1.61	1.11	0.60	2.37	0.00
1125-1175	A.D. 1150	93.41	86.95	0.00	0.08	0.39	1.65	1.54	0.08	2.56	0.14
1075-1125	A.D. 1100	92.74	86.95	0.00	0.00	0.21	1.03	1.54	0.16	2.64	0.21
1025-1075	A.D. 1050	91.27	83.04	0.28	0.00	1.01	2.61	1.64	0.18	2.35	0.18
975-1025	A.D. 1000	87.37	80.36	0.03	0.00	0.96	2.42	0.79	0.01	2.57	0.23
925-975	A.D. 950	89.24	80.77	0.00	0.14	2.15	2.73	0.86	0.14	2.44	0.00

Appendix J. Results from Time Series and Granger Tests (Output from eViews V.4) Run on Proxies Taken at 50 cal-year Intervals From A.D. 950 to 1900

Table J.1. Pairwise Granger Causality Tests, One Lag (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
ACER does not Granger Cause ABIES	19	1.07109	0.31609
ABIES does not Granger Cause ACER		0.31446	0.58272
ALNUS does not Granger Cause ABIES	19	0.14885	0.70472
ABIES does not Granger Cause ALNUS		10.0391	0.00596
AMBROSIA does not Granger Cause ABIES	19	4.34948	0.05339
ABIES does not Granger Cause AMBROSIA		0.39684	0.53762
ARTEMESIA does not Granger Cause ABIES	19	0.39774	0.53717
ABIES does not Granger Cause ARTEMESIA		0.22189	0.64396
ASTER does not Granger Cause ABIES	19	0.60522	0.44795
ABIES does not Granger Cause ASTER		0.30351	0.58930
BETULA does not Granger Cause ABIES	19	4.22356	0.05657
ABIES does not Granger Cause BETULA		0.41571	0.52822
CHARCOAL does not Granger Cause ABIES	19	2.88795	0.10860
ABIES does not Granger Cause CHARCOAL		0.11315	0.74096
CHENOPODIACEAE does not Granger Cause ABIES	19	2.81615	0.11274
ABIES does not Granger Cause CHENOPODIACEAE		0.10939	0.74513
LARIX does not Granger Cause ABIES	19	1.19834	0.28986
ABIES does not Granger Cause LARIX		0.02183	0.88438
LIGULAFLORAE does not Granger Cause ABIES	19	0.90720	0.35503
ABIES does not Granger Cause LIGULAFLORAE		1.94998	0.18166
OXYGEN‰ does not Granger Cause ABIES	19	5.1E-05	0.99439
ABIES does not Granger Cause OXYGEN‰		13.1675	0.00226
POPULATION does not Granger Cause ABIES	19	0.51804	0.48206
ABIES does not Granger Cause POPULATION		0.12727	0.72594
PICEA does not Granger Cause ABIES	19	0.01311	0.91026
ABIES does not Granger Cause PICEA		2.10012	0.16660
PINE does not Granger Cause ABIES	19	2.08904	0.16766
ABIES does not Granger Cause PINE		0.00936	0.92412
POACEAE does not Granger Cause ABIES	19	0.00175	0.96719
ABIES does not Granger Cause POACEAE		2.37000	0.14323
POLYGONACEAE does not Granger Cause ABIES	19	0.59145	0.45306
ABIES does not Granger Cause POLYGONACEAE		0.19698	0.66311
QUERCUS does not Granger Cause ABIES	19	6.17841	0.02437
ABIES does not Granger Cause QUERCUS		0.22980	0.63816
TSUGA does not Granger Cause ABIES	19	0.67931	0.42194
ABIES does not Granger Cause TSUGA		0.51068	0.48514
APIACEAE does not Granger Cause ABIES	19	0.20664	0.65552
ABIES does not Granger Cause APIACEAE		0.02354	0.87998
ALNUS does not Granger Cause ACER	19	0.00440	0.94792
ACER does not Granger Cause ALNUS		1.10332	0.30915
AMBROSIA does not Granger Cause ACER	19	0.05051	0.82502
ACER does not Granger Cause AMBROSIA		0.16959	0.68594
ARTEMESIA does not Granger Cause ACER	19	2.58288	0.12758
ACER does not Granger Cause ARTEMESIA		0.04496	0.83476
ASTER does not Granger Cause ACER	19	12.5680	0.00269
ACER does not Granger Cause ASTER		3.44686	0.08188
BETULA does not Granger Cause ACER	19	0.16812	0.68722
ACER does not Granger Cause BETULA		10.6387	0.00490
CHARCOAL does not Granger Cause ACER	19	1.34531	0.26312
ACER does not Granger Cause CHARCOAL		1.15659	0.29812

Table J.1. Pairwise Granger Causality Tests, One Lag (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
CHENOPODIACEAE does not Granger Cause ACER	19	0.10756	0.74720
ACER does not Granger Cause CHENOPODIACEAE		1.92839	0.18396
LARIX does not Granger Cause ACER	19	4.23667	0.05623
ACER does not Granger Cause LARIX		6.90769	0.01826
LIGULAFLORAE does not Granger Cause ACER	19	1.04122	0.32272
ACER does not Granger Cause LIGULAFLORAE		2.78007	0.11489
OXYGEN‰ does not Granger Cause ACER	19	0.21723	0.64744
ACER does not Granger Cause OXYGEN‰		0.17400	0.68213
POPULATION does not Granger Cause ACER	19	1.39680	0.25453
ACER does not Granger Cause POPULATION		0.12528	0.72800
PICEA does not Granger Cause ACER	19	0.79331	0.38630
ACER does not Granger Cause PICEA		0.12829	0.72489
PINE does not Granger Cause ACER	19	0.31389	0.58306
ACER does not Granger Cause PINE		0.00194	0.96542
POACEAE does not Granger Cause ACER	19	0.03449	0.85500
ACER does not Granger Cause POACEAE		1.9E-07	0.99966
POLYGONACEAE does not Granger Cause ACER	19	0.02253	0.88255
ACER does not Granger Cause POLYGONACEAE		1.32241	0.26706
QUERCUS does not Granger Cause ACER	19	0.01945	0.89082
ACER does not Granger Cause QUERCUS		9.35035	0.00751
TSUGA does not Granger Cause ACER	19	0.30198	0.59023
ACER does not Granger Cause TSUGA		0.03984	0.84431
APIACEAE does not Granger Cause ACER	19	0.50564	0.48727
ACER does not Granger Cause APIACEAE		6.43869	0.02195
AMBROSIA does not Granger Cause ALNUS	19	2.48529	0.13448
ALNUS does not Granger Cause AMBROSIA		0.13831	0.71485
ARTEMESIA does not Granger Cause ALNUS	19	6.26868	0.02350
ALNUS does not Granger Cause ARTEMESIA		2.54471	0.13022
ASTER does not Granger Cause ALNUS	19	1.75018	0.20445
ALNUS does not Granger Cause ASTER		0.63755	0.43629
BETULA does not Granger Cause ALNUS	19	3.39754	0.08390
ALNUS does not Granger Cause BETULA		0.03753	0.84883
CHARCOAL does not Granger Cause ALNUS	19	3.34399	0.08615
ALNUS does not Granger Cause CHARCOAL		1.77741	0.20114
CHENOPODIACEAE does not Granger Cause ALNUS	19	1.02375	0.32669
ALNUS does not Granger Cause CHENOPODIACEAE		0.03188	0.86054
LARIX does not Granger Cause ALNUS	19	0.26361	0.61467
ALNUS does not Granger Cause LARIX		0.39158	0.54029
LIGULAFLORAE does not Granger Cause ALNUS	19	4.04191	0.06155
ALNUS does not Granger Cause LIGULAFLORAE		5.83624	0.02802
OXYGEN‰ does not Granger Cause ALNUS	19	1.46908	0.24309
ALNUS does not Granger Cause OXYGEN‰		0.93356	0.34832
POPULATION does not Granger Cause ALNUS	19	1.43780	0.24795
ALNUS does not Granger Cause POPULATION		2.94563	0.10540
PICEA does not Granger Cause ALNUS	19	0.20083	0.66006
ALNUS does not Granger Cause PICEA		0.01506	0.90387
PINE does not Granger Cause ALNUS	19	4.28607	0.05497
ALNUS does not Granger Cause PINE		0.01504	0.90391
POACEAE does not Granger Cause ALNUS	19	1.26166	0.27791
ALNUS does not Granger Cause POACEAE		2.68352	0.12090

Table J.1. Pairwise Granger Causality Tests, One Lag (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
POLYGONACEAE does not Granger Cause ALNUS	19	11.0799	0.00425
ALNUS does not Granger Cause POLYGONACEAE		1.01392	0.32895
QUERCUS does not Granger Cause ALNUS	19	2.80922	0.11315
ALNUS does not Granger Cause QUERCUS		0.02155	0.88514
TSUGA does not Granger Cause ALNUS	19	0.01497	0.90414
ALNUS does not Granger Cause TSUGA		1.73140	0.20677
APIACEAE does not Granger Cause ALNUS	19	2.39415	0.14134
ALNUS does not Granger Cause APIACEAE		1.15262	0.29893
ARTEMESIA does not Granger Cause AMBROSIA	19	7.17669	0.01647
AMBROSIA does not Granger Cause ARTEMESIA		0.97022	0.33929
ASTER does not Granger Cause AMBROSIA	19	7.73860	0.01333
AMBROSIA does not Granger Cause ASTER		0.06685	0.79927
BETULA does not Granger Cause AMBROSIA	19	2.88881	0.10855
AMBROSIA does not Granger Cause BETULA		6.45310	0.02183
CHARCOAL does not Granger Cause AMBROSIA	19	1.77319	0.20165
AMBROSIA does not Granger Cause CHARCOAL		5.28338	0.03535
CHENOPODIACEAE does not Granger Cause AMBROSIA	19	0.02410	0.87857
AMBROSIA does not Granger Cause CHENOPODIACEAE		2.78640	0.11451
LARIX does not Granger Cause AMBROSIA	19	2.83669	0.11154
AMBROSIA does not Granger Cause LARIX		3.49352	0.08003
LIGULAFLORAE does not Granger Cause AMBROSIA	19	0.04708	0.83097
AMBROSIA does not Granger Cause LIGULAFLORAE		6.17771	0.02437
OXYGEN‰ does not Granger Cause AMBROSIA	19	0.46903	0.50323
AMBROSIA does not Granger Cause OXYGEN‰		0.17614	0.68029
POPULATION does not Granger Cause AMBROSIA	19	3.52189	0.07892
AMBROSIA does not Granger Cause POPULATION		1.70908	0.20958
PICEA does not Granger Cause AMBROSIA	19	1.04233	0.32247
AMBROSIA does not Granger Cause PICEA		0.00049	0.98254
PINE does not Granger Cause AMBROSIA	19	3.51684	0.07912
AMBROSIA does not Granger Cause PINE		0.03002	0.86461
POACEAE does not Granger Cause AMBROSIA	19	0.01774	0.89571
AMBROSIA does not Granger Cause POACEAE		0.91748	0.35239
POLYGONACEAE does not Granger Cause AMBROSIA	19	0.01387	0.90770
AMBROSIA does not Granger Cause POLYGONACEAE		1.41929	0.25089
QUERCUS does not Granger Cause AMBROSIA	19	0.27521	0.60705
AMBROSIA does not Granger Cause QUERCUS		5.99075	0.02630
TSUGA does not Granger Cause AMBROSIA	19	1.35358	0.26171
AMBROSIA does not Granger Cause TSUGA		0.00990	0.92199
APIACEAE does not Granger Cause AMBROSIA	19	0.06429	0.80307
AMBROSIA does not Granger Cause APIACEAE		1.89061	0.18808
ASTER does not Granger Cause ARTEMESIA	19	0.40451	0.53376
ARTEMESIA does not Granger Cause ASTER		2.71840	0.11869
BETULA does not Granger Cause ARTEMESIA	19	0.01220	0.91341
ARTEMESIA does not Granger Cause BETULA		9.59269	0.00692
CHARCOAL does not Granger Cause ARTEMESIA	19	0.08346	0.77637
ARTEMESIA does not Granger Cause CHARCOAL		7.65851	0.01373
CHENOPODIACEAE does not Granger Cause ARTEMESIA	19	0.00146	0.97003
ARTEMESIA does not Granger Cause CHENOPODIACEAE		13.1256	0.00229

Table J.1. Pairwise Granger Causality Tests, One Lag (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause ARTEMESIA	19	0.25633	0.61956
ARTEMESIA does not Granger Cause LARIX		3.80187	0.06894
LIGULAFLORAE does not Granger Cause ARTEMESIA	19	6.26341	0.02355
ARTEMESIA does not Granger Cause LIGULAFLORAE		1.16202	0.29703
OXYGEN‰ does not Granger Cause ARTEMESIA	19	3.15291	0.09481
ARTEMESIA does not Granger Cause OXYGEN‰		0.06745	0.79840
POPULATION does not Granger Cause ARTEMESIA	19	1.2E-08	0.99991
ARTEMESIA does not Granger Cause POPULATION		4.28312	0.05504
PICEA does not Granger Cause ARTEMESIA	19	1.53516	0.23321
ARTEMESIA does not Granger Cause PICEA		0.08536	0.77391
PINE does not Granger Cause ARTEMESIA	19	0.23844	0.63196
ARTEMESIA does not Granger Cause PINE		10.9534	0.00443
POACEAE does not Granger Cause ARTEMESIA	19	1.17192	0.29505
ARTEMESIA does not Granger Cause POACEAE		5.28287	0.03535
POLYGONACEAE does not Granger Cause ARTEMESIA	19	1.09948	0.30996
ARTEMESIA does not Granger Cause POLYGONACEAE		0.62199	0.44184
QUERCUS does not Granger Cause ARTEMESIA	19	0.23629	0.63349
ARTEMESIA does not Granger Cause QUERCUS		5.45307	0.03289
TSUGA does not Granger Cause ARTEMESIA	19	0.06570	0.80098
ARTEMESIA does not Granger Cause TSUGA		1.10435	0.30893
APIACEAE does not Granger Cause ARTEMESIA	19	0.10736	0.74742
ARTEMESIA does not Granger Cause APIACEAE		3.00182	0.10240
BETULA does not Granger Cause ASTER	19	0.45051	0.51167
ASTER does not Granger Cause BETULA		6.55065	0.02100
CHARCOAL does not Granger Cause ASTER	19	0.61565	0.44413
ASTER does not Granger Cause CHARCOAL		4.24135	0.05611
CHENOPODIACEAE does not Granger Cause ASTER	19	2.13569	0.16327
ASTER does not Granger Cause CHENOPODIACEAE		22.3697	0.00023
LARIX does not Granger Cause ASTER	19	8.50557	0.01009
ASTER does not Granger Cause LARIX		16.0185	0.00103
LIGULAFLORAE does not Granger Cause ASTER	19	0.07882	0.78250
ASTER does not Granger Cause LIGULAFLORAE		1.43718	0.24805
OXYGEN‰ does not Granger Cause ASTER	19	1.01338	0.32908
ASTER does not Granger Cause OXYGEN‰		0.03029	0.86403
POPULATION does not Granger Cause ASTER	19	0.27812	0.60517
ASTER does not Granger Cause POPULATION		0.65495	0.43022
PICEA does not Granger Cause ASTER	19	3.28416	0.08876
ASTER does not Granger Cause PICEA		0.12661	0.72662
PINE does not Granger Cause ASTER	19	0.00028	0.98677
ASTER does not Granger Cause PINE		2.27184	0.15123
POACEAE does not Granger Cause ASTER	19	0.00224	0.96280
ASTER does not Granger Cause POACEAE		1.41642	0.25135
POLYGONACEAE does not Granger Cause ASTER	19	0.05689	0.81451
ASTER does not Granger Cause POLYGONACEAE		1.33338	0.26516
QUERCUS does not Granger Cause ASTER	19	0.16046	0.69403
ASTER does not Granger Cause QUERCUS		9.04772	0.00834
TSUGA does not Granger Cause ASTER	19	0.00262	0.95985
ASTER does not Granger Cause TSUGA		0.45965	0.50748

Table J.1. Pairwise Granger Causality Tests, One Lag (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause ASTER	19	0.37319	0.54985
ASTER does not Granger Cause APIACEAE		5.71230	0.02950
CHARCOAL does not Granger Cause BETULA	19	1.11607	0.30646
BETULA does not Granger Cause CHARCOAL		4.11659	0.05944
CHENOPODIACEAE does not Granger Cause BETULA	19	2.49195	0.13399
BETULA does not Granger Cause CHENOPODIACEAE		1.84296	0.19345
LARIX does not Granger Cause BETULA	19	5.34600	0.03441
BETULA does not Granger Cause LARIX		2.26285	0.15199
LIGULAFLORAE does not Granger Cause BETULA	19	7.50608	0.01454
BETULA does not Granger Cause LIGULAFLORAE		3.15110	0.09490
OXYGEN‰ does not Granger Cause BETULA	19	2.12937	0.16385
BETULA does not Granger Cause OXYGEN‰		0.50568	0.48725
POPULATION does not Granger Cause BETULA	19	9.78235	0.00649
BETULA does not Granger Cause POPULATION		0.43353	0.51962
PICEA does not Granger Cause BETULA	19	0.37533	0.54872
BETULA does not Granger Cause PICEA		0.00333	0.95471
PINE does not Granger Cause BETULA	19	19.1827	0.00047
BETULA does not Granger Cause PINE		0.11186	0.74238
POACEAE does not Granger Cause BETULA	19	7.81578	0.01296
BETULA does not Granger Cause POACEAE		2.10589	0.16606
POLYGONACEAE does not Granger Cause BETULA	19	0.64297	0.43439
BETULA does not Granger Cause POLYGONACEAE		0.12585	0.72741
QUERCUS does not Granger Cause BETULA	19	0.01461	0.90530
BETULA does not Granger Cause QUERCUS		3.86924	0.06677
TSUGA does not Granger Cause BETULA	19	5.44508	0.03300
BETULA does not Granger Cause TSUGA		0.08821	0.77029
APIACEAE does not Granger Cause BETULA	19	13.2640	0.00220
BETULA does not Granger Cause APIACEAE		0.32870	0.57439
CHENOPODIACEAE does not Granger Cause CHARCOAL	19	1.80369	0.19801
CHARCOAL does not Granger Cause CHENOPODIACEAE		8.89496	0.00880
LARIX does not Granger Cause CHARCOAL	19	2.43060	0.13855
CHARCOAL does not Granger Cause LARIX		2.76408	0.11586
LIGULAFLORAE does not Granger Cause CHARCOAL	19	1.28157	0.27429
CHARCOAL does not Granger Cause LIGULAFLORAE		2.50037	0.13338
OXYGEN‰ does not Granger Cause CHARCOAL	19	1.68176	0.21308
CHARCOAL does not Granger Cause OXYGEN‰		0.10699	0.74784
POPULATION does not Granger Cause CHARCOAL	19	9.23782	0.00781
CHARCOAL does not Granger Cause POPULATION		2.46115	0.13626
PICEA does not Granger Cause CHARCOAL	19	4.81720	0.04328
CHARCOAL does not Granger Cause PICEA		0.91536	0.35293
PINE does not Granger Cause CHARCOAL	19	9.18832	0.00794
CHARCOAL does not Granger Cause PINE		2.35205	0.14465
POACEAE does not Granger Cause CHARCOAL	19	4.83453	0.04295
CHARCOAL does not Granger Cause POACEAE		4.64651	0.04669
POLYGONACEAE does not Granger Cause CHARCOAL	19	0.57144	0.46067
CHARCOAL does not Granger Cause POLYGONACEAE		1.43425	0.24851
QUERCUS does not Granger Cause CHARCOAL	19	5.68807	0.02980
CHARCOAL does not Granger Cause QUERCUS		2.00628	0.17582

Table J.1. Pairwise Granger Causality Tests, One Lag (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
TSUGA does not Granger Cause CHARCOAL	19	0.20273	0.65857
CHARCOAL does not Granger Cause TSUGA		0.96224	0.34122
APIACEAE does not Granger Cause CHARCOAL	19	3.24672	0.09044
CHARCOAL does not Granger Cause APIACEAE		1.04288	0.32235
LARIX does not Granger Cause CHENOPODIACEAE	19	0.03526	0.85342
CHENOPODIACEAE does not Granger Cause LARIX		5.53171	0.03181
LIGULAFLORAE does not Granger Cause CHENOPODIACEAE	19	0.09257	0.76486
CHENOPODIACEAE does not Granger Cause LIGULAFLORAE		6.85845	0.01861
OXYGEN‰ does not Granger Cause CHENOPODIACEAE	19	0.24025	0.63068
CHENOPODIACEAE does not Granger Cause OXYGEN‰		0.61349	0.44492
POPULATION does not Granger Cause CHENOPODIACEAE	19	7.35157	0.01541
CHENOPODIACEAE does not Granger Cause POPULATION		0.23648	0.63335
PICEA does not Granger Cause CHENOPODIACEAE	19	0.95568	0.34283
CHENOPODIACEAE does not Granger Cause PICEA		0.01843	0.89372
PINE does not Granger Cause CHENOPODIACEAE	19	6.29726	0.02323
CHENOPODIACEAE does not Granger Cause PINE		4.35638	0.05323
POACEAE does not Granger Cause CHENOPODIACEAE	19	0.39999	0.53603
CHENOPODIACEAE does not Granger Cause POACEAE		0.05463	0.81816
POLYGONACEAE does not Granger Cause CHENOPODIACEAE	19	0.12142	0.73204
CHENOPODIACEAE does not Granger Cause POLYGONACEAE		1.33833	0.26431
QUERCUS does not Granger Cause CHENOPODIACEAE	19	0.06257	0.80566
CHENOPODIACEAE does not Granger Cause QUERCUS		6.29968	0.02321
TSUGA does not Granger Cause CHENOPODIACEAE	19	3.67306	0.07334
CHENOPODIACEAE does not Granger Cause TSUGA		0.83423	0.37461
APIACEAE does not Granger Cause CHENOPODIACEAE	19	1.91842	0.18504
CHENOPODIACEAE does not Granger Cause APIACEAE		1.31270	0.26875
LIGULAFLORAE does not Granger Cause LARIX	19	6.8E-06	0.99794
LARIX does not Granger Cause LIGULAFLORAE		2.82197	0.11240
OXYGEN‰ does not Granger Cause LARIX	19	0.10160	0.75404
LARIX does not Granger Cause OXYGEN‰		0.16944	0.68607
POPULATION does not Granger Cause LARIX	19	4.98362	0.04023
LARIX does not Granger Cause POPULATION		0.03629	0.85132
PICEA does not Granger Cause LARIX	19	4.6E-05	0.99468
LARIX does not Granger Cause PICEA		0.01224	0.91329
PINE does not Granger Cause LARIX	19	3.98346	0.06326
LARIX does not Granger Cause PINE		1.49191	0.23961
POACEAE does not Granger Cause LARIX	19	0.60803	0.44691
LARIX does not Granger Cause POACEAE		0.54076	0.47276
POLYGONACEAE does not Granger Cause LARIX	19	0.00804	0.92968
LARIX does not Granger Cause POLYGONACEAE		2.54164	0.13044
QUERCUS does not Granger Cause LARIX	19	1.26836	0.27668
LARIX does not Granger Cause QUERCUS		2.74459	0.11706
TSUGA does not Granger Cause LARIX	19	3.80615	0.06880
LARIX does not Granger Cause TSUGA		0.91083	0.35409

Table J.1. Pairwise Granger Causality Tests, One Lag (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause LARIX	19	0.04218	0.83986
LARIX does not Granger Cause APIACEAE		0.33491	0.57084
OXYGEN‰ does not Granger Cause LIGULAFLORAE	19	0.10069	0.75511
LIGULAFLORAE does not Granger Cause OXYGEN‰		2.39330	0.14141
POPULATION does not Granger Cause LIGULAFLORAE	19	0.36386	0.55483
LIGULAFLORAE does not Granger Cause POPULATION		3.92684	0.06497
PICEA does not Granger Cause LIGULAFLORAE	19	0.37211	0.55042
LIGULAFLORAE does not Granger Cause PICEA		0.44293	0.51519
PINE does not Granger Cause LIGULAFLORAE	19	6.22821	0.02388
LIGULAFLORAE does not Granger Cause PINE		1.64980	0.21727
POACEAE does not Granger Cause LIGULAFLORAE	19	2.90778	0.10749
LIGULAFLORAE does not Granger Cause POACEAE		1.71304	0.20908
POLYGONACEAE does not Granger Cause LIGULAFLORAE	19	0.31310	0.58353
LIGULAFLORAE does not Granger Cause POLYGONACEAE		19.9097	0.00039
QUERCUS does not Granger Cause LIGULAFLORAE	19	6.70693	0.01975
LIGULAFLORAE does not Granger Cause QUERCUS		2.05422	0.17104
TSUGA does not Granger Cause LIGULAFLORAE	19	1.90251	0.18677
LIGULAFLORAE does not Granger Cause TSUGA		0.01046	0.91980
APIACEAE does not Granger Cause LIGULAFLORAE	19	0.02792	0.86939
LIGULAFLORAE does not Granger Cause APIACEAE		0.94082	0.34650
POPULATION does not Granger Cause OXYGEN‰	19	0.00334	0.95461
OXYGEN‰ does not Granger Cause POPULATION		1.64020	0.21855
PICEA does not Granger Cause OXYGEN‰	19	5.01511	0.03968
OXYGEN‰ does not Granger Cause PICEA		9.71292	0.00665
PINE does not Granger Cause OXYGEN‰	19	0.19631	0.66365
OXYGEN‰ does not Granger Cause PINE		2.73632	0.11757
POACEAE does not Granger Cause OXYGEN‰	19	0.22405	0.64237
OXYGEN‰ does not Granger Cause POACEAE		2.15931	0.16110
POLYGONACEAE does not Granger Cause OXYGEN‰	19	2.98145	0.10348
OXYGEN‰ does not Granger Cause POLYGONACEAE		0.05525	0.81715
QUERCUS does not Granger Cause OXYGEN‰	19	0.58101	0.45701
OXYGEN‰ does not Granger Cause QUERCUS		0.00106	0.97444
TSUGA does not Granger Cause OXYGEN‰	19	1.98096	0.17842
OXYGEN‰ does not Granger Cause TSUGA		1.71368	0.20900
APIACEAE does not Granger Cause OXYGEN‰	19	3.56221	0.07739
OXYGEN‰ does not Granger Cause APIACEAE		1.06211	0.31806
PICEA does not Granger Cause POPULATION	19	1.80248	0.19815
POPULATION does not Granger Cause PICEA		0.22555	0.64126
PINE does not Granger Cause POPULATION	19	2.18036	0.15919
POPULATION does not Granger Cause PINE		1.59265	0.22504
POACEAE does not Granger Cause POPULATION	19	1.99700	0.17677
POPULATION does not Granger Cause POACEAE		0.70445	0.41366
POLYGONACEAE does not Granger Cause POPULATION	19	0.21991	0.64543
POPULATION does not Granger Cause POLYGONACEAE		1.49844	0.23863
QUERCUS does not Granger Cause POPULATION	19	0.00436	0.94819
POPULATION does not Granger Cause QUERCUS		14.0147	0.00177
TSUGA does not Granger Cause POPULATION	19	0.16983	0.68573
POPULATION does not Granger Cause TSUGA		0.31913	0.57997

Table J.1. Pairwise Granger Causality Tests, One Lag (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause POPULATION	19	0.25576	0.61994
POPULATION does not Granger Cause APIACEAE		4.92439	0.04129
PINE does not Granger Cause PICEA	19	0.00026	0.98734
PICEA does not Granger Cause PINE		0.98161	0.33655
POACEAE does not Granger Cause PICEA	19	0.09350	0.76372
PICEA does not Granger Cause POACEAE		0.68591	0.41974
POLYGONACEAE does not Granger Cause PICEA	19	0.89680	0.35773
PICEA does not Granger Cause POLYGONACEAE		0.21445	0.64954
QUERCUS does not Granger Cause PICEA	19	0.00261	0.95990
PICEA does not Granger Cause QUERCUS		0.00463	0.94659
TSUGA does not Granger Cause PICEA	19	0.01109	0.91742
PICEA does not Granger Cause TSUGA		1.41547	0.25151
APIACEAE does not Granger Cause PICEA	19	0.12805	0.72514
PICEA does not Granger Cause APIACEAE		1.17122	0.29519
POACEAE does not Granger Cause PINE	19	0.01651	0.89937
PINE does not Granger Cause POACEAE		2.14630	0.16229
POLYGONACEAE does not Granger Cause PINE	19	0.36170	0.55599
PINE does not Granger Cause POLYGONACEAE		1.12644	0.30429
QUERCUS does not Granger Cause PINE	19	7.47538	0.01471
PINE does not Granger Cause QUERCUS		10.1161	0.00581
TSUGA does not Granger Cause PINE	19	3.77891	0.06970
PINE does not Granger Cause TSUGA		0.02772	0.86985
APIACEAE does not Granger Cause PINE	19	0.08148	0.77896
PINE does not Granger Cause APIACEAE		2.25442	0.15271
POLYGONACEAE does not Granger Cause POACEAE	19	4.09045	0.06017
POACEAE does not Granger Cause POLYGONACEAE		0.30300	0.58961
QUERCUS does not Granger Cause POACEAE	19	0.07439	0.78854
POACEAE does not Granger Cause QUERCUS		2.49027	0.13412
TSUGA does not Granger Cause POACEAE	19	0.14221	0.71105
POACEAE does not Granger Cause TSUGA		0.20737	0.65495
APIACEAE does not Granger Cause POACEAE	19	0.85039	0.37014
POACEAE does not Granger Cause APIACEAE		3.82526	0.06818
QUERCUS does not Granger Cause POLYGONACEAE	19	0.01114	0.91727
POLYGONACEAE does not Granger Cause QUERCUS		0.07159	0.79246
TSUGA does not Granger Cause POLYGONACEAE	19	3.47642	0.08070
POLYGONACEAE does not Granger Cause TSUGA		0.14508	0.70829
APIACEAE does not Granger Cause POLYGONACEAE	19	0.41559	0.52828
POLYGONACEAE does not Granger Cause APIACEAE		0.11809	0.73559
TSUGA does not Granger Cause QUERCUS	19	25.9543	0.00011
QUERCUS does not Granger Cause TSUGA		0.77625	0.39133
APIACEAE does not Granger Cause QUERCUS	19	7.93951	0.01238
QUERCUS does not Granger Cause APIACEAE		0.00626	0.93793
APIACEAE does not Granger Cause TSUGA	19	0.26461	0.61400
TSUGA does not Granger Cause APIACEAE		2.52737	0.13145

Table J.2. Pairwise Granger Causality Tests, Two Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
ACER does not Granger Cause ABIES	18	1.12384	0.35466
ABIES does not Granger Cause ACER		0.24048	0.78967
ALNUS does not Granger Cause ABIES	18	0.16737	0.84768
ABIES does not Granger Cause ALNUS		6.35600	0.01188
AMBROSIA does not Granger Cause ABIES	18	1.82115	0.20079
ABIES does not Granger Cause AMBROSIA		1.64980	0.22987
ARTEMESIA does not Granger Cause ABIES	18	1.34521	0.29445
ABIES does not Granger Cause ARTEMESIA		0.22709	0.79995
ASTER does not Granger Cause ABIES	18	2.29781	0.13980
ABIES does not Granger Cause ASTER		0.21731	0.80755
BETULA does not Granger Cause ABIES	18	2.38477	0.13114
ABIES does not Granger Cause BETULA		0.13852	0.87191
CHARCOAL does not Granger Cause ABIES	18	2.31802	0.13773
ABIES does not Granger Cause CHARCOAL		0.03040	0.97013
CHENOPODIACEAE does not Granger Cause ABIES	18	3.55613	0.05863
ABIES does not Granger Cause CHENOPODIACEAE		0.49460	0.62084
LARIX does not Granger Cause ABIES	18	1.64003	0.23167
ABIES does not Granger Cause LARIX		0.12320	0.88511
LIGULAFLORAE does not Granger Cause ABIES	18	1.72961	0.21576
ABIES does not Granger Cause LIGULAFLORAE		1.49921	0.25950
OXYGEN‰ does not Granger Cause ABIES	18	0.15544	0.85761
ABIES does not Granger Cause OXYGEN‰		2.88602	0.09179
POPULATION does not Granger Cause ABIES	18	3.89165	0.04737
ABIES does not Granger Cause POPULATION		0.48243	0.62791
PICEA does not Granger Cause ABIES	18	0.10790	0.89851
ABIES does not Granger Cause PICEA		0.56014	0.58432
PINE does not Granger Cause ABIES	18	3.18136	0.07505
ABIES does not Granger Cause PINE		0.30167	0.74462
POACEAE does not Granger Cause ABIES	18	0.22074	0.80487
ABIES does not Granger Cause POACEAE		2.24029	0.14589
POLYGONACEAE does not Granger Cause ABIES	18	0.25874	0.77591
ABIES does not Granger Cause POLYGONACEAE		1.48409	0.26271
QUERCUS does not Granger Cause ABIES	18	5.25776	0.02122
ABIES does not Granger Cause QUERCUS		0.06646	0.93601
TSUGA does not Granger Cause ABIES	18	0.22692	0.80007
ABIES does not Granger Cause TSUGA		0.04955	0.95184
APIACEAE does not Granger Cause ABIES	18	1.02616	0.38566
ABIES does not Granger Cause APIACEAE		0.08510	0.91893
ALNUS does not Granger Cause ACER	18	0.45301	0.64537
ACER does not Granger Cause ALNUS		1.52624	0.25387
AMBROSIA does not Granger Cause ACER	18	0.17715	0.83964
ACER does not Granger Cause AMBROSIA		0.74376	0.49450
ARTEMESIA does not Granger Cause ACER	18	1.80712	0.20301
ACER does not Granger Cause ARTEMESIA		0.28659	0.75544
ASTER does not Granger Cause ACER	18	6.44049	0.01138
ACER does not Granger Cause ASTER		0.83207	0.45705
BETULA does not Granger Cause ACER	18	1.24645	0.31972
ACER does not Granger Cause BETULA		4.30759	0.03670
CHARCOAL does not Granger Cause ACER	18	1.09082	0.36480
ACER does not Granger Cause CHARCOAL		0.94256	0.41471
CHENOPODIACEAE does not Granger Cause ACER	18	4.15084	0.04036
ACER does not Granger Cause CHENOPODIACEAE		0.89132	0.43375

Table J.2. Pairwise Granger Causality Tests, Two Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause ACER	18	2.47951	0.12240
ACER does not Granger Cause LARIX		2.82708	0.09563
LIGULAFLORAE does not Granger Cause ACER	18	1.00147	0.39399
ACER does not Granger Cause LIGULAFLORAE		1.14215	0.34917
OXYGEN‰ does not Granger Cause ACER	18	2.54395	0.11684
ACER does not Granger Cause OXYGEN‰		0.35687	0.70651
POPULATION does not Granger Cause ACER	18	0.76136	0.48677
ACER does not Granger Cause POPULATION		0.14855	0.86340
PICEA does not Granger Cause ACER	18	4.35230	0.03573
ACER does not Granger Cause PICEA		0.75431	0.48985
PINE does not Granger Cause ACER	18	0.96858	0.40540
ACER does not Granger Cause PINE		0.10111	0.90454
POACEAE does not Granger Cause ACER	18	0.03329	0.96734
ACER does not Granger Cause POACEAE		0.11101	0.89577
POLYGONACEAE does not Granger Cause ACER	18	0.02322	0.97709
ACER does not Granger Cause POLYGONACEAE		0.55518	0.58699
QUERCUS does not Granger Cause ACER	18	0.08006	0.92352
ACER does not Granger Cause QUERCUS		18.9252	0.00014
TSUGA does not Granger Cause ACER	18	0.26290	0.77281
ACER does not Granger Cause TSUGA		2.57707	0.11410
APIACEAE does not Granger Cause ACER	18	9.32754	0.00307
ACER does not Granger Cause APIACEAE		2.78262	0.09865
AMBROSIA does not Granger Cause ALNUS	18	2.92429	0.08940
ALNUS does not Granger Cause AMBROSIA		1.12271	0.35500
ARTEMESIA does not Granger Cause ALNUS	18	2.82526	0.09575
ALNUS does not Granger Cause ARTEMESIA		4.40525	0.03462
ASTER does not Granger Cause ALNUS	18	1.40539	0.28018
ALNUS does not Granger Cause ASTER		0.80350	0.46880
BETULA does not Granger Cause ALNUS	18	1.64150	0.23140
ALNUS does not Granger Cause BETULA		1.67324	0.22562
CHARCOAL does not Granger Cause ALNUS	18	2.23608	0.14634
ALNUS does not Granger Cause CHARCOAL		1.50361	0.25857
CHENOPODIACEAE does not Granger Cause ALNUS	18	1.14229	0.34913
ALNUS does not Granger Cause CHENOPODIACEAE		0.14616	0.86542
LARIX does not Granger Cause ALNUS	18	2.39368	0.13029
ALNUS does not Granger Cause LARIX		0.83873	0.45436
LIGULAFLORAE does not Granger Cause ALNUS	18	1.84616	0.19691
ALNUS does not Granger Cause LIGULAFLORAE		3.74322	0.05201
OXYGEN‰ does not Granger Cause ALNUS	18	1.63355	0.23287
ALNUS does not Granger Cause OXYGEN‰		0.80054	0.47003
POPULATION does not Granger Cause ALNUS	18	1.72751	0.21612
ALNUS does not Granger Cause POPULATION		10.8975	0.00166
PICEA does not Granger Cause ALNUS	18	0.06674	0.93576
ALNUS does not Granger Cause PICEA		0.15124	0.86113
PINE does not Granger Cause ALNUS	18	1.54256	0.25054
ALNUS does not Granger Cause PINE		1.20578	0.33085
POACEAE does not Granger Cause ALNUS	18	0.37914	0.69177
ALNUS does not Granger Cause POACEAE		1.39632	0.28228
POLYGONACEAE does not Granger Cause ALNUS	18	5.30493	0.02068
ALNUS does not Granger Cause POLYGONACEAE		5.14460	0.02260
QUERCUS does not Granger Cause ALNUS	18	1.69716	0.22137
ALNUS does not Granger Cause QUERCUS		0.21993	0.80550

Table J.2. Pairwise Granger Causality Tests, Two Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
TSUGA does not Granger Cause ALNUS	18	0.46735	0.63679
ALNUS does not Granger Cause TSUGA		0.31169	0.73753
APIACEAE does not Granger Cause ALNUS	18	0.75882	0.48788
ALNUS does not Granger Cause APIACEAE		0.51762	0.60772
ARTEMESIA does not Granger Cause AMBROSIA	18	6.61337	0.01044
AMBROSIA does not Granger Cause ARTEMESIA		0.60558	0.56045
ASTER does not Granger Cause AMBROSIA	18	6.34852	0.01192
AMBROSIA does not Granger Cause ASTER		0.25803	0.77643
BETULA does not Granger Cause AMBROSIA	18	2.92097	0.08960
AMBROSIA does not Granger Cause BETULA		4.67439	0.02954
CHARCOAL does not Granger Cause AMBROSIA	18	0.63558	0.54531
AMBROSIA does not Granger Cause CHARCOAL		2.72328	0.10284
CHENOPODIACEAE does not Granger Cause AMBROSIA	18	7.64494	0.00638
AMBROSIA does not Granger Cause CHENOPODIACEAE		8.38306	0.00459
LARIX does not Granger Cause AMBROSIA	18	1.05561	0.37600
AMBROSIA does not Granger Cause LARIX		1.12038	0.35570
LIGULAFLORAE does not Granger Cause AMBROSIA	18	0.62021	0.55301
AMBROSIA does not Granger Cause LIGULAFLORAE		2.95118	0.08776
OXYGEN‰ does not Granger Cause AMBROSIA	18	4.22954	0.03847
AMBROSIA does not Granger Cause OXYGEN‰		0.92212	0.42219
POPULATION does not Granger Cause AMBROSIA	18	1.71793	0.21776
AMBROSIA does not Granger Cause POPULATION		1.25074	0.31857
PICEA does not Granger Cause AMBROSIA	18	2.00980	0.17356
AMBROSIA does not Granger Cause PICEA		0.29860	0.74681
PINE does not Granger Cause AMBROSIA	18	1.13080	0.35256
AMBROSIA does not Granger Cause PINE		0.02542	0.97495
POACEAE does not Granger Cause AMBROSIA	18	0.18430	0.83382
AMBROSIA does not Granger Cause POACEAE		1.61635	0.23610
POLYGONACEAE does not Granger Cause AMBROSIA	18	0.24804	0.78394
AMBROSIA does not Granger Cause POLYGONACEAE		0.71256	0.50858
QUERCUS does not Granger Cause AMBROSIA	18	0.99821	0.39511
AMBROSIA does not Granger Cause QUERCUS		20.9386	8.6E-05
TSUGA does not Granger Cause AMBROSIA	18	1.37323	0.28770
AMBROSIA does not Granger Cause TSUGA		0.89779	0.43130
APIACEAE does not Granger Cause AMBROSIA	18	7.09269	0.00827
AMBROSIA does not Granger Cause APIACEAE		0.62832	0.54893
ASTER does not Granger Cause ARTEMESIA	18	0.49338	0.62154
ARTEMESIA does not Granger Cause ASTER		3.23358	0.07247
BETULA does not Granger Cause ARTEMESIA	18	0.29421	0.74995
ARTEMESIA does not Granger Cause BETULA		3.22179	0.07304
CHARCOAL does not Granger Cause ARTEMESIA	18	0.10625	0.89998
ARTEMESIA does not Granger Cause CHARCOAL		2.48322	0.12208
CHENOPODIACEAE does not Granger Cause ARTEMESIA	18	1.13200	0.35220
ARTEMESIA does not Granger Cause CHENOPODIACEAE		9.71651	0.00263
LARIX does not Granger Cause ARTEMESIA	18	0.15814	0.85535
ARTEMESIA does not Granger Cause LARIX		3.50090	0.06077
LIGULAFLORAE does not Granger Cause ARTEMESIA	18	2.70445	0.10422
ARTEMESIA does not Granger Cause LIGULAFLORAE		7.33366	0.00738

Table J.2. Pairwise Granger Causality Tests, Two Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
OXYGEN‰ does not Granger Cause ARTEMESIA	18	1.58477	0.24216
ARTEMESIA does not Granger Cause OXYGEN‰		0.65851	0.53406
POPULATION does not Granger Cause ARTEMESIA	18	0.71901	0.50563
ARTEMESIA does not Granger Cause POPULATION		2.76517	0.09986
PICEA does not Granger Cause ARTEMESIA	18	0.84218	0.45297
ARTEMESIA does not Granger Cause PICEA		0.25549	0.77833
PINE does not Granger Cause ARTEMESIA	18	0.38191	0.68997
ARTEMESIA does not Granger Cause PINE		5.49172	0.01867
POACEAE does not Granger Cause ARTEMESIA	18	0.55164	0.58891
ARTEMESIA does not Granger Cause POACEAE		3.49339	0.06107
POLYGONACEAE does not Granger Cause ARTEMESIA	18	0.78381	0.47710
ARTEMESIA does not Granger Cause POLYGONACEAE		0.36949	0.69811
QUERCUS does not Granger Cause ARTEMESIA	18	3.01932	0.08375
ARTEMESIA does not Granger Cause QUERCUS		3.86303	0.04823
TSUGA does not Granger Cause ARTEMESIA	18	1.30581	0.30424
ARTEMESIA does not Granger Cause TSUGA		0.67171	0.52770
APIACEAE does not Granger Cause ARTEMESIA	18	1.88978	0.19035
ARTEMESIA does not Granger Cause APIACEAE		1.17810	0.33868
BETULA does not Granger Cause ASTER	18	3.47376	0.06185
ASTER does not Granger Cause BETULA		2.41681	0.12811
CHARCOAL does not Granger Cause ASTER	18	1.56271	0.24650
ASTER does not Granger Cause CHARCOAL		0.55952	0.58465
CHENOPODIACEAE does not Granger Cause ASTER	18	0.07318	0.92981
ASTER does not Granger Cause CHENOPODIACEAE		14.6266	0.00047
LARIX does not Granger Cause ASTER	18	3.02579	0.08338
ASTER does not Granger Cause LARIX		12.3001	0.00100
LIGULAFLORAE does not Granger Cause ASTER	18	0.27949	0.76060
ASTER does not Granger Cause LIGULAFLORAE		1.01867	0.38817
OXYGEN‰ does not Granger Cause ASTER	18	11.1009	0.00154
ASTER does not Granger Cause OXYGEN‰		0.83345	0.45649
POPULATION does not Granger Cause ASTER	18	0.30228	0.74419
ASTER does not Granger Cause POPULATION		0.26701	0.76977
PICEA does not Granger Cause ASTER	18	6.80927	0.00948
ASTER does not Granger Cause PICEA		2.29164	0.14044
PINE does not Granger Cause ASTER	18	0.57437	0.57672
ASTER does not Granger Cause PINE		1.05193	0.37719
POACEAE does not Granger Cause ASTER	18	1.78545	0.20648
ASTER does not Granger Cause POACEAE		1.09315	0.36408
POLYGONACEAE does not Granger Cause ASTER	18	0.51825	0.60736
ASTER does not Granger Cause POLYGONACEAE		0.58313	0.57210
QUERCUS does not Granger Cause ASTER	18	0.22707	0.79996
ASTER does not Granger Cause QUERCUS		10.6156	0.00185
TSUGA does not Granger Cause ASTER	18	0.16843	0.84681
ASTER does not Granger Cause TSUGA		8.25984	0.00484
APIACEAE does not Granger Cause ASTER	18	4.22285	0.03863
ASTER does not Granger Cause APIACEAE		1.78571	0.20644
CHARCOAL does not Granger Cause BETULA	18	1.77482	0.20821
BETULA does not Granger Cause CHARCOAL		2.76168	0.10010
CHENOPODIACEAE does not Granger Cause BETULA	18	1.20547	0.33093
BETULA does not Granger Cause CHENOPODIACEAE		2.50386	0.12027

Table J.2. Pairwise Granger Causality Tests, Two Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause BETULA	18	1.93257	0.18416
BETULA does not Granger Cause LARIX		0.98356	0.40016
LIGULAFLORAE does not Granger Cause BETULA	18	2.76648	0.09977
BETULA does not Granger Cause LIGULAFLORAE		8.50396	0.00435
OXYGEN‰ does not Granger Cause BETULA	18	0.45897	0.64179
BETULA does not Granger Cause OXYGEN‰		1.19419	0.33410
POPULATION does not Granger Cause BETULA	18	3.49921	0.06084
BETULA does not Granger Cause POPULATION		1.91488	0.18669
PICEA does not Granger Cause BETULA	18	0.42399	0.66316
BETULA does not Granger Cause PICEA		0.70734	0.51098
PINE does not Granger Cause BETULA	18	12.2971	0.00101
BETULA does not Granger Cause PINE		0.28792	0.75448
POACEAE does not Granger Cause BETULA	18	3.11521	0.07847
BETULA does not Granger Cause POACEAE		1.20399	0.33135
POLYGONACEAE does not Granger Cause BETULA	18	0.19737	0.82330
BETULA does not Granger Cause POLYGONACEAE		0.74506	0.49393
QUERCUS does not Granger Cause BETULA	18	0.20172	0.81983
BETULA does not Granger Cause QUERCUS		3.99024	0.04455
TSUGA does not Granger Cause BETULA	18	5.69222	0.01676
BETULA does not Granger Cause TSUGA		0.24833	0.78372
APIACEAE does not Granger Cause BETULA	18	11.0474	0.00157
BETULA does not Granger Cause APIACEAE		0.00346	0.99655
CHENOPODIACEAE does not Granger Cause CHARCOAL	18	1.72186	0.21709
CHARCOAL does not Granger Cause CHENOPODIACEAE		5.94328	0.01468
LARIX does not Granger Cause CHARCOAL	18	0.70975	0.50987
CHARCOAL does not Granger Cause LARIX		2.03118	0.17076
LIGULAFLORAE does not Granger Cause CHARCOAL	18	0.11720	0.89034
CHARCOAL does not Granger Cause LIGULAFLORAE		3.40796	0.06457
OXYGEN‰ does not Granger Cause CHARCOAL	18	1.21030	0.32959
CHARCOAL does not Granger Cause OXYGEN‰		1.80806	0.20286
POPULATION does not Granger Cause CHARCOAL	18	2.35130	0.13440
CHARCOAL does not Granger Cause POPULATION		4.29660	0.03695
PICEA does not Granger Cause CHARCOAL	18	1.21122	0.32934
CHARCOAL does not Granger Cause PICEA		1.10819	0.35942
PINE does not Granger Cause CHARCOAL	18	5.06078	0.02369
CHARCOAL does not Granger Cause PINE		1.77941	0.20746
POACEAE does not Granger Cause CHARCOAL	18	6.11086	0.01346
CHARCOAL does not Granger Cause POACEAE		2.81097	0.09671
POLYGONACEAE does not Granger Cause CHARCOAL	18	0.23780	0.79171
CHARCOAL does not Granger Cause POLYGONACEAE		0.89936	0.43070
QUERCUS does not Granger Cause CHARCOAL	18	1.32889	0.29846
CHARCOAL does not Granger Cause QUERCUS		2.55876	0.11561
TSUGA does not Granger Cause CHARCOAL	18	1.50396	0.25850
CHARCOAL does not Granger Cause TSUGA		0.60055	0.56304
APIACEAE does not Granger Cause CHARCOAL	18	0.92685	0.42044
CHARCOAL does not Granger Cause APIACEAE		0.30013	0.74572
LARIX does not Granger Cause CHENOPODIACEAE	18	0.55018	0.58970
CHENOPODIACEAE does not Granger Cause LARIX		21.1336	8.2E-05
LIGULAFLORAE does not Granger Cause CHENOPODIACEAE	18	1.22728	0.32491
CHENOPODIACEAE does not Granger Cause LIGULAFLORAE		3.64672	0.05531

Table J.2. Pairwise Granger Causality Tests, Two Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
OXYGEN‰ does not Granger Cause CHENOPODIACEAE	18	1.46725	0.26634
CHENOPODIACEAE does not Granger Cause OXYGEN‰		0.55360	0.58785
POPULATION does not Granger Cause CHENOPODIACEAE	18	7.50294	0.00682
CHENOPODIACEAE does not Granger Cause POPULATION		0.15959	0.85414
PICEA does not Granger Cause CHENOPODIACEAE	18	3.12609	0.07790
CHENOPODIACEAE does not Granger Cause PICEA		0.31871	0.73261
PINE does not Granger Cause CHENOPODIACEAE	18	4.82304	0.02711
CHENOPODIACEAE does not Granger Cause PINE		2.69044	0.10526
POACEAE does not Granger Cause CHENOPODIACEAE	18	0.83310	0.45663
CHENOPODIACEAE does not Granger Cause POACEAE		0.03139	0.96917
POLYGONACEAE does not Granger Cause CHENOPODIACEAE	18	0.53867	0.59600
CHENOPODIACEAE does not Granger Cause POLYGONACEAE		0.87767	0.43900
QUERCUS does not Granger Cause CHENOPODIACEAE	18	0.91921	0.42327
CHENOPODIACEAE does not Granger Cause QUERCUS		3.35519	0.06685
TSUGA does not Granger Cause CHENOPODIACEAE	18	0.82285	0.46080
CHENOPODIACEAE does not Granger Cause TSUGA		1.90667	0.18788
APIACEAE does not Granger Cause CHENOPODIACEAE	18	2.94704	0.08801
CHENOPODIACEAE does not Granger Cause APIACEAE		3.15617	0.07633
LIGULAFLORAE does not Granger Cause LARIX	18	0.09169	0.91297
LARIX does not Granger Cause LIGULAFLORAE		1.09582	0.36325
OXYGEN‰ does not Granger Cause LARIX	18	2.29642	0.13994
LARIX does not Granger Cause OXYGEN‰		0.59986	0.56339
POPULATION does not Granger Cause LARIX	18	2.62006	0.11065
LARIX does not Granger Cause POPULATION		0.10235	0.90343
PICEA does not Granger Cause LARIX	18	3.01137	0.08421
LARIX does not Granger Cause PICEA		1.07744	0.36901
PINE does not Granger Cause LARIX	18	2.65164	0.10819
LARIX does not Granger Cause PINE		0.69541	0.51651
POACEAE does not Granger Cause LARIX	18	0.29198	0.75155
LARIX does not Granger Cause POACEAE		1.63364	0.23285
POLYGONACEAE does not Granger Cause LARIX	18	0.06644	0.93604
LARIX does not Granger Cause POLYGONACEAE		1.06352	0.37345
QUERCUS does not Granger Cause LARIX	18	0.31630	0.73429
LARIX does not Granger Cause QUERCUS		5.12813	0.02281
TSUGA does not Granger Cause LARIX	18	2.86526	0.09312
LARIX does not Granger Cause TSUGA		1.81987	0.20099
APIACEAE does not Granger Cause LARIX	18	6.82513	0.00941
LARIX does not Granger Cause APIACEAE		0.26403	0.77197
OXYGEN‰ does not Granger Cause LIGULAFLORAE	18	0.03760	0.96320
LIGULAFLORAE does not Granger Cause OXYGEN‰		1.57376	0.24431
POPULATION does not Granger Cause LIGULAFLORAE	18	2.66208	0.10739
LIGULAFLORAE does not Granger Cause POPULATION		2.82442	0.09581
PICEA does not Granger Cause LIGULAFLORAE	18	0.12302	0.88526
LIGULAFLORAE does not Granger Cause PICEA		0.49172	0.62250

Table J.2. Pairwise Granger Causality Tests, Two Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
PINE does not Granger Cause LIGULAFLORAE	18	7.49355	0.00685
LIGULAFLORAE does not Granger Cause PINE		1.10578	0.36016
POACEAE does not Granger Cause LIGULAFLORAE	18	1.38848	0.28411
LIGULAFLORAE does not Granger Cause POACEAE		1.78330	0.20683
POLYGONACEAE does not Granger Cause LIGULAFLORAE	18	6.41809	0.01151
LIGULAFLORAE does not Granger Cause POLYGONACEAE		8.44215	0.00447
QUERCUS does not Granger Cause LIGULAFLORAE	18	21.6643	7.3E-05
LIGULAFLORAE does not Granger Cause QUERCUS		4.63333	0.03026
TSUGA does not Granger Cause LIGULAFLORAE	18	0.96908	0.40523
LIGULAFLORAE does not Granger Cause TSUGA		0.78980	0.47455
APIACEAE does not Granger Cause LIGULAFLORAE	18	0.30520	0.74212
LIGULAFLORAE does not Granger Cause APIACEAE		1.68061	0.22430
POPULATION does not Granger Cause OXYGEN‰	18	0.77125	0.48248
OXYGEN‰ does not Granger Cause POPULATION		1.49961	0.25941
PICEA does not Granger Cause OXYGEN‰	18	0.04332	0.95774
OXYGEN‰ does not Granger Cause PICEA		3.23305	0.07250
PINE does not Granger Cause OXYGEN‰	18	0.71714	0.50648
OXYGEN‰ does not Granger Cause PINE		2.42974	0.12691
POACEAE does not Granger Cause OXYGEN‰	18	0.34337	0.71562
OXYGEN‰ does not Granger Cause POACEAE		1.69634	0.22152
POLYGONACEAE does not Granger Cause OXYGEN‰	18	0.86242	0.44494
OXYGEN‰ does not Granger Cause POLYGONACEAE		0.14560	0.86590
QUERCUS does not Granger Cause OXYGEN‰	18	1.94844	0.18192
OXYGEN‰ does not Granger Cause QUERCUS		0.77680	0.48009
TSUGA does not Granger Cause OXYGEN‰	18	0.05018	0.95124
OXYGEN‰ does not Granger Cause TSUGA		2.75300	0.10072
APIACEAE does not Granger Cause OXYGEN‰	18	1.98533	0.17684
OXYGEN‰ does not Granger Cause APIACEAE		3.04525	0.08228
PICEA does not Granger Cause POPULATION	18	6.63396	0.01034
POPULATION does not Granger Cause PICEA		0.25048	0.78210
PINE does not Granger Cause POPULATION	18	3.39163	0.06527
POPULATION does not Granger Cause PINE		0.63806	0.54409
POACEAE does not Granger Cause POPULATION	18	2.70992	0.10382
POPULATION does not Granger Cause POACEAE		0.67246	0.52734
POLYGONACEAE does not Granger Cause POPULATION	18	2.96221	0.08709
POPULATION does not Granger Cause POLYGONACEAE		0.62711	0.54954
QUERCUS does not Granger Cause POPULATION	18	4.40666	0.03459
POPULATION does not Granger Cause QUERCUS		8.58536	0.00420
TSUGA does not Granger Cause POPULATION	18	3.37274	0.06608
POPULATION does not Granger Cause TSUGA		1.04032	0.38098
APIACEAE does not Granger Cause POPULATION	18	0.34939	0.71154
POPULATION does not Granger Cause APIACEAE		2.63632	0.10938
PINE does not Granger Cause PICEA	18	0.38228	0.68973
PICEA does not Granger Cause PINE		4.55088	0.03176
POACEAE does not Granger Cause PICEA	18	1.05440	0.37639
PICEA does not Granger Cause POACEAE		1.85052	0.19625
POLYGONACEAE does not Granger Cause PICEA	18	1.06342	0.37348
PICEA does not Granger Cause POLYGONACEAE		0.55713	0.58594

Table J.2. Pairwise Granger Causality Tests, Two Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
QUERCUS does not Granger Cause PICEA	18	0.05813	0.94377
PICEA does not Granger Cause QUERCUS		0.95170	0.41141
TSUGA does not Granger Cause PICEA	18	2.20534	0.14974
PICEA does not Granger Cause TSUGA		2.49045	0.12144
APIACEAE does not Granger Cause PICEA	18	0.20894	0.81412
PICEA does not Granger Cause APIACEAE		4.62813	0.03035
POACEAE does not Granger Cause PINE	18	0.19677	0.82378
PINE does not Granger Cause POACEAE		1.38173	0.28569
POLYGONACEAE does not Granger Cause PINE	18	0.22345	0.80276
PINE does not Granger Cause POLYGONACEAE		1.70151	0.22061
QUERCUS does not Granger Cause PINE	18	4.37404	0.03527
PINE does not Granger Cause QUERCUS		9.92921	0.00241
TSUGA does not Granger Cause PINE	18	5.85128	0.01541
PINE does not Granger Cause TSUGA		1.80470	0.20339
APIACEAE does not Granger Cause PINE	18	0.03245	0.96815
PINE does not Granger Cause APIACEAE		1.95830	0.18055
POLYGONACEAE does not Granger Cause POACEAE	18	1.82142	0.20075
POACEAE does not Granger Cause POLYGONACEAE		0.21978	0.80562
QUERCUS does not Granger Cause POACEAE	18	2.42231	0.12760
POACEAE does not Granger Cause QUERCUS		1.88183	0.19153
TSUGA does not Granger Cause POACEAE	18	1.65935	0.22813
POACEAE does not Granger Cause TSUGA		0.14605	0.86551
APIACEAE does not Granger Cause POACEAE	18	0.93125	0.41883
POACEAE does not Granger Cause APIACEAE		1.60136	0.23895
QUERCUS does not Granger Cause POLYGONACEAE	18	6.19419	0.01290
POLYGONACEAE does not Granger Cause QUERCUS		2.80993	0.09678
TSUGA does not Granger Cause POLYGONACEAE	18	2.87313	0.09262
POLYGONACEAE does not Granger Cause TSUGA		0.95150	0.41148
APIACEAE does not Granger Cause POLYGONACEAE	18	0.87662	0.43941
POLYGONACEAE does not Granger Cause APIACEAE		0.01796	0.98223
TSUGA does not Granger Cause QUERCUS	18	13.1329	0.00076
QUERCUS does not Granger Cause TSUGA		0.10726	0.89908
APIACEAE does not Granger Cause QUERCUS	18	5.92679	0.01481
QUERCUS does not Granger Cause APIACEAE		0.80993	0.46612
APIACEAE does not Granger Cause TSUGA	18	0.07968	0.92386
TSUGA does not Granger Cause APIACEAE		2.07117	0.16564

Table J.3. Pairwise Granger Causality Tests, Three Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
ACER does not Granger Cause ABIES	17	1.58923	0.25301
ABIES does not Granger Cause ACER		0.23948	0.86685
ALNUS does not Granger Cause ABIES	17	0.17371	0.91174
ABIES does not Granger Cause ALNUS		5.18624	0.02036
AMBROSIA does not Granger Cause ABIES	17	1.11343	0.38902
ABIES does not Granger Cause AMBROSIA		1.60494	0.24954
ARTEMESIA does not Granger Cause ABIES	17	1.08265	0.40028
ABIES does not Granger Cause ARTEMESIA		15.8811	0.00039
ASTER does not Granger Cause ABIES	17	2.02543	0.17428
ABIES does not Granger Cause ASTER		0.97283	0.44347
BETULA does not Granger Cause ABIES	17	1.28690	0.33168
ABIES does not Granger Cause BETULA		0.06550	0.97695
CHARCOAL does not Granger Cause ABIES	17	2.27103	0.14264
ABIES does not Granger Cause CHARCOAL		0.05847	0.98041
CHENOPODIACEAE does not Granger Cause ABIES	17	2.54220	0.11521
ABIES does not Granger Cause CHENOPODIACEAE		0.11020	0.95217
LARIX does not Granger Cause ABIES	17	2.56842	0.11290
ABIES does not Granger Cause LARIX		0.07393	0.97263
LIGULAFLORAE does not Granger Cause ABIES	17	2.99666	0.08195
ABIES does not Granger Cause LIGULAFLORAE		0.23155	0.87234
OXYGEN‰ does not Granger Cause ABIES	17	1.07673	0.40249
ABIES does not Granger Cause OXYGEN‰		4.62651	0.02810
POPULATION does not Granger Cause ABIES	17	7.37498	0.00681
ABIES does not Granger Cause POPULATION		3.43761	0.06002
PICEA does not Granger Cause ABIES	17	0.41685	0.74478
ABIES does not Granger Cause PICEA		0.45363	0.72048
PINE does not Granger Cause ABIES	17	1.91995	0.19035
ABIES does not Granger Cause PINE		1.57247	0.25677
POACEAE does not Granger Cause ABIES	17	0.35529	0.78649
ABIES does not Granger Cause POACEAE		2.11064	0.16245
POLYGONACEAE does not Granger Cause ABIES	17	0.19534	0.89718
ABIES does not Granger Cause POLYGONACEAE		1.70050	0.22959
QUERCUS does not Granger Cause ABIES	17	2.92243	0.08651
ABIES does not Granger Cause QUERCUS		0.80384	0.51980
TSUGA does not Granger Cause ABIES	17	0.59804	0.63067
ABIES does not Granger Cause TSUGA		0.15239	0.92577
APIACEAE does not Granger Cause ABIES	17	1.29495	0.32926
ABIES does not Granger Cause APIACEAE		0.78460	0.52930
ALNUS does not Granger Cause ACER	17	1.61210	0.24798
ACER does not Granger Cause ALNUS		0.80393	0.51976
AMBROSIA does not Granger Cause ACER	17	0.33459	0.80075
ACER does not Granger Cause AMBROSIA		0.33671	0.79928
ARTEMESIA does not Granger Cause ACER	17	2.36686	0.13215
ACER does not Granger Cause ARTEMESIA		2.23914	0.14634
ASTER does not Granger Cause ACER	17	6.04915	0.01285
ACER does not Granger Cause ASTER		0.78940	0.52692
BETULA does not Granger Cause ACER	17	1.53317	0.26584
ACER does not Granger Cause BETULA		4.15444	0.03749
CHARCOAL does not Granger Cause ACER	17	1.89243	0.19481
ACER does not Granger Cause CHARCOAL		0.90194	0.47396
CHENOPODIACEAE does not Granger Cause ACER	17	3.54672	0.05571
ACER does not Granger Cause CHENOPODIACEAE		1.07107	0.40461

Table J.3. Pairwise Granger Causality Tests, Three Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause ACER	17	3.62545	0.05284
ACER does not Granger Cause LARIX		2.59923	0.11026
LIGULAFLORAE does not Granger Cause ACER	17	1.13360	0.38182
ACER does not Granger Cause LIGULAFLORAE		2.25876	0.14405
OXYGEN‰ does not Granger Cause ACER	17	1.71752	0.22623
ACER does not Granger Cause OXYGEN‰		0.22447	0.87724
POPULATION does not Granger Cause ACER	17	0.62533	0.61479
ACER does not Granger Cause POPULATION		0.13986	0.93384
PICEA does not Granger Cause ACER	17	2.51105	0.11802
ACER does not Granger Cause PICEA		2.06625	0.16850
PINE does not Granger Cause ACER	17	0.97638	0.44199
ACER does not Granger Cause PINE		2.11384	0.16203
POACEAE does not Granger Cause ACER	17	0.84135	0.50176
ACER does not Granger Cause POACEAE		0.22233	0.87871
POLYGONACEAE does not Granger Cause ACER	17	0.05429	0.98239
ACER does not Granger Cause POLYGONACEAE		0.69178	0.57764
QUERCUS does not Granger Cause ACER	17	0.44423	0.72665
ACER does not Granger Cause QUERCUS		14.2363	0.00061
TSUGA does not Granger Cause ACER	17	0.81423	0.51474
ACER does not Granger Cause TSUGA		1.81270	0.20846
APIACEAE does not Granger Cause ACER	17	5.14614	0.02082
ACER does not Granger Cause APIACEAE		2.10093	0.16375
AMBROSIA does not Granger Cause ALNUS	17	2.16592	0.15528
ALNUS does not Granger Cause AMBROSIA		1.13834	0.38015
ARTEMESIA does not Granger Cause ALNUS	17	3.08305	0.07698
ALNUS does not Granger Cause ARTEMESIA		3.44606	0.05967
ASTER does not Granger Cause ALNUS	17	0.84407	0.50047
ALNUS does not Granger Cause ASTER		0.58082	0.64087
BETULA does not Granger Cause ALNUS	17	1.63173	0.24375
ALNUS does not Granger Cause BETULA		1.00278	0.43121
CHARCOAL does not Granger Cause ALNUS	17	1.38379	0.30379
ALNUS does not Granger Cause CHARCOAL		0.94672	0.45445
CHENOPODIACEAE does not Granger Cause ALNUS	17	1.06036	0.40867
ALNUS does not Granger Cause CHENOPODIACEAE		1.62986	0.24415
LARIX does not Granger Cause ALNUS	17	1.90916	0.19208
ALNUS does not Granger Cause LARIX		1.40151	0.29898
LIGULAFLORAE does not Granger Cause ALNUS	17	3.00097	0.08169
ALNUS does not Granger Cause LIGULAFLORAE		1.38069	0.30464
OXYGEN‰ does not Granger Cause ALNUS	17	1.18903	0.36278
ALNUS does not Granger Cause OXYGEN‰		0.59739	0.63105
POPULATION does not Granger Cause ALNUS	17	1.08169	0.40064
ALNUS does not Granger Cause POPULATION		6.98829	0.00813
PICEA does not Granger Cause ALNUS	17	0.01799	0.99650
ALNUS does not Granger Cause PICEA		0.51654	0.68020
PINE does not Granger Cause ALNUS	17	1.10905	0.39060
ALNUS does not Granger Cause PINE		1.53271	0.26595
POACEAE does not Granger Cause ALNUS	17	0.22471	0.87707
ALNUS does not Granger Cause POACEAE		1.15462	0.37447
POLYGONACEAE does not Granger Cause ALNUS	17	4.05638	0.03989
ALNUS does not Granger Cause POLYGONACEAE		1.10457	0.39222
QUERCUS does not Granger Cause ALNUS	17	3.65173	0.05192
ALNUS does not Granger Cause QUERCUS		0.48886	0.69771

Table J.3. Pairwise Granger Causality Tests, Three Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
TSUGA does not Granger Cause ALNUS	17	0.68870	0.57931
ALNUS does not Granger Cause TSUGA		0.50765	0.68578
APIACEAE does not Granger Cause ALNUS	17	0.51731	0.67971
ALNUS does not Granger Cause APIACEAE		0.50347	0.68842
ARTEMESIA does not Granger Cause AMBROSIA	17	9.02923	0.00340
AMBROSIA does not Granger Cause ARTEMESIA		3.66986	0.05129
ASTER does not Granger Cause AMBROSIA	17	3.54456	0.05580
AMBROSIA does not Granger Cause ASTER		0.81136	0.51613
BETULA does not Granger Cause AMBROSIA	17	1.57190	0.25690
AMBROSIA does not Granger Cause BETULA		3.57019	0.05484
CHARCOAL does not Granger Cause AMBROSIA	17	0.68051	0.58378
AMBROSIA does not Granger Cause CHARCOAL		1.48392	0.27772
CHENOPODIACEAE does not Granger Cause AMBROSIA	17	4.41433	0.03193
AMBROSIA does not Granger Cause CHENOPODIACEAE		3.76773	0.04807
LARIX does not Granger Cause AMBROSIA	17	1.08211	0.40048
AMBROSIA does not Granger Cause LARIX		1.32227	0.32118
LIGULAFLORAE does not Granger Cause AMBROSIA	17	0.50874	0.68510
AMBROSIA does not Granger Cause LIGULAFLORAE		4.88366	0.02417
OXYGEN‰ does not Granger Cause AMBROSIA	17	2.34050	0.13494
AMBROSIA does not Granger Cause OXYGEN‰		0.81984	0.51203
POPULATION does not Granger Cause AMBROSIA	17	1.20425	0.35774
AMBROSIA does not Granger Cause POPULATION		0.91883	0.46650
PICEA does not Granger Cause AMBROSIA	17	1.16785	0.36993
AMBROSIA does not Granger Cause PICEA		0.40094	0.75545
PINE does not Granger Cause AMBROSIA	17	1.90800	0.19227
AMBROSIA does not Granger Cause PINE		1.55845	0.25996
POACEAE does not Granger Cause AMBROSIA	17	0.34104	0.79630
AMBROSIA does not Granger Cause POACEAE		0.78140	0.53091
POLYGONACEAE does not Granger Cause AMBROSIA	17	0.21807	0.88165
AMBROSIA does not Granger Cause POLYGONACEAE		0.77003	0.53662
QUERCUS does not Granger Cause AMBROSIA	17	0.85979	0.49312
AMBROSIA does not Granger Cause QUERCUS		11.7725	0.00128
TSUGA does not Granger Cause AMBROSIA	17	1.38240	0.30418
AMBROSIA does not Granger Cause TSUGA		0.45120	0.72207
APIACEAE does not Granger Cause AMBROSIA	17	3.52791	0.05643
AMBROSIA does not Granger Cause APIACEAE		1.08944	0.39777
ASTER does not Granger Cause ARTEMESIA	17	4.14179	0.03779
ARTEMESIA does not Granger Cause ASTER		2.27297	0.14241
BETULA does not Granger Cause ARTEMESIA	17	0.36224	0.78173
ARTEMESIA does not Granger Cause BETULA		4.35122	0.03318
CHARCOAL does not Granger Cause ARTEMESIA	17	0.44319	0.72733
ARTEMESIA does not Granger Cause CHARCOAL		2.05056	0.17069
CHENOPODIACEAE does not Granger Cause ARTEMESIA	17	3.17832	0.07192
ARTEMESIA does not Granger Cause CHENOPODIACEAE		4.89613	0.02400
LARIX does not Granger Cause ARTEMESIA	17	4.42376	0.03174
ARTEMESIA does not Granger Cause LARIX		4.20708	0.03628
LIGULAFLORAE does not Granger Cause ARTEMESIA	17	0.35358	0.78767
ARTEMESIA does not Granger Cause LIGULAFLORAE		3.16225	0.07275

Table J.3. Pairwise Granger Causality Tests, Three Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
OXYGEN‰ does not Granger Cause ARTEMESIA	17	3.29974	0.06603
ARTEMESIA does not Granger Cause OXYGEN‰		1.35739	0.31112
POPULATION does not Granger Cause ARTEMESIA	17	2.20223	0.15077
ARTEMESIA does not Granger Cause POPULATION		5.71653	0.01527
PICEA does not Granger Cause ARTEMESIA	17	1.53486	0.26544
ARTEMESIA does not Granger Cause PICEA		0.37626	0.77216
PINE does not Granger Cause ARTEMESIA	17	1.58259	0.25449
ARTEMESIA does not Granger Cause PINE		6.93528	0.00833
POACEAE does not Granger Cause ARTEMESIA	17	0.78706	0.52808
ARTEMESIA does not Granger Cause POACEAE		1.75686	0.21868
POLYGONACEAE does not Granger Cause ARTEMESIA	17	5.18279	0.02040
ARTEMESIA does not Granger Cause POLYGONACEAE		2.23214	0.14717
QUERCUS does not Granger Cause ARTEMESIA	17	2.44292	0.12446
ARTEMESIA does not Granger Cause QUERCUS		5.98383	0.01328
TSUGA does not Granger Cause ARTEMESIA	17	3.51260	0.05702
ARTEMESIA does not Granger Cause TSUGA		0.84997	0.49771
APIACEAE does not Granger Cause ARTEMESIA	17	2.39745	0.12899
ARTEMESIA does not Granger Cause APIACEAE		1.14166	0.37898
BETULA does not Granger Cause ASTER	17	2.83581	0.09223
ASTER does not Granger Cause BETULA		4.60064	0.02854
CHARCOAL does not Granger Cause ASTER	17	1.25575	0.34124
ASTER does not Granger Cause CHARCOAL		1.85958	0.20031
CHENOPODIACEAE does not Granger Cause ASTER	17	0.33395	0.80119
ASTER does not Granger Cause CHENOPODIACEAE		26.3512	4.6E-05
LARIX does not Granger Cause ASTER	17	3.66050	0.05161
ASTER does not Granger Cause LARIX		12.6531	0.00097
LIGULAFLORAE does not Granger Cause ASTER	17	0.16334	0.91861
ASTER does not Granger Cause LIGULAFLORAE		1.13436	0.38155
OXYGEN‰ does not Granger Cause ASTER	17	6.04512	0.01287
ASTER does not Granger Cause OXYGEN‰		1.01021	0.42823
POPULATION does not Granger Cause ASTER	17	0.15418	0.92461
ASTER does not Granger Cause POPULATION		0.16777	0.91569
PICEA does not Granger Cause ASTER	17	3.89680	0.04419
ASTER does not Granger Cause PICEA		1.47961	0.27879
PINE does not Granger Cause ASTER	17	0.56957	0.64761
ASTER does not Granger Cause PINE		2.09893	0.16402
POACEAE does not Granger Cause ASTER	17	3.82472	0.04631
ASTER does not Granger Cause POACEAE		0.82988	0.50721
POLYGONACEAE does not Granger Cause ASTER	17	1.09375	0.39618
ASTER does not Granger Cause POLYGONACEAE		1.07054	0.40482
QUERCUS does not Granger Cause ASTER	17	0.18572	0.90369
ASTER does not Granger Cause QUERCUS		5.87465	0.01405
TSUGA does not Granger Cause ASTER	17	0.11694	0.94811
ASTER does not Granger Cause TSUGA		6.60290	0.00976
APIACEAE does not Granger Cause ASTER	17	2.57090	0.11269
ASTER does not Granger Cause APIACEAE		1.13763	0.38039
CHARCOAL does not Granger Cause BETULA	17	0.69109	0.57801
BETULA does not Granger Cause CHARCOAL		1.27318	0.33585
CHENOPODIACEAE does not Granger Cause BETULA	17	1.74789	0.22038
BETULA does not Granger Cause CHENOPODIACEAE		2.39204	0.12954

Table J.3. Pairwise Granger Causality Tests, Three Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause BETULA	17	1.96582	0.18316
BETULA does not Granger Cause LARIX		1.30904	0.32506
LIGULAFLORAE does not Granger Cause BETULA	17	0.92641	0.46320
BETULA does not Granger Cause LIGULAFLORAE		3.51330	0.05699
OXYGEN‰ does not Granger Cause BETULA	17	1.37159	0.30715
BETULA does not Granger Cause OXYGEN‰		0.75991	0.54176
POPULATION does not Granger Cause BETULA	17	1.28372	0.33264
BETULA does not Granger Cause POPULATION		3.00981	0.08117
PICEA does not Granger Cause BETULA	17	1.93344	0.18820
BETULA does not Granger Cause PICEA		0.69760	0.57449
PINE does not Granger Cause BETULA	17	6.00808	0.01312
BETULA does not Granger Cause PINE		1.09033	0.39744
POACEAE does not Granger Cause BETULA	17	1.61980	0.24631
BETULA does not Granger Cause POACEAE		2.08629	0.16574
POLYGONACEAE does not Granger Cause BETULA	17	0.23445	0.87034
BETULA does not Granger Cause POLYGONACEAE		3.11547	0.07522
QUERCUS does not Granger Cause BETULA	17	1.23067	0.34917
BETULA does not Granger Cause QUERCUS		4.45110	0.03122
TSUGA does not Granger Cause BETULA	17	2.71194	0.10119
BETULA does not Granger Cause TSUGA		1.42548	0.29262
APIACEAE does not Granger Cause BETULA	17	11.5911	0.00136
BETULA does not Granger Cause APIACEAE		0.96327	0.44746
CHENOPODIACEAE does not Granger Cause CHARCOAL	17	0.80151	0.52094
CHARCOAL does not Granger Cause CHENOPODIACEAE		4.32659	0.03369
LARIX does not Granger Cause CHARCOAL	17	0.47488	0.70669
CHARCOAL does not Granger Cause LARIX		2.03937	0.17228
LIGULAFLORAE does not Granger Cause CHARCOAL	17	1.17553	0.36732
CHARCOAL does not Granger Cause LIGULAFLORAE		1.86975	0.19859
OXYGEN‰ does not Granger Cause CHARCOAL	17	1.78090	0.21422
CHARCOAL does not Granger Cause OXYGEN‰		1.69001	0.23169
POPULATION does not Granger Cause CHARCOAL	17	2.57248	0.11255
CHARCOAL does not Granger Cause POPULATION		3.96899	0.04218
PICEA does not Granger Cause CHARCOAL	17	4.09545	0.03891
CHARCOAL does not Granger Cause PICEA		2.06023	0.16934
PINE does not Granger Cause CHARCOAL	17	2.85492	0.09093
CHARCOAL does not Granger Cause PINE		0.60252	0.62804
POACEAE does not Granger Cause CHARCOAL	17	6.35445	0.01102
CHARCOAL does not Granger Cause POACEAE		1.34891	0.31352
POLYGONACEAE does not Granger Cause CHARCOAL	17	0.19015	0.90070
CHARCOAL does not Granger Cause POLYGONACEAE		2.51572	0.11760
QUERCUS does not Granger Cause CHARCOAL	17	0.54108	0.66495
CHARCOAL does not Granger Cause QUERCUS		2.08246	0.16626
TSUGA does not Granger Cause CHARCOAL	17	1.62989	0.24415
CHARCOAL does not Granger Cause TSUGA		0.86856	0.48907
APIACEAE does not Granger Cause CHARCOAL	17	1.08015	0.40121
CHARCOAL does not Granger Cause APIACEAE		0.48935	0.69740
LARIX does not Granger Cause CHENOPODIACEAE	17	0.74227	0.55084
CHENOPODIACEAE does not Granger Cause LARIX		13.7628	0.00070
LIGULAFLORAE does not Granger Cause CHENOPODIACEAE	17	0.86776	0.48944
CHENOPODIACEAE does not Granger Cause LIGULAFLORAE		2.62159	0.10839

Table J.3. Pairwise Granger Causality Tests, Three Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
OXYGEN‰ does not Granger Cause CHENOPODIACEAE	17	2.34581	0.13437
CHENOPODIACEAE does not Granger Cause OXYGEN‰		0.61837	0.61881
POPULATION does not Granger Cause CHENOPODIACEAE	17	3.43251	0.06023
CHENOPODIACEAE does not Granger Cause POPULATION		0.07446	0.97235
PICEA does not Granger Cause CHENOPODIACEAE	17	2.45492	0.12330
CHENOPODIACEAE does not Granger Cause PICEA		0.37866	0.77052
PINE does not Granger Cause CHENOPODIACEAE	17	2.12501	0.16055
CHENOPODIACEAE does not Granger Cause PINE		2.99523	0.08203
POACEAE does not Granger Cause CHENOPODIACEAE	17	0.46336	0.71414
CHENOPODIACEAE does not Granger Cause POACEAE		0.40541	0.75245
POLYGONACEAE does not Granger Cause CHENOPODIACEAE	17	0.34960	0.79040
CHENOPODIACEAE does not Granger Cause POLYGONACEAE		1.94683	0.18610
QUERCUS does not Granger Cause CHENOPODIACEAE	17	0.49648	0.69286
CHENOPODIACEAE does not Granger Cause QUERCUS		4.33751	0.03346
TSUGA does not Granger Cause CHENOPODIACEAE	17	2.32456	0.13666
CHENOPODIACEAE does not Granger Cause TSUGA		1.31473	0.32338
APIACEAE does not Granger Cause CHENOPODIACEAE	17	1.96950	0.18260
CHENOPODIACEAE does not Granger Cause APIACEAE		2.89306	0.08840
LIGULAFLORAE does not Granger Cause LARIX	17	0.48822	0.69812
LARIX does not Granger Cause LIGULAFLORAE		3.28175	0.06686
OXYGEN‰ does not Granger Cause LARIX	17	1.62466	0.24527
LARIX does not Granger Cause OXYGEN‰		0.24124	0.86564
POPULATION does not Granger Cause LARIX	17	2.94530	0.08507
LARIX does not Granger Cause POPULATION		0.47749	0.70500
PICEA does not Granger Cause LARIX	17	1.98431	0.18035
LARIX does not Granger Cause PICEA		0.58060	0.64100
PINE does not Granger Cause LARIX	17	2.54295	0.11514
LARIX does not Granger Cause PINE		3.59835	0.05381
POACEAE does not Granger Cause LARIX	17	1.15230	0.37527
LARIX does not Granger Cause POACEAE		1.37960	0.30494
POLYGONACEAE does not Granger Cause LARIX	17	0.18861	0.90174
LARIX does not Granger Cause POLYGONACEAE		3.11912	0.07502
QUERCUS does not Granger Cause LARIX	17	1.25446	0.34164
LARIX does not Granger Cause QUERCUS		7.02371	0.00799
TSUGA does not Granger Cause LARIX	17	2.46710	0.12213
LARIX does not Granger Cause TSUGA		1.71823	0.22609
APIACEAE does not Granger Cause LARIX	17	5.18810	0.02034
LARIX does not Granger Cause APIACEAE		0.43343	0.73377
OXYGEN‰ does not Granger Cause LIGULAFLORAE	17	0.03554	0.99047
LIGULAFLORAE does not Granger Cause OXYGEN‰		2.37905	0.13088
POPULATION does not Granger Cause LIGULAFLORAE	17	0.81692	0.51344
LIGULAFLORAE does not Granger Cause POPULATION		5.99634	0.01320
PICEA does not Granger Cause LIGULAFLORAE	17	0.76093	0.54124
LIGULAFLORAE does not Granger Cause PICEA		0.40430	0.75319
PINE does not Granger Cause LIGULAFLORAE	17	3.72250	0.04953
LIGULAFLORAE does not Granger Cause PINE		1.19581	0.36052

Table J.3. Pairwise Granger Causality Tests, Three Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
POACEAE does not Granger Cause LIGULAFLORAE	17	1.45424	0.28518
LIGULAFLORAE does not Granger Cause POACEAE		2.68851	0.10300
POLYGONACEAE does not Granger Cause LIGULAFLORAE	17	2.24954	0.14512
LIGULAFLORAE does not Granger Cause POLYGONACEAE		1.97579	0.18164
QUERCUS does not Granger Cause LIGULAFLORAE	17	10.0900	0.00228
LIGULAFLORAE does not Granger Cause QUERCUS		1.53481	0.26545
TSUGA does not Granger Cause LIGULAFLORAE	17	0.42608	0.73864
LIGULAFLORAE does not Granger Cause TSUGA		0.91374	0.46874
APIACEAE does not Granger Cause LIGULAFLORAE	17	1.09584	0.39541
LIGULAFLORAE does not Granger Cause APIACEAE		1.00892	0.42875
POPULATION does not Granger Cause OXYGEN‰	17	6.20620	0.01186
OXYGEN‰ does not Granger Cause POPULATION		1.47255	0.28055
PICEA does not Granger Cause OXYGEN‰	17	0.04797	0.98526
OXYGEN‰ does not Granger Cause PICEA		2.15056	0.15724
PINE does not Granger Cause OXYGEN‰	17	1.67289	0.23516
OXYGEN‰ does not Granger Cause PINE		1.41153	0.29630
POACEAE does not Granger Cause OXYGEN‰	17	1.24245	0.34542
OXYGEN‰ does not Granger Cause POACEAE		0.78276	0.53023
POLYGONACEAE does not Granger Cause OXYGEN‰	17	1.19974	0.35922
OXYGEN‰ does not Granger Cause POLYGONACEAE		4.23514	0.03565
QUERCUS does not Granger Cause OXYGEN‰	17	1.05727	0.40984
OXYGEN‰ does not Granger Cause QUERCUS		0.96287	0.44762
TSUGA does not Granger Cause OXYGEN‰	17	0.21458	0.88404
OXYGEN‰ does not Granger Cause TSUGA		3.56306	0.05510
APIACEAE does not Granger Cause OXYGEN‰	17	1.85989	0.20026
OXYGEN‰ does not Granger Cause APIACEAE		1.94414	0.18652
PICEA does not Granger Cause POPULATION	17	6.05093	0.01284
POPULATION does not Granger Cause PICEA		0.39442	0.75984
PINE does not Granger Cause POPULATION	17	2.07977	0.16663
POPULATION does not Granger Cause PINE		0.31272	0.81590
POACEAE does not Granger Cause POPULATION	17	1.53054	0.26646
POPULATION does not Granger Cause POACEAE		0.25682	0.85481
POLYGONACEAE does not Granger Cause POPULATION	17	7.03335	0.00796
POPULATION does not Granger Cause POLYGONACEAE		1.42232	0.29345
QUERCUS does not Granger Cause POPULATION	17	4.66631	0.02745
POPULATION does not Granger Cause QUERCUS		3.75538	0.04847
TSUGA does not Granger Cause POPULATION	17	2.71739	0.10078
POPULATION does not Granger Cause TSUGA		0.55644	0.65556
APIACEAE does not Granger Cause POPULATION	17	0.19412	0.89801
POPULATION does not Granger Cause APIACEAE		1.55308	0.26120
PINE does not Granger Cause PICEA	17	1.42673	0.29229
PICEA does not Granger Cause PINE		2.74444	0.09875
POACEAE does not Granger Cause PICEA	17	1.74446	0.22103
PICEA does not Granger Cause POACEAE		1.78947	0.21265
POLYGONACEAE does not Granger Cause PICEA	17	0.70680	0.56954
PICEA does not Granger Cause POLYGONACEAE		0.38641	0.76526
QUERCUS does not Granger Cause PICEA	17	0.57663	0.64337
PICEA does not Granger Cause QUERCUS		1.72788	0.22421
TSUGA does not Granger Cause PICEA	17	1.65995	0.23782
PICEA does not Granger Cause TSUGA		3.21266	0.07019

Table J.3. Pairwise Granger Causality Tests, Three Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause PICEA	17	0.19623	0.89658
PICEA does not Granger Cause APIACEAE		4.81098	0.02521
POACEAE does not Granger Cause PINE	17	0.16069	0.92035
PINE does not Granger Cause POACEAE		0.79702	0.52315
POLYGONACEAE does not Granger Cause PINE	17	4.26683	0.03495
PINE does not Granger Cause POLYGONACEAE		1.49711	0.27448
QUERCUS does not Granger Cause PINE	17	2.58096	0.11182
PINE does not Granger Cause QUERCUS		4.44646	0.03131
TSUGA does not Granger Cause PINE	17	5.09032	0.02149
PINE does not Granger Cause TSUGA		0.67319	0.58782
APIACEAE does not Granger Cause PINE	17	1.26463	0.33849
PINE does not Granger Cause APIACEAE		1.31656	0.32285
POLYGONACEAE does not Granger Cause POACEAE	17	1.57969	0.25514
POACEAE does not Granger Cause POLYGONACEAE		0.83628	0.50416
QUERCUS does not Granger Cause POACEAE	17	1.22013	0.35256
POACEAE does not Granger Cause QUERCUS		0.88433	0.48187
TSUGA does not Granger Cause POACEAE	17	0.89997	0.47484
POACEAE does not Granger Cause TSUGA		0.59095	0.63485
APIACEAE does not Granger Cause POACEAE	17	0.83276	0.50583
POACEAE does not Granger Cause APIACEAE		1.62904	0.24433
QUERCUS does not Granger Cause POLYGONACEAE	17	3.98873	0.04165
POLYGONACEAE does not Granger Cause QUERCUS		4.13755	0.03789
TSUGA does not Granger Cause POLYGONACEAE	17	0.52527	0.67475
POLYGONACEAE does not Granger Cause TSUGA		1.16798	0.36988
APIACEAE does not Granger Cause POLYGONACEAE	17	0.64360	0.60436
POLYGONACEAE does not Granger Cause APIACEAE		1.22347	0.35148
TSUGA does not Granger Cause QUERCUS	17	13.7402	0.00070
QUERCUS does not Granger Cause TSUGA		0.69213	0.57744
APIACEAE does not Granger Cause QUERCUS	17	3.98940	0.04163
QUERCUS does not Granger Cause APIACEAE		1.05373	0.41120
APIACEAE does not Granger Cause TSUGA	17	0.45081	0.72232
TSUGA does not Granger Cause APIACEAE		2.24693	0.14543

Table J.4. Pairwise Granger Causality Tests, Four Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
ACER does not Granger Cause ABIES	16	1.13786	0.41212
ABIES does not Granger Cause ACER		0.45370	0.76785
ALNUS does not Granger Cause ABIES	16	0.10367	0.97759
ABIES does not Granger Cause ALNUS		2.45716	0.14130
AMBROSIA does not Granger Cause ABIES	16	1.15179	0.40697
ABIES does not Granger Cause AMBROSIA		0.80351	0.55995
ARTEMESIA does not Granger Cause ABIES	16	1.86861	0.22082
ABIES does not Granger Cause ARTEMESIA		9.06815	0.00670
ASTER does not Granger Cause ABIES	16	2.23814	0.16590
ABIES does not Granger Cause ASTER		1.41603	0.32210
BETULA does not Granger Cause ABIES	16	1.02807	0.45536
ABIES does not Granger Cause BETULA		0.23174	0.91194
CHARCOAL does not Granger Cause ABIES	16	1.05441	0.44455
ABIES does not Granger Cause CHARCOAL		0.73112	0.59862
CHENOPODIACEAE does not Granger Cause ABIES	16	1.99931	0.19913
ABIES does not Granger Cause CHENOPODIACEAE		0.46012	0.76364
LARIX does not Granger Cause ABIES	16	1.85077	0.22400
ABIES does not Granger Cause LARIX		0.04832	0.99457
LIGULAFLORAE does not Granger Cause ABIES	16	1.30866	0.35382
ABIES does not Granger Cause LIGULAFLORAE		0.32856	0.85056
OXYGEN‰ does not Granger Cause ABIES	16	0.41416	0.79394
ABIES does not Granger Cause OXYGEN‰		3.89735	0.05657
POPULATION does not Granger Cause ABIES	16	2.93522	0.10168
ABIES does not Granger Cause POPULATION		4.22026	0.04737
PICEA does not Granger Cause ABIES	16	0.38444	0.81364
ABIES does not Granger Cause PICEA		1.70387	0.25246
PINE does not Granger Cause ABIES	16	1.82382	0.22891
ABIES does not Granger Cause PINE		1.79057	0.23516
POACEAE does not Granger Cause ABIES	16	1.02262	0.45764
ABIES does not Granger Cause POACEAE		1.37526	0.33373
POLYGONACEAE does not Granger Cause ABIES	16	0.27293	0.88648
ABIES does not Granger Cause POLYGONACEAE		0.87449	0.52442
QUERCUS does not Granger Cause ABIES	16	3.10392	0.09112
ABIES does not Granger Cause QUERCUS		0.63231	0.65534
TSUGA does not Granger Cause ABIES	16	0.53946	0.71246
ABIES does not Granger Cause TSUGA		0.29117	0.87485
APIACEAE does not Granger Cause ABIES	16	0.85407	0.53440
ABIES does not Granger Cause APIACEAE		1.24878	0.37310
ALNUS does not Granger Cause ACER	16	1.12788	0.41585
ACER does not Granger Cause ALNUS		0.55955	0.69981
AMBROSIA does not Granger Cause ACER	16	0.98736	0.47266
ACER does not Granger Cause AMBROSIA		0.30422	0.86643
ARTEMESIA does not Granger Cause ACER	16	1.17903	0.39711
ACER does not Granger Cause ARTEMESIA		1.50791	0.29761
ASTER does not Granger Cause ACER	16	4.34977	0.04422
ACER does not Granger Cause ASTER		0.71668	0.60663
BETULA does not Granger Cause ACER	16	1.87142	0.22032
ACER does not Granger Cause BETULA		3.66930	0.06448
CHARCOAL does not Granger Cause ACER	16	1.26430	0.36798
ACER does not Granger Cause CHARCOAL		1.20384	0.38837

Table J.4. Pairwise Granger Causality Tests, Four Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
CHENOPODIACEAE does not Granger Cause ACER	16	4.58873	0.03907
ACER does not Granger Cause CHENOPODIACEAE		2.09555	0.18482
LARIX does not Granger Cause ACER	16	7.75030	0.01034
ACER does not Granger Cause LARIX		2.12682	0.18045
LIGULAFLORAE does not Granger Cause ACER	16	0.68078	0.62696
ACER does not Granger Cause LIGULAFLORAE		2.31257	0.15698
OXYGEN‰ does not Granger Cause ACER	16	3.75774	0.06126
ACER does not Granger Cause OXYGEN‰		0.27818	0.88315
POPULATION does not Granger Cause ACER	16	1.08225	0.43342
ACER does not Granger Cause POPULATION		2.61377	0.12647
PICEA does not Granger Cause ACER	16	1.47646	0.30573
ACER does not Granger Cause PICEA		0.88387	0.51990
PINE does not Granger Cause ACER	16	0.80693	0.55818
ACER does not Granger Cause PINE		1.78647	0.23595
POACEAE does not Granger Cause ACER	16	0.47360	0.75482
ACER does not Granger Cause POACEAE		0.51993	0.72488
POLYGONACEAE does not Granger Cause ACER	16	0.43392	0.78087
ACER does not Granger Cause POLYGONACEAE		1.21273	0.38529
QUERCUS does not Granger Cause ACER	16	0.47900	0.75130
ACER does not Granger Cause QUERCUS		13.2149	0.00224
TSUGA does not Granger Cause ACER	16	2.71583	0.11784
ACER does not Granger Cause TSUGA		2.75957	0.11438
APIACEAE does not Granger Cause ACER	16	3.65433	0.06505
ACER does not Granger Cause APIACEAE		1.57502	0.28112
AMBROSIA does not Granger Cause ALNUS	16	1.74077	0.24491
ALNUS does not Granger Cause AMBROSIA		1.00085	0.46685
ARTEMESIA does not Granger Cause ALNUS	16	2.35943	0.15167
ALNUS does not Granger Cause ARTEMESIA		3.17958	0.08683
ASTER does not Granger Cause ALNUS	16	1.15802	0.40469
ALNUS does not Granger Cause ASTER		0.35104	0.83576
BETULA does not Granger Cause ALNUS	16	1.62728	0.26904
ALNUS does not Granger Cause BETULA		0.54290	0.71028
CHARCOAL does not Granger Cause ALNUS	16	2.39343	0.14796
ALNUS does not Granger Cause CHARCOAL		0.92295	0.50150
CHENOPODIACEAE does not Granger Cause ALNUS	16	1.26749	0.36694
ALNUS does not Granger Cause CHENOPODIACEAE		0.89918	0.51261
LARIX does not Granger Cause ALNUS	16	0.99603	0.46892
ALNUS does not Granger Cause LARIX		4.88500	0.03370
LIGULAFLORAE does not Granger Cause ALNUS	16	1.12756	0.41597
ALNUS does not Granger Cause LIGULAFLORAE		1.56369	0.28383
OXYGEN‰ does not Granger Cause ALNUS	16	2.27310	0.16163
ALNUS does not Granger Cause OXYGEN‰		1.16147	0.40344
POPULATION does not Granger Cause ALNUS	16	2.29835	0.15864
ALNUS does not Granger Cause POPULATION		7.95530	0.00963
PICEA does not Granger Cause ALNUS	16	1.35126	0.34081
ALNUS does not Granger Cause PICEA		0.23911	0.90748
PINE does not Granger Cause ALNUS	16	1.53378	0.29112
ALNUS does not Granger Cause PINE		1.34854	0.34162
POACEAE does not Granger Cause ALNUS	16	0.31518	0.85931
ALNUS does not Granger Cause POACEAE		1.23671	0.37713

Table J.4. Pairwise Granger Causality Tests, Four Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
POLYGONACEAE does not Granger Cause ALNUS	16	1.74240	0.24458
ALNUS does not Granger Cause POLYGONACEAE		0.76786	0.57869
QUERCUS does not Granger Cause ALNUS	16	1.95556	0.20608
ALNUS does not Granger Cause QUERCUS		0.25636	0.89688
TSUGA does not Granger Cause ALNUS	16	0.13458	0.96443
ALNUS does not Granger Cause TSUGA		0.62189	0.66157
APIACEAE does not Granger Cause ALNUS	16	1.04776	0.44725
ALNUS does not Granger Cause APIACEAE		0.49843	0.73870
ARTEMESIA does not Granger Cause AMBROSIA	16	8.53663	0.00793
AMBROSIA does not Granger Cause ARTEMESIA		1.67218	0.25916
ASTER does not Granger Cause AMBROSIA	16	1.65105	0.26376
AMBROSIA does not Granger Cause ASTER		0.58908	0.68150
BETULA does not Granger Cause AMBROSIA	16	1.63297	0.26777
AMBROSIA does not Granger Cause BETULA		2.67811	0.12094
CHARCOAL does not Granger Cause AMBROSIA	16	0.55229	0.70437
AMBROSIA does not Granger Cause CHARCOAL		1.79656	0.23402
CHENOPODIACEAE does not Granger Cause AMBROSIA	16	1.84539	0.22497
AMBROSIA does not Granger Cause CHENOPODIACEAE		3.38378	0.07648
LARIX does not Granger Cause AMBROSIA	16	1.40107	0.32631
AMBROSIA does not Granger Cause LARIX		1.31727	0.35114
LIGULAFLORAE does not Granger Cause AMBROSIA	16	0.05334	0.99344
AMBROSIA does not Granger Cause LIGULAFLORAE		11.1502	0.00370
OXYGEN‰ does not Granger Cause AMBROSIA	16	3.52795	0.07010
AMBROSIA does not Granger Cause OXYGEN‰		0.53223	0.71704
POPULATION does not Granger Cause AMBROSIA	16	1.22666	0.38053
AMBROSIA does not Granger Cause POPULATION		4.42487	0.04251
PICEA does not Granger Cause AMBROSIA	16	1.53843	0.28997
AMBROSIA does not Granger Cause PICEA		0.16359	0.95026
PINE does not Granger Cause AMBROSIA	16	1.40255	0.32589
AMBROSIA does not Granger Cause PINE		1.63307	0.26774
POACEAE does not Granger Cause AMBROSIA	16	0.61336	0.66671
AMBROSIA does not Granger Cause POACEAE		0.35975	0.83000
POLYGONACEAE does not Granger Cause AMBROSIA	16	1.97436	0.20306
AMBROSIA does not Granger Cause POLYGONACEAE		0.61158	0.66779
QUERCUS does not Granger Cause AMBROSIA	16	0.51815	0.72602
AMBROSIA does not Granger Cause QUERCUS		8.58648	0.00780
TSUGA does not Granger Cause AMBROSIA	16	0.55461	0.70291
AMBROSIA does not Granger Cause TSUGA		0.76972	0.57770
APIACEAE does not Granger Cause AMBROSIA	16	1.58518	0.27872
AMBROSIA does not Granger Cause APIACEAE		1.64206	0.26574
ASTER does not Granger Cause ARTEMESIA	16	3.81279	0.05935
ARTEMESIA does not Granger Cause ASTER		1.31744	0.35109
BETULA does not Granger Cause ARTEMESIA	16	0.88105	0.52125
ARTEMESIA does not Granger Cause BETULA		3.12222	0.09006
CHARCOAL does not Granger Cause ARTEMESIA	16	0.06766	0.98975
ARTEMESIA does not Granger Cause CHARCOAL		3.42479	0.07459
CHENOPODIACEAE does not Granger Cause ARTEMESIA	16	1.33450	0.34586
ARTEMESIA does not Granger Cause CHENOPODIACEAE		3.58302	0.06784

Table J.4. Pairwise Granger Causality Tests, Four Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause ARTEMESIA	16	2.01618	0.19653
ARTEMESIA does not Granger Cause LARIX		3.40377	0.07555
LIGULAFLORAE does not Granger Cause ARTEMESIA	16	1.13807	0.41204
ARTEMESIA does not Granger Cause LIGULAFLORAE		2.38157	0.14924
OXYGEN‰ does not Granger Cause ARTEMESIA	16	2.75450	0.11477
ARTEMESIA does not Granger Cause OXYGEN‰		1.10913	0.42297
POPULATION does not Granger Cause ARTEMESIA	16	1.13886	0.41175
ARTEMESIA does not Granger Cause POPULATION		4.38027	0.04351
PICEA does not Granger Cause ARTEMESIA	16	1.80155	0.23308
ARTEMESIA does not Granger Cause PICEA		0.10629	0.97657
PINE does not Granger Cause ARTEMESIA	16	0.73104	0.59867
ARTEMESIA does not Granger Cause PINE		3.98385	0.05390
POACEAE does not Granger Cause ARTEMESIA	16	0.45994	0.76376
ARTEMESIA does not Granger Cause POACEAE		0.80720	0.55805
POLYGONACEAE does not Granger Cause ARTEMESIA	16	4.83348	0.03457
ARTEMESIA does not Granger Cause POLYGONACEAE		1.63552	0.26720
QUERCUS does not Granger Cause ARTEMESIA	16	1.23655	0.37718
ARTEMESIA does not Granger Cause QUERCUS		6.90320	0.01411
TSUGA does not Granger Cause ARTEMESIA	16	1.98740	0.20099
ARTEMESIA does not Granger Cause TSUGA		2.41802	0.14534
APIACEAE does not Granger Cause ARTEMESIA	16	2.25874	0.16337
ARTEMESIA does not Granger Cause APIACEAE		3.63912	0.06563
BETULA does not Granger Cause ASTER	16	2.73179	0.11656
ASTER does not Granger Cause BETULA		3.72685	0.06236
CHARCOAL does not Granger Cause ASTER	16	0.66199	0.63784
ASTER does not Granger Cause CHARCOAL		2.28230	0.16053
CHENOPODIACEAE does not Granger Cause ASTER	16	0.32952	0.84993
ASTER does not Granger Cause CHENOPODIACEAE		53.9367	2.4E-05
LARIX does not Granger Cause ASTER	16	2.26323	0.16282
ASTER does not Granger Cause LARIX		11.7912	0.00314
LIGULAFLORAE does not Granger Cause ASTER	16	0.55897	0.70018
ASTER does not Granger Cause LIGULAFLORAE		1.22509	0.38106
OXYGEN‰ does not Granger Cause ASTER	16	6.32550	0.01773
ASTER does not Granger Cause OXYGEN‰		0.86142	0.53078
POPULATION does not Granger Cause ASTER	16	0.97431	0.47835
ASTER does not Granger Cause POPULATION		0.68842	0.62258
PICEA does not Granger Cause ASTER	16	2.25848	0.16340
ASTER does not Granger Cause PICEA		0.98461	0.47386
PINE does not Granger Cause ASTER	16	1.72177	0.24876
ASTER does not Granger Cause PINE		1.85653	0.22297
POACEAE does not Granger Cause ASTER	16	2.28477	0.16024
ASTER does not Granger Cause POACEAE		1.64419	0.26527
POLYGONACEAE does not Granger Cause ASTER	16	0.86531	0.52888
ASTER does not Granger Cause POLYGONACEAE		0.46767	0.75870
QUERCUS does not Granger Cause ASTER	16	0.06589	0.99025
ASTER does not Granger Cause QUERCUS		6.96162	0.01379
TSUGA does not Granger Cause ASTER	16	0.13042	0.96633
ASTER does not Granger Cause TSUGA		4.50198	0.04085

Table J.4. Pairwise Granger Causality Tests, Four Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause ASTER	16	1.26973	0.36622
ASTER does not Granger Cause APIACEAE		1.42211	0.32040
CHARCOAL does not Granger Cause BETULA	16	0.66817	0.63424
BETULA does not Granger Cause CHARCOAL		1.83451	0.22695
CHENOPODIACEAE does not Granger Cause BETULA	16	7.05856	0.01330
BETULA does not Granger Cause CHENOPODIACEAE		2.91034	0.10337
LARIX does not Granger Cause BETULA	16	4.47154	0.04149
BETULA does not Granger Cause LARIX		1.18177	0.39613
LIGULAFLORAE does not Granger Cause BETULA	16	1.07181	0.43755
BETULA does not Granger Cause LIGULAFLORAE		1.85587	0.22308
OXYGEN‰ does not Granger Cause BETULA	16	0.90674	0.50904
BETULA does not Granger Cause OXYGEN‰		0.53861	0.71299
POPULATION does not Granger Cause BETULA	16	0.65224	0.64354
BETULA does not Granger Cause POPULATION		3.25082	0.08303
PICEA does not Granger Cause BETULA	16	6.11857	0.01931
BETULA does not Granger Cause PICEA		2.04175	0.19266
PINE does not Granger Cause BETULA	16	3.70311	0.06322
BETULA does not Granger Cause PINE		1.67122	0.25937
POACEAE does not Granger Cause BETULA	16	2.19080	0.17190
BETULA does not Granger Cause POACEAE		2.35687	0.15195
POLYGONACEAE does not Granger Cause BETULA	16	0.33999	0.84305
BETULA does not Granger Cause POLYGONACEAE		2.56945	0.13046
QUERCUS does not Granger Cause BETULA	16	0.41945	0.79044
BETULA does not Granger Cause QUERCUS		5.17122	0.02938
TSUGA does not Granger Cause BETULA	16	1.31663	0.35134
BETULA does not Granger Cause TSUGA		1.87922	0.21895
APIACEAE does not Granger Cause BETULA	16	12.1436	0.00288
BETULA does not Granger Cause APIACEAE		1.31012	0.35336
CHENOPODIACEAE does not Granger Cause CHARCOAL	16	0.39857	0.80427
CHARCOAL does not Granger Cause CHENOPODIACEAE		5.01800	0.03160
LARIX does not Granger Cause CHARCOAL	16	0.29689	0.87117
CHARCOAL does not Granger Cause LARIX		1.63043	0.26834
LIGULAFLORAE does not Granger Cause CHARCOAL	16	0.71230	0.60908
CHARCOAL does not Granger Cause LIGULAFLORAE		0.86540	0.52884
OXYGEN‰ does not Granger Cause CHARCOAL	16	4.73862	0.03623
CHARCOAL does not Granger Cause OXYGEN‰		1.23153	0.37887
POPULATION does not Granger Cause CHARCOAL	16	2.11709	0.18180
CHARCOAL does not Granger Cause POPULATION		8.07877	0.00923
PICEA does not Granger Cause CHARCOAL	16	4.67647	0.03737
CHARCOAL does not Granger Cause PICEA		2.59467	0.12817
PINE does not Granger Cause CHARCOAL	16	3.36483	0.07737
CHARCOAL does not Granger Cause PINE		1.09282	0.42928
POACEAE does not Granger Cause CHARCOAL	16	5.64629	0.02366
CHARCOAL does not Granger Cause POACEAE		0.74270	0.59227
POLYGONACEAE does not Granger Cause CHARCOAL	16	0.34014	0.84295
CHARCOAL does not Granger Cause POLYGONACEAE		1.70241	0.25276
QUERCUS does not Granger Cause CHARCOAL	16	0.86048	0.53125
CHARCOAL does not Granger Cause QUERCUS		1.11906	0.41918

Table J.4. Pairwise Granger Causality Tests, Four Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
TSUGA does not Granger Cause CHARCOAL	16	0.66001	0.63899
CHARCOAL does not Granger Cause TSUGA		3.56130	0.06872
APIACEAE does not Granger Cause CHARCOAL	16	1.56200	0.28423
CHARCOAL does not Granger Cause APIACEAE		0.33378	0.84713
LARIX does not Granger Cause CHENOPODIACEAE	16	0.61443	0.66606
CHENOPODIACEAE does not Granger Cause LARIX		6.97053	0.01375
LIGULAFLORAE does not Granger Cause CHENOPODIACEAE	16	1.34567	0.34248
CHENOPODIACEAE does not Granger Cause LIGULAFLORAE		6.19794	0.01868
OXYGEN‰ does not Granger Cause CHENOPODIACEAE	16	20.0044	0.00062
CHENOPODIACEAE does not Granger Cause OXYGEN‰		0.28242	0.88045
POPULATION does not Granger Cause CHENOPODIACEAE	16	2.55576	0.13172
CHENOPODIACEAE does not Granger Cause POPULATION		0.57485	0.69028
PICEA does not Granger Cause CHENOPODIACEAE	16	2.15454	0.17669
CHENOPODIACEAE does not Granger Cause PICEA		0.13855	0.96259
PINE does not Granger Cause CHENOPODIACEAE	16	4.05423	0.05184
CHENOPODIACEAE does not Granger Cause PINE		4.76457	0.03577
POACEAE does not Granger Cause CHENOPODIACEAE	16	3.55502	0.06897
CHENOPODIACEAE does not Granger Cause POACEAE		0.21649	0.92100
POLYGONACEAE does not Granger Cause CHENOPODIACEAE	16	1.11510	0.42069
CHENOPODIACEAE does not Granger Cause POLYGONACEAE		3.82089	0.05908
QUERCUS does not Granger Cause CHENOPODIACEAE	16	1.32426	0.34899
CHENOPODIACEAE does not Granger Cause QUERCUS		11.0225	0.00383
TSUGA does not Granger Cause CHENOPODIACEAE	16	1.17378	0.39899
CHENOPODIACEAE does not Granger Cause TSUGA		1.36734	0.33605
APIACEAE does not Granger Cause CHENOPODIACEAE	16	17.3845	0.00097
CHENOPODIACEAE does not Granger Cause APIACEAE		1.58014	0.27991
LIGULAFLORAE does not Granger Cause LARIX	16	0.58578	0.68353
LARIX does not Granger Cause LIGULAFLORAE		5.15320	0.02963
OXYGEN‰ does not Granger Cause LARIX	16	2.18203	0.17304
LARIX does not Granger Cause OXYGEN‰		0.11971	0.97104
POPULATION does not Granger Cause LARIX	16	2.64483	0.12376
LARIX does not Granger Cause POPULATION		2.71387	0.11800
PICEA does not Granger Cause LARIX	16	1.58413	0.27897
LARIX does not Granger Cause PICEA		0.25335	0.89874
PINE does not Granger Cause LARIX	16	1.32675	0.34822
LARIX does not Granger Cause PINE		2.94241	0.10120
POACEAE does not Granger Cause LARIX	16	0.72883	0.59989
LARIX does not Granger Cause POACEAE		0.79795	0.56283
POLYGONACEAE does not Granger Cause LARIX	16	0.29717	0.87100
LARIX does not Granger Cause POLYGONACEAE		2.94355	0.10112
QUERCUS does not Granger Cause LARIX	16	1.76407	0.24029
LARIX does not Granger Cause QUERCUS		3.67377	0.06431
TSUGA does not Granger Cause LARIX	16	1.91361	0.21304
LARIX does not Granger Cause TSUGA		2.10539	0.18344

Table J.4. Pairwise Granger Causality Tests, Four Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause LARIX	16	5.69303	0.02317
LARIX does not Granger Cause APIACEAE		0.28923	0.87610
OXYGEN‰ does not Granger Cause LIGULAFLORAE	16	0.12522	0.96865
LIGULAFLORAE does not Granger Cause OXYGEN‰		1.31433	0.35205
POPULATION does not Granger Cause LIGULAFLORAE	16	1.12321	0.41761
LIGULAFLORAE does not Granger Cause POPULATION		3.52501	0.07022
PICEA does not Granger Cause LIGULAFLORAE	16	0.48661	0.74636
LIGULAFLORAE does not Granger Cause PICEA		0.42623	0.78595
PINE does not Granger Cause LIGULAFLORAE	16	4.24589	0.04672
LIGULAFLORAE does not Granger Cause PINE		0.78857	0.56773
POACEAE does not Granger Cause LIGULAFLORAE	16	1.20645	0.38746
LIGULAFLORAE does not Granger Cause POACEAE		1.33362	0.34612
POLYGONACEAE does not Granger Cause LIGULAFLORAE	16	1.80743	0.23197
LIGULAFLORAE does not Granger Cause POLYGONACEAE		1.64617	0.26483
QUERCUS does not Granger Cause LIGULAFLORAE	16	6.18600	0.01877
LIGULAFLORAE does not Granger Cause QUERCUS		0.85647	0.53321
TSUGA does not Granger Cause LIGULAFLORAE	16	1.16279	0.40295
LIGULAFLORAE does not Granger Cause TSUGA		0.98639	0.47308
APIACEAE does not Granger Cause LIGULAFLORAE	16	1.05668	0.44363
LIGULAFLORAE does not Granger Cause APIACEAE		1.05866	0.44282
POPULATION does not Granger Cause OXYGEN‰	16	4.89059	0.03361
OXYGEN‰ does not Granger Cause POPULATION		1.37706	0.33320
PICEA does not Granger Cause OXYGEN‰	16	0.08242	0.98523
OXYGEN‰ does not Granger Cause PICEA		3.29790	0.08063
PINE does not Granger Cause OXYGEN‰	16	1.33129	0.34683
OXYGEN‰ does not Granger Cause PINE		2.89682	0.10430
POACEAE does not Granger Cause OXYGEN‰	16	0.73951	0.59401
OXYGEN‰ does not Granger Cause POACEAE		2.91585	0.10299
POLYGONACEAE does not Granger Cause OXYGEN‰	16	1.12425	0.41722
OXYGEN‰ does not Granger Cause POLYGONACEAE		7.48352	0.01137
QUERCUS does not Granger Cause OXYGEN‰	16	0.59746	0.67637
OXYGEN‰ does not Granger Cause QUERCUS		1.75620	0.24184
TSUGA does not Granger Cause OXYGEN‰	16	0.38884	0.81072
OXYGEN‰ does not Granger Cause TSUGA		3.16995	0.08736
APIACEAE does not Granger Cause OXYGEN‰	16	1.46942	0.30758
OXYGEN‰ does not Granger Cause APIACEAE		1.14506	0.40945
PICEA does not Granger Cause POPULATION	16	6.99711	0.01361
POPULATION does not Granger Cause PICEA		1.13907	0.41167
PINE does not Granger Cause POPULATION	16	2.75833	0.11447
POPULATION does not Granger Cause PINE		0.40630	0.79914
POACEAE does not Granger Cause POPULATION	16	2.13657	0.17912
POPULATION does not Granger Cause POACEAE		0.21307	0.92300
POLYGONACEAE does not Granger Cause POPULATION	16	4.03629	0.05236
POPULATION does not Granger Cause POLYGONACEAE		4.34084	0.04443
QUERCUS does not Granger Cause POPULATION	16	2.72347	0.11723
POPULATION does not Granger Cause QUERCUS		2.56079	0.13125
TSUGA does not Granger Cause POPULATION	16	2.60045	0.12765
POPULATION does not Granger Cause TSUGA		0.67999	0.62742

Table J.4. Pairwise Granger Causality Tests, Four Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause POPULATION	16	1.41962	0.32110
POPULATION does not Granger Cause APIACEAE		1.66685	0.26031
PINE does not Granger Cause PICEA	16	0.24331	0.90492
PICEA does not Granger Cause PINE		1.32194	0.34970
POACEAE does not Granger Cause PICEA	16	2.47572	0.13943
PICEA does not Granger Cause POACEAE		0.68504	0.62452
POLYGONACEAE does not Granger Cause PICEA	16	1.33317	0.34626
PICEA does not Granger Cause POLYGONACEAE		0.30753	0.86429
QUERCUS does not Granger Cause PICEA	16	0.85610	0.53340
PICEA does not Granger Cause QUERCUS		3.54151	0.06953
TSUGA does not Granger Cause PICEA	16	1.02279	0.45757
PICEA does not Granger Cause TSUGA		3.53683	0.06972
APIACEAE does not Granger Cause PICEA	16	1.76508	0.24009
PICEA does not Granger Cause APIACEAE		4.57444	0.03936
POACEAE does not Granger Cause PINE	16	1.18324	0.39561
PINE does not Granger Cause POACEAE		0.64835	0.64583
POLYGONACEAE does not Granger Cause PINE	16	3.39728	0.07585
PINE does not Granger Cause POLYGONACEAE		2.02128	0.19575
QUERCUS does not Granger Cause PINE	16	3.54158	0.06953
PINE does not Granger Cause QUERCUS		2.36077	0.15152
TSUGA does not Granger Cause PINE	16	2.82570	0.10937
PINE does not Granger Cause TSUGA		0.93432	0.49627
APIACEAE does not Granger Cause PINE	16	1.23270	0.37848
PINE does not Granger Cause APIACEAE		1.05513	0.44425
POLYGONACEAE does not Granger Cause POACEAE	16	1.29259	0.35888
POACEAE does not Granger Cause POLYGONACEAE		1.43196	0.31768
QUERCUS does not Granger Cause POACEAE	16	0.86806	0.52754
POACEAE does not Granger Cause QUERCUS		0.68138	0.62661
TSUGA does not Granger Cause POACEAE	16	0.21822	0.91999
POACEAE does not Granger Cause TSUGA		1.24706	0.37367
APIACEAE does not Granger Cause POACEAE	16	3.16713	0.08752
POACEAE does not Granger Cause APIACEAE		0.95443	0.48717
QUERCUS does not Granger Cause POLYGONACEAE	16	2.37442	0.15002
POLYGONACEAE does not Granger Cause QUERCUS		2.27556	0.16134
TSUGA does not Granger Cause POLYGONACEAE	16	0.44730	0.77205
POLYGONACEAE does not Granger Cause TSUGA		3.74042	0.06187
APIACEAE does not Granger Cause POLYGONACEAE	16	8.68217	0.00757
POLYGONACEAE does not Granger Cause APIACEAE		0.78200	0.57118
TSUGA does not Granger Cause QUERCUS	16	8.53494	0.00793
QUERCUS does not Granger Cause TSUGA		1.22645	0.38060
APIACEAE does not Granger Cause QUERCUS	16	7.64677	0.01073
QUERCUS does not Granger Cause APIACEAE		1.48974	0.30227
APIACEAE does not Granger Cause TSUGA	16	0.69811	0.61707
TSUGA does not Granger Cause APIACEAE		1.99744	0.19942

Table J.5. Pairwise Granger Causality Tests, Five Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
ACER does not Granger Cause ABIES	15	1.83247	0.28857
ABIES does not Granger Cause ACER		0.54656	0.73914
ALNUS does not Granger Cause ABIES	15	1.22200	0.43521
ABIES does not Granger Cause ALNUS		1.70726	0.31220
AMBROSIA does not Granger Cause ABIES	15	2.07250	0.24997
ABIES does not Granger Cause AMBROSIA		0.77636	0.61381
ARTEMESIA does not Granger Cause ABIES	15	6.23898	0.05023
ABIES does not Granger Cause ARTEMESIA		4.25279	0.09283
ASTER does not Granger Cause ABIES	15	2.71364	0.17744
ABIES does not Granger Cause ASTER		1.62810	0.32859
BETULA does not Granger Cause ABIES	15	0.91379	0.55014
ABIES does not Granger Cause BETULA		0.31878	0.87919
CHARCOAL does not Granger Cause ABIES	15	6.02104	0.05328
ABIES does not Granger Cause CHARCOAL		0.47118	0.78475
CHENOPODIACEAE does not Granger Cause ABIES	15	3.60129	0.11919
ABIES does not Granger Cause CHENOPODIACEAE		0.90183	0.55535
LARIX does not Granger Cause ABIES	15	1.94161	0.27002
ABIES does not Granger Cause LARIX		0.32349	0.87632
LIGULAFLORAE does not Granger Cause ABIES	15	2.12404	0.24267
ABIES does not Granger Cause LIGULAFLORAE		0.45351	0.79565
OXYGEN‰ does not Granger Cause ABIES	15	0.45222	0.79645
ABIES does not Granger Cause OXYGEN‰		2.22430	0.22932
POPULATION does not Granger Cause ABIES	15	5.57444	0.06047
ABIES does not Granger Cause POPULATION		10.3323	0.02099
PICEA does not Granger Cause ABIES	15	0.81037	0.59727
ABIES does not Granger Cause PICEA		1.04123	0.49828
PINE does not Granger Cause ABIES	15	2.89941	0.16220
ABIES does not Granger Cause PINE		2.39033	0.20948
POACEAE does not Granger Cause ABIES	15	0.82297	0.59127
ABIES does not Granger Cause POACEAE		1.05924	0.49147
POLYGONACEAE does not Granger Cause ABIES	15	2.40287	0.20808
ABIES does not Granger Cause POLYGONACEAE		0.89050	0.56034
QUERCUS does not Granger Cause ABIES	15	2.66244	0.18201
ABIES does not Granger Cause QUERCUS		0.22218	0.93488
TSUGA does not Granger Cause ABIES	15	1.80923	0.29276
ABIES does not Granger Cause TSUGA		0.25075	0.91923
APIACEAE does not Granger Cause ABIES	15	0.57141	0.72452
ABIES does not Granger Cause APIACEAE		0.79499	0.60468
ALNUS does not Granger Cause ACER	15	1.34034	0.39968
ACER does not Granger Cause ALNUS		1.96456	0.26634
AMBROSIA does not Granger Cause ACER	15	0.55701	0.73296
ACER does not Granger Cause AMBROSIA		0.15819	0.96581
ARTEMESIA does not Granger Cause ACER	15	3.19101	0.14191
ACER does not Granger Cause ARTEMESIA		1.36813	0.39192
ASTER does not Granger Cause ACER	15	2.19818	0.23269
ACER does not Granger Cause ASTER		1.02724	0.50366
BETULA does not Granger Cause ACER	15	8.26624	0.03111
ACER does not Granger Cause BETULA		2.77982	0.17178
CHARCOAL does not Granger Cause ACER	15	1.23878	0.42991
ACER does not Granger Cause CHARCOAL		0.78782	0.60817
CHENOPODIACEAE does not Granger Cause ACER	15	3.04521	0.15156
ACER does not Granger Cause CHENOPODIACEAE		1.12418	0.46792

Table J.5. Pairwise Granger Causality Tests, Five Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause ACER	15	5.38801	0.06390
ACER does not Granger Cause LARIX		0.88478	0.56288
LIGULAFLORAE does not Granger Cause ACER	15	0.63448	0.68849
ACER does not Granger Cause LIGULAFLORAE		1.29064	0.41410
OXYGEN‰ does not Granger Cause ACER	15	9.15071	0.02604
ACER does not Granger Cause OXYGEN‰		0.99965	0.51448
POPULATION does not Granger Cause ACER	15	0.78149	0.61128
ACER does not Granger Cause POPULATION		2.32517	0.21695
PICEA does not Granger Cause ACER	15	1.79827	0.29476
ACER does not Granger Cause PICEA		2.54058	0.19361
PINE does not Granger Cause ACER	15	0.68778	0.65937
ACER does not Granger Cause PINE		1.33335	0.40166
POACEAE does not Granger Cause ACER	15	0.64281	0.68386
ACER does not Granger Cause POACEAE		0.57697	0.72128
POLYGONACEAE does not Granger Cause ACER	15	1.86573	0.28273
ACER does not Granger Cause POLYGONACEAE		1.57773	0.33967
QUERCUS does not Granger Cause ACER	15	4.91634	0.07402
ACER does not Granger Cause QUERCUS		9.61271	0.02387
TSUGA does not Granger Cause ACER	15	2.76730	0.17283
ACER does not Granger Cause TSUGA		1.07297	0.48636
APIACEAE does not Granger Cause ACER	15	2.17523	0.23572
ACER does not Granger Cause APIACEAE		1.38271	0.38793
AMBROSIA does not Granger Cause ALNUS	15	2.44927	0.20303
ALNUS does not Granger Cause AMBROSIA		0.84865	0.57927
ARTEMESIA does not Granger Cause ALNUS	15	2.74131	0.17504
ALNUS does not Granger Cause ARTEMESIA		13.1554	0.01356
ASTER does not Granger Cause ALNUS	15	0.90175	0.55538
ALNUS does not Granger Cause ASTER		0.15705	0.96630
BETULA does not Granger Cause ALNUS	15	1.45920	0.36792
ALNUS does not Granger Cause BETULA		1.71782	0.31010
CHARCOAL does not Granger Cause ALNUS	15	1.45159	0.36984
ALNUS does not Granger Cause CHARCOAL		0.23730	0.92670
CHENOPODIACEAE does not Granger Cause ALNUS	15	1.55887	0.34395
ALNUS does not Granger Cause CHENOPODIACEAE		2.02459	0.25705
LARIX does not Granger Cause ALNUS	15	1.88841	0.27884
ALNUS does not Granger Cause LARIX		2.11237	0.24429
LIGULAFLORAE does not Granger Cause ALNUS	15	0.98718	0.51947
ALNUS does not Granger Cause LIGULAFLORAE		1.96904	0.26563
OXYGEN‰ does not Granger Cause ALNUS	15	1.39204	0.38541
ALNUS does not Granger Cause OXYGEN‰		0.55512	0.73408
POPULATION does not Granger Cause ALNUS	15	4.69692	0.07955
ALNUS does not Granger Cause POPULATION		5.98017	0.05388
PICEA does not Granger Cause ALNUS	15	1.07537	0.48548
ALNUS does not Granger Cause PICEA		1.44235	0.37220
PINE does not Granger Cause ALNUS	15	2.59997	0.18782
ALNUS does not Granger Cause PINE		2.90056	0.16211
POACEAE does not Granger Cause ALNUS	15	1.11835	0.46997
ALNUS does not Granger Cause POACEAE		2.51853	0.19583
POLYGONACEAE does not Granger Cause ALNUS	15	13.3117	0.01327
ALNUS does not Granger Cause POLYGONACEAE		0.69264	0.65678
QUERCUS does not Granger Cause ALNUS	15	1.40617	0.38164
ALNUS does not Granger Cause QUERCUS		0.58796	0.71491

Table J.5. Pairwise Granger Causality Tests, Five Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
TSUGA does not Granger Cause ALNUS	15	0.92879	0.54369
ALNUS does not Granger Cause TSUGA		4.22965	0.09362
APIACEAE does not Granger Cause ALNUS	15	1.24313	0.42856
ALNUS does not Granger Cause APIACEAE		0.32533	0.87520
ARTEMESIA does not Granger Cause AMBROSIA	15	8.51100	0.02957
AMBROSIA does not Granger Cause ARTEMESIA		2.07899	0.24903
ASTER does not Granger Cause AMBROSIA	15	1.22098	0.43553
AMBROSIA does not Granger Cause ASTER		0.25387	0.91747
BETULA does not Granger Cause AMBROSIA	15	1.97189	0.26518
AMBROSIA does not Granger Cause BETULA		4.05881	0.09969
CHARCOAL does not Granger Cause AMBROSIA	15	1.23043	0.43254
AMBROSIA does not Granger Cause CHARCOAL		0.80235	0.60112
CHENOPODIACEAE does not Granger Cause AMBROSIA	15	1.33995	0.39979
AMBROSIA does not Granger Cause CHENOPODIACEAE		1.67343	0.31906
LARIX does not Granger Cause AMBROSIA	15	1.93027	0.27187
AMBROSIA does not Granger Cause LARIX		0.72001	0.64237
LIGULAFLORAE does not Granger Cause AMBROSIA	15	0.04565	0.99772
AMBROSIA does not Granger Cause LIGULAFLORAE		5.82033	0.05634
OXYGEN‰ does not Granger Cause AMBROSIA	15	7.18943	0.03956
AMBROSIA does not Granger Cause OXYGEN‰		0.74897	0.62751
POPULATION does not Granger Cause AMBROSIA	15	1.05417	0.49338
AMBROSIA does not Granger Cause POPULATION		4.02939	0.10080
PICEA does not Granger Cause AMBROSIA	15	6.14320	0.05154
AMBROSIA does not Granger Cause PICEA		0.39975	0.82909
PINE does not Granger Cause AMBROSIA	15	9.35368	0.02505
AMBROSIA does not Granger Cause PINE		1.04895	0.49535
POACEAE does not Granger Cause AMBROSIA	15	1.77044	0.29994
AMBROSIA does not Granger Cause POACEAE		0.18364	0.95432
POLYGONACEAE does not Granger Cause AMBROSIA	15	7.22585	0.03922
AMBROSIA does not Granger Cause POLYGONACEAE		1.25836	0.42385
QUERCUS does not Granger Cause AMBROSIA	15	0.36902	0.84824
AMBROSIA does not Granger Cause QUERCUS		3.23071	0.13945
TSUGA does not Granger Cause AMBROSIA	15	1.69457	0.31474
AMBROSIA does not Granger Cause TSUGA		0.26653	0.91024
APIACEAE does not Granger Cause AMBROSIA	15	1.02104	0.50606
AMBROSIA does not Granger Cause APIACEAE		0.99892	0.51477
ASTER does not Granger Cause ARTEMESIA	15	4.22356	0.09382
ARTEMESIA does not Granger Cause ASTER		1.38393	0.38760
BETULA does not Granger Cause ARTEMESIA	15	0.94842	0.53539
ARTEMESIA does not Granger Cause BETULA		3.81222	0.10955
CHARCOAL does not Granger Cause ARTEMESIA	15	0.92069	0.54715
ARTEMESIA does not Granger Cause CHARCOAL		0.91423	0.54995
CHENOPODIACEAE does not Granger Cause ARTEMESIA	15	0.67635	0.66551
ARTEMESIA does not Granger Cause CHENOPODIACEAE		1.59767	0.33522
LARIX does not Granger Cause ARTEMESIA	15	1.21290	0.43812
ARTEMESIA does not Granger Cause LARIX		1.84395	0.28653
LIGULAFLORAE does not Granger Cause ARTEMESIA	15	1.80255	0.29397
ARTEMESIA does not Granger Cause LIGULAFLORAE		2.80247	0.16990

Table J.5. Pairwise Granger Causality Tests, Five Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
OXYGEN‰ does not Granger Cause ARTEMESIA	15	1.74515	0.30476
ARTEMESIA does not Granger Cause OXYGEN‰		0.63861	0.68619
POPULATION does not Granger Cause ARTEMESIA	15	2.94044	0.15910
ARTEMESIA does not Granger Cause POPULATION		7.52768	0.03657
PICEA does not Granger Cause ARTEMESIA	15	1.67620	0.31849
ARTEMESIA does not Granger Cause PICEA		0.46848	0.78641
PINE does not Granger Cause ARTEMESIA	15	0.93650	0.54041
ARTEMESIA does not Granger Cause PINE		2.86558	0.16483
POACEAE does not Granger Cause ARTEMESIA	15	0.34774	0.86142
ARTEMESIA does not Granger Cause POACEAE		0.24564	0.92209
POLYGONACEAE does not Granger Cause ARTEMESIA	15	3.21877	0.14018
ARTEMESIA does not Granger Cause POLYGONACEAE		3.77073	0.11136
QUERCUS does not Granger Cause ARTEMESIA	15	0.69499	0.65552
ARTEMESIA does not Granger Cause QUERCUS		3.63460	0.11759
TSUGA does not Granger Cause ARTEMESIA	15	0.93458	0.54122
ARTEMESIA does not Granger Cause TSUGA		1.23124	0.43229
APIACEAE does not Granger Cause ARTEMESIA	15	2.88566	0.16326
ARTEMESIA does not Granger Cause APIACEAE		3.20254	0.14119
BETULA does not Granger Cause ASTER	15	1.35580	0.39534
ASTER does not Granger Cause BETULA		1.70446	0.31276
CHARCOAL does not Granger Cause ASTER	15	1.53190	0.35022
ASTER does not Granger Cause CHARCOAL		0.67588	0.66576
CHENOPODIACEAE does not Granger Cause ASTER	15	0.72846	0.63800
ASTER does not Granger Cause CHENOPODIACEAE		29.6004	0.00295
LARIX does not Granger Cause ASTER	15	1.51166	0.35502
ASTER does not Granger Cause LARIX		5.67794	0.05868
LIGULAFLORAE does not Granger Cause ASTER	15	2.22476	0.22927
ASTER does not Granger Cause LIGULAFLORAE		1.05080	0.49465
OXYGEN‰ does not Granger Cause ASTER	15	6.26327	0.04990
ASTER does not Granger Cause OXYGEN‰		0.49850	0.76803
POPULATION does not Granger Cause ASTER	15	1.39816	0.38377
ASTER does not Granger Cause POPULATION		0.57454	0.72269
PICEA does not Granger Cause ASTER	15	7.68060	0.03533
ASTER does not Granger Cause PICEA		2.27078	0.22350
PINE does not Granger Cause ASTER	15	1.71049	0.31155
ASTER does not Granger Cause PINE		1.62299	0.32969
POACEAE does not Granger Cause ASTER	15	2.88421	0.16337
ASTER does not Granger Cause POACEAE		0.72562	0.63947
POLYGONACEAE does not Granger Cause ASTER	15	0.98560	0.52011
ASTER does not Granger Cause POLYGONACEAE		0.45511	0.79466
QUERCUS does not Granger Cause ASTER	15	0.30750	0.88602
ASTER does not Granger Cause QUERCUS		2.58699	0.18907
TSUGA does not Granger Cause ASTER	15	0.75113	0.62642
ASTER does not Granger Cause TSUGA		2.58028	0.18972
APIACEAE does not Granger Cause ASTER	15	0.94398	0.53725
ASTER does not Granger Cause APIACEAE		1.53895	0.34856
CHARCOAL does not Granger Cause BETULA	15	0.48727	0.77488
BETULA does not Granger Cause CHARCOAL		0.72717	0.63867
CHENOPODIACEAE does not Granger Cause BETULA	15	6.22840	0.05037
BETULA does not Granger Cause CHENOPODIACEAE		1.48475	0.36156

Table J.5. Pairwise Granger Causality Tests, Five Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause BETULA	15	1.77496	0.29909
BETULA does not Granger Cause LARIX		1.44342	0.37193
LIGULAFLORAE does not Granger Cause BETULA	15	1.81581	0.29156
BETULA does not Granger Cause LIGULAFLORAE		6.45650	0.04744
OXYGEN‰ does not Granger Cause BETULA	15	2.48500	0.19927
BETULA does not Granger Cause OXYGEN‰		1.95593	0.26772
POPULATION does not Granger Cause BETULA	15	0.40128	0.82814
BETULA does not Granger Cause POPULATION		3.23287	0.13931
PICEA does not Granger Cause BETULA	15	4.66893	0.08031
BETULA does not Granger Cause PICEA		1.52378	0.35213
PINE does not Granger Cause BETULA	15	2.35537	0.21344
BETULA does not Granger Cause PINE		7.16815	0.03976
POACEAE does not Granger Cause BETULA	15	1.25391	0.42522
BETULA does not Granger Cause POACEAE		14.9995	0.01065
POLYGONACEAE does not Granger Cause BETULA	15	0.29475	0.89367
BETULA does not Granger Cause POLYGONACEAE		3.10733	0.14733
QUERCUS does not Granger Cause BETULA	15	1.15346	0.45779
BETULA does not Granger Cause QUERCUS		3.96915	0.10312
TSUGA does not Granger Cause BETULA	15	3.43513	0.12769
BETULA does not Granger Cause TSUGA		2.49441	0.19829
APIACEAE does not Granger Cause BETULA	15	7.27776	0.03874
BETULA does not Granger Cause APIACEAE		2.25147	0.22589
CHENOPODIACEAE does not Granger Cause CHARCOAL	15	0.46416	0.78907
CHARCOAL does not Granger Cause CHENOPODIACEAE		2.87098	0.16440
LARIX does not Granger Cause CHARCOAL	15	1.34262	0.39903
CHARCOAL does not Granger Cause LARIX		1.64364	0.32528
LIGULAFLORAE does not Granger Cause CHARCOAL	15	6.20321	0.05071
CHARCOAL does not Granger Cause LIGULAFLORAE		1.09785	0.47728
OXYGEN‰ does not Granger Cause CHARCOAL	15	4.50125	0.08503
CHARCOAL does not Granger Cause OXYGEN‰		0.86319	0.57261
POPULATION does not Granger Cause CHARCOAL	15	0.69849	0.65367
CHARCOAL does not Granger Cause POPULATION		3.89047	0.10627
PICEA does not Granger Cause CHARCOAL	15	1.92037	0.27349
CHARCOAL does not Granger Cause PICEA		1.53182	0.35023
PINE does not Granger Cause CHARCOAL	15	1.50982	0.35546
CHARCOAL does not Granger Cause PINE		1.14228	0.46162
POACEAE does not Granger Cause CHARCOAL	15	4.25044	0.09291
CHARCOAL does not Granger Cause POACEAE		2.50229	0.19748
POLYGONACEAE does not Granger Cause CHARCOAL	15	0.65466	0.67732
CHARCOAL does not Granger Cause POLYGONACEAE		4.04750	0.10012
QUERCUS does not Granger Cause CHARCOAL	15	0.96705	0.52766
CHARCOAL does not Granger Cause QUERCUS		1.97893	0.26407
TSUGA does not Granger Cause CHARCOAL	15	0.13622	0.97467
CHARCOAL does not Granger Cause TSUGA		2.46318	0.20156
APIACEAE does not Granger Cause CHARCOAL	15	0.70590	0.64976
CHARCOAL does not Granger Cause APIACEAE		1.00908	0.51075
LARIX does not Granger Cause CHENOPODIACEAE	15	1.07417	0.48592
CHENOPODIACEAE does not Granger Cause LARIX		28.8528	0.00310
LIGULAFLORAE does not Granger Cause CHENOPODIACEAE	15	0.52778	0.75034
CHENOPODIACEAE does not Granger Cause LIGULAFLORAE		16.1092	0.00933

Table J.5. Pairwise Granger Causality Tests, Five Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
OXYGEN‰ does not Granger Cause CHENOPODIACEAE	15	17.4851	0.00801
CHENOPODIACEAE does not Granger Cause OXYGEN‰		3.75682	0.11197
POPULATION does not Granger Cause CHENOPODIACEAE	15	1.94282	0.26982
CHENOPODIACEAE does not Granger Cause POPULATION		0.49911	0.76766
PICEA does not Granger Cause CHENOPODIACEAE	15	1.19269	0.44468
CHENOPODIACEAE does not Granger Cause PICEA		9.94852	0.02246
PINE does not Granger Cause CHENOPODIACEAE	15	3.42731	0.12811
CHENOPODIACEAE does not Granger Cause PINE		21.1511	0.00560
POACEAE does not Granger Cause CHENOPODIACEAE	15	3.44698	0.12706
CHENOPODIACEAE does not Granger Cause POACEAE		0.93821	0.53968
POLYGONACEAE does not Granger Cause CHENOPODIACEAE	15	40.4047	0.00162
CHENOPODIACEAE does not Granger Cause POLYGONACEAE		7.66000	0.03549
QUERCUS does not Granger Cause CHENOPODIACEAE	15	17.8748	0.00769
CHENOPODIACEAE does not Granger Cause QUERCUS		14.9752	0.01069
TSUGA does not Granger Cause CHENOPODIACEAE	15	12.7199	0.01442
CHENOPODIACEAE does not Granger Cause TSUGA		1.91658	0.27412
APIACEAE does not Granger Cause CHENOPODIACEAE	15	9.47558	0.02448
CHENOPODIACEAE does not Granger Cause APIACEAE		0.88077	0.56467
LIGULAFLORAE does not Granger Cause LARIX	15	1.14904	0.45930
LARIX does not Granger Cause LIGULAFLORAE		2.35981	0.21293
OXYGEN‰ does not Granger Cause LARIX	15	86.5765	0.00036
LARIX does not Granger Cause OXYGEN‰		0.83477	0.58572
POPULATION does not Granger Cause LARIX	15	1.36810	0.39193
LARIX does not Granger Cause POPULATION		1.74315	0.30515
PICEA does not Granger Cause LARIX	15	1.61153	0.33218
LARIX does not Granger Cause PICEA		1.13975	0.46250
PINE does not Granger Cause LARIX	15	1.61067	0.33236
LARIX does not Granger Cause PINE		2.75439	0.17392
POACEAE does not Granger Cause LARIX	15	1.47551	0.36384
LARIX does not Granger Cause POACEAE		0.48890	0.77388
POLYGONACEAE does not Granger Cause LARIX	15	1.20096	0.44198
LARIX does not Granger Cause POLYGONACEAE		1.61240	0.33199
QUERCUS does not Granger Cause LARIX	15	1.22907	0.43297
LARIX does not Granger Cause QUERCUS		6.19087	0.05088
TSUGA does not Granger Cause LARIX	15	1.29183	0.41374
LARIX does not Granger Cause TSUGA		4.11062	0.09779
APIACEAE does not Granger Cause LARIX	15	4.57495	0.08290
LARIX does not Granger Cause APIACEAE		0.79815	0.60315
OXYGEN‰ does not Granger Cause LIGULAFLORAE	15	0.27025	0.90808
LIGULAFLORAE does not Granger Cause OXYGEN‰		0.57722	0.72113
POPULATION does not Granger Cause LIGULAFLORAE	15	1.11796	0.47011
LIGULAFLORAE does not Granger Cause POPULATION		3.56568	0.12094
PICEA does not Granger Cause LIGULAFLORAE	15	0.25969	0.91416
LIGULAFLORAE does not Granger Cause PICEA		0.55697	0.73299
PINE does not Granger Cause LIGULAFLORAE	15	4.56650	0.08314
LIGULAFLORAE does not Granger Cause PINE		0.54177	0.74199

Table J.5. Pairwise Granger Causality Tests, Five Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
POACEAE does not Granger Cause LIGULAFLORAE	15	0.46545	0.78828
LIGULAFLORAE does not Granger Cause POACEAE		1.10140	0.47601
POLYGONACEAE does not Granger Cause LIGULAFLORAE	15	1.53541	0.34939
LIGULAFLORAE does not Granger Cause POLYGONACEAE		3.03418	0.15233
QUERCUS does not Granger Cause LIGULAFLORAE	15	3.38916	0.13020
LIGULAFLORAE does not Granger Cause QUERCUS		1.59922	0.33488
TSUGA does not Granger Cause LIGULAFLORAE	15	1.90013	0.27686
LIGULAFLORAE does not Granger Cause TSUGA		1.53755	0.34889
APIACEAE does not Granger Cause LIGULAFLORAE	15	0.44316	0.80206
LIGULAFLORAE does not Granger Cause APIACEAE		0.75417	0.62488
POPULATION does not Granger Cause OXYGEN‰	15	2.01043	0.25920
OXYGEN‰ does not Granger Cause POPULATION		1.45623	0.36867
PICEA does not Granger Cause OXYGEN‰	15	0.54336	0.74104
OXYGEN‰ does not Granger Cause PICEA		4.02456	0.10098
PINE does not Granger Cause OXYGEN‰	15	1.35351	0.39598
OXYGEN‰ does not Granger Cause PINE		1.81263	0.29214
POACEAE does not Granger Cause OXYGEN‰	15	1.47747	0.36335
OXYGEN‰ does not Granger Cause POACEAE		3.19832	0.14145
POLYGONACEAE does not Granger Cause OXYGEN‰	15	0.93340	0.54172
OXYGEN‰ does not Granger Cause POLYGONACEAE		6.92405	0.04217
QUERCUS does not Granger Cause OXYGEN‰	15	2.64167	0.18391
OXYGEN‰ does not Granger Cause QUERCUS		0.96808	0.52724
TSUGA does not Granger Cause OXYGEN‰	15	0.90606	0.55350
OXYGEN‰ does not Granger Cause TSUGA		4.36817	0.08908
APIACEAE does not Granger Cause OXYGEN‰	15	1.66585	0.32062
OXYGEN‰ does not Granger Cause APIACEAE		15.7642	0.00972
PICEA does not Granger Cause POPULATION	15	4.45977	0.08626
POPULATION does not Granger Cause PICEA		1.16746	0.45305
PINE does not Granger Cause POPULATION	15	1.75670	0.30255
POPULATION does not Granger Cause PINE		0.42013	0.81638
POACEAE does not Granger Cause POPULATION	15	2.58502	0.18926
POPULATION does not Granger Cause POACEAE		0.55892	0.73184
POLYGONACEAE does not Granger Cause POPULATION	15	2.61123	0.18676
POPULATION does not Granger Cause POLYGONACEAE		2.51805	0.19588
QUERCUS does not Granger Cause POPULATION	15	3.72871	0.11323
POPULATION does not Granger Cause QUERCUS		1.09652	0.47776
TSUGA does not Granger Cause POPULATION	15	2.74405	0.17480
POPULATION does not Granger Cause TSUGA		4.24193	0.09320
APIACEAE does not Granger Cause POPULATION	15	0.73426	0.63501
POPULATION does not Granger Cause APIACEAE		2.52179	0.19550
PINE does not Granger Cause PICEA	15	54.0946	0.00092
PICEA does not Granger Cause PINE		2.25577	0.22536
POACEAE does not Granger Cause PICEA	15	6.48064	0.04714
PICEA does not Granger Cause POACEAE		2.22746	0.22892
POLYGONACEAE does not Granger Cause PICEA	15	2.33538	0.21576
PICEA does not Granger Cause POLYGONACEAE		0.17309	0.95923
QUERCUS does not Granger Cause PICEA	15	0.47100	0.78486
PICEA does not Granger Cause QUERCUS		1.84995	0.28548
TSUGA does not Granger Cause PICEA	15	1.21025	0.43897
PICEA does not Granger Cause TSUGA		3.84501	0.10816

Table J.5. Pairwise Granger Causality Tests, Five Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause PICEA	15	1.66557	0.32068
PICEA does not Granger Cause APIACEAE		2.78740	0.17114
POACEAE does not Granger Cause PINE	15	0.99972	0.51446
PINE does not Granger Cause POACEAE		0.25997	0.91400
POLYGONACEAE does not Granger Cause PINE	15	5.00040	0.07205
PINE does not Granger Cause POLYGONACEAE		1.02785	0.50342
QUERCUS does not Granger Cause PINE	15	2.38098	0.21053
PINE does not Granger Cause QUERCUS		1.31308	0.40750
TSUGA does not Granger Cause PINE	15	3.47243	0.12571
PINE does not Granger Cause TSUGA		0.68965	0.65837
APIACEAE does not Granger Cause PINE	15	0.50020	0.76700
PINE does not Granger Cause APIACEAE		1.15047	0.45881
POLYGONACEAE does not Granger Cause POACEAE	15	1.59811	0.33512
POACEAE does not Granger Cause POLYGONACEAE		0.93763	0.53993
QUERCUS does not Granger Cause POACEAE	15	0.88704	0.56188
POACEAE does not Granger Cause QUERCUS		1.33143	0.40221
TSUGA does not Granger Cause POACEAE	15	0.42783	0.81159
POACEAE does not Granger Cause TSUGA		2.39629	0.20881
APIACEAE does not Granger Cause POACEAE	15	1.60238	0.33418
POACEAE does not Granger Cause APIACEAE		1.05911	0.49152
QUERCUS does not Granger Cause POLYGONACEAE	15	1.11033	0.47281
POLYGONACEAE does not Granger Cause QUERCUS		2.70431	0.17826
TSUGA does not Granger Cause POLYGONACEAE	15	0.56664	0.72730
POLYGONACEAE does not Granger Cause TSUGA		3.17140	0.14316
APIACEAE does not Granger Cause POLYGONACEAE	15	28.3091	0.00321
POLYGONACEAE does not Granger Cause APIACEAE		0.50592	0.76352
TSUGA does not Granger Cause QUERCUS	15	3.29549	0.13555
QUERCUS does not Granger Cause TSUGA		1.91821	0.27385
APIACEAE does not Granger Cause QUERCUS	15	5.14514	0.06883
QUERCUS does not Granger Cause APIACEAE		1.49302	0.35953
APIACEAE does not Granger Cause TSUGA	15	1.83428	0.28825
TSUGA does not Granger Cause APIACEAE		0.98167	0.52170

Table J.6. Pairwise Granger Causality Tests, Six Lags (Using Data in Appendix H)

Null Hypothesis:	Obs	F-Statistic	Probability
ACER does not Granger Cause ABIES	14	0.81977	0.68830
ABIES does not Granger Cause ACER		8.85372	0.25174
ALNUS does not Granger Cause ABIES	14	0.47698	0.80221
ABIES does not Granger Cause ALNUS		1.80070	0.51570
AMBROSIA does not Granger Cause ABIES	14	3.08883	0.40999
ABIES does not Granger Cause AMBROSIA		2.60295	0.44184
ARTEMESIA does not Granger Cause ABIES	14	3.61769	0.38209
ABIES does not Granger Cause ARTEMESIA		37.2770	0.12472
ASTER does not Granger Cause ABIES	14	6.24543	0.29709
ABIES does not Granger Cause ASTER		5.97507	0.30333
BETULA does not Granger Cause ABIES	14	0.48974	0.79705
ABIES does not Granger Cause BETULA		2.31631	0.46448
CHARCOAL does not Granger Cause ABIES	14	4.47837	0.34676
ABIES does not Granger Cause CHARCOAL		0.94258	0.65727
CHENOPODIACEAE does not Granger Cause ABIES	14	6.56047	0.29029
ABIES does not Granger Cause CHENOPODIACEAE		0.40307	0.83370
LARIX does not Granger Cause ABIES	14	1.31346	0.58355
ABIES does not Granger Cause LARIX		7.05070	0.28057
LIGULAFLORAE does not Granger Cause ABIES	14	2.25161	0.47009
ABIES does not Granger Cause LIGULAFLORAE		0.30996	0.87740
OXYGEN‰ does not Granger Cause ABIES	14	0.25465	0.90520
ABIES does not Granger Cause OXYGEN‰		623.745	0.03064
POPULATION does not Granger Cause ABIES	14	153.008	0.06180
ABIES does not Granger Cause POPULATION		4.13348	0.35971
PICEA does not Granger Cause ABIES	14	18.6046	0.17563
ABIES does not Granger Cause PICEA		0.41710	0.82750
PINE does not Granger Cause ABIES	14	0.90886	0.66539
ABIES does not Granger Cause PINE		177.438	0.05740
POACEAE does not Granger Cause ABIES	14	0.48304	0.79975
ABIES does not Granger Cause POACEAE		4.31040	0.35289
POLYGONACEAE does not Granger Cause ABIES	14	13.9768	0.20195
ABIES does not Granger Cause POLYGONACEAE		28.7675	0.14176
QUERCUS does not Granger Cause ABIES	14	349.574	0.04092
ABIES does not Granger Cause QUERCUS		0.47996	0.80099
TSUGA does not Granger Cause ABIES	14	0.63611	0.74345
ABIES does not Granger Cause TSUGA		31.4218	0.13572
APIACEAE does not Granger Cause ABIES	14	0.46878	0.80556
ABIES does not Granger Cause APIACEAE		6.65162	0.28841
ALNUS does not Granger Cause ACER	14	2.61486	0.44096
ACER does not Granger Cause ALNUS		10.7158	0.22968
AMBROSIA does not Granger Cause ACER	14	5.79599	0.30768
ACER does not Granger Cause AMBROSIA		1.02721	0.63809
ARTEMESIA does not Granger Cause ACER	14	25.3920	0.15075
ACER does not Granger Cause ARTEMESIA		0.52425	0.78352
ASTER does not Granger Cause ACER	14	11.8061	0.21918
ACER does not Granger Cause ASTER		1.33595	0.57982
BETULA does not Granger Cause ACER	14	9.03948	0.24925
ACER does not Granger Cause BETULA		77.7440	0.08660
CHARCOAL does not Granger Cause ACER	14	0.36898	0.84919
ACER does not Granger Cause CHARCOAL		0.95423	0.65453
CHENOPODIACEAE does not Granger Cause ACER	14	97.9573	0.07719
ACER does not Granger Cause CHENOPODIACEAE		1.25312	0.59391

Table J.6. Pairwise Granger Causality Tests, Six Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause ACER	14	1.71176	0.52635
ACER does not Granger Cause LARIX		2.44552	0.45385
LIGULAFLORAE does not Granger Cause ACER	14	0.19810	0.93427
ACER does not Granger Cause LIGULAFLORAE		24.5378	0.15331
OXYGEN‰ does not Granger Cause ACER	14	6.70687	0.28728
ACER does not Granger Cause OXYGEN‰		4.64887	0.34086
POPULATION does not Granger Cause ACER	14	31.4975	0.13556
ACER does not Granger Cause POPULATION		0.87938	0.67273
PICEA does not Granger Cause ACER	14	101.363	0.07588
ACER does not Granger Cause PICEA		4.05777	0.36275
PINE does not Granger Cause ACER	14	0.62248	0.74805
ACER does not Granger Cause PINE		30.7970	0.13707
POACEAE does not Granger Cause ACER	14	0.92283	0.66199
ACER does not Granger Cause POACEAE		3.11935	0.40821
POLYGONACEAE does not Granger Cause ACER	14	11.2463	0.22439
ACER does not Granger Cause POLYGONACEAE		1.26746	0.59140
QUERCUS does not Granger Cause ACER	14	2.56419	0.44471
ACER does not Granger Cause QUERCUS		1429.34	0.02024
TSUGA does not Granger Cause ACER	14	4.66069	0.34046
ACER does not Granger Cause TSUGA		957.281	0.02474
APIACEAE does not Granger Cause ACER	14	29.5273	0.13995
ACER does not Granger Cause APIACEAE		3.92883	0.36811
AMBROSIA does not Granger Cause ALNUS	14	2.30255	0.46565
ALNUS does not Granger Cause AMBROSIA		7.29792	0.27603
ARTEMESIA does not Granger Cause ALNUS	14	44.8347	0.11383
ALNUS does not Granger Cause ARTEMESIA		18.0492	0.17826
ASTER does not Granger Cause ALNUS	14	0.24292	0.91121
ALNUS does not Granger Cause ASTER		0.07340	0.98980
BETULA does not Granger Cause ALNUS	14	2.09515	0.48453
ALNUS does not Granger Cause BETULA		3.16656	0.40550
CHARCOAL does not Granger Cause ALNUS	14	11.0793	0.22601
ALNUS does not Granger Cause CHARCOAL		407.319	0.03791
CHENOPODIACEAE does not Granger Cause ALNUS	14	1.36167	0.57564
ALNUS does not Granger Cause CHENOPODIACEAE		0.94047	0.65777
LARIX does not Granger Cause ALNUS	14	4.54347	0.34447
ALNUS does not Granger Cause LARIX		5.09835	0.32663
LIGULAFLORAE does not Granger Cause ALNUS	14	0.94710	0.65621
ALNUS does not Granger Cause LIGULAFLORAE		0.67680	0.73019
OXYGEN‰ does not Granger Cause ALNUS	14	9.60624	0.24209
ALNUS does not Granger Cause OXYGEN‰		145.784	0.06331
POPULATION does not Granger Cause ALNUS	14	2.37053	0.45993
ALNUS does not Granger Cause POPULATION		9.01809	0.24954
PICEA does not Granger Cause ALNUS	14	110.257	0.07277
ALNUS does not Granger Cause PICEA		0.40453	0.83305
PINE does not Granger Cause ALNUS	14	0.86763	0.67572
ALNUS does not Granger Cause PINE		192.465	0.05512
POACEAE does not Granger Cause ALNUS	14	6.61567	0.28914
ALNUS does not Granger Cause POACEAE		1.68769	0.52935
POLYGONACEAE does not Granger Cause ALNUS	14	29.9609	0.13894
ALNUS does not Granger Cause POLYGONACEAE		16.1812	0.18804
QUERCUS does not Granger Cause ALNUS	14	422.743	0.03721
ALNUS does not Granger Cause QUERCUS		0.47032	0.80493

Table J.6. Pairwise Granger Causality Tests, Six Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
TSUGA does not Granger Cause ALNUS	14	5.15596	0.32493
ALNUS does not Granger Cause TSUGA		6.03409	0.30194
APIACEAE does not Granger Cause ALNUS	14	0.35318	0.85657
ALNUS does not Granger Cause APIACEAE		0.11104	0.97602
ARTEMESIA does not Granger Cause AMBROSIA	14	9.58584	0.24234
AMBROSIA does not Granger Cause ARTEMESIA		0.60501	0.75404
ASTER does not Granger Cause AMBROSIA	14	1.73959	0.52295
AMBROSIA does not Granger Cause ASTER		0.57614	0.76424
BETULA does not Granger Cause AMBROSIA	14	0.83022	0.68550
AMBROSIA does not Granger Cause BETULA		17.8090	0.17943
CHARCOAL does not Granger Cause AMBROSIA	14	0.97026	0.65082
AMBROSIA does not Granger Cause CHARCOAL		3.44384	0.39062
CHENOPODIACEAE does not Granger Cause AMBROSIA	14	2.04667	0.48927
AMBROSIA does not Granger Cause CHENOPODIACEAE		31.0365	0.13655
LARIX does not Granger Cause AMBROSIA	14	0.57787	0.76362
AMBROSIA does not Granger Cause LARIX		1.67529	0.53091
LIGULAFLORAE does not Granger Cause AMBROSIA	14	0.40471	0.83297
AMBROSIA does not Granger Cause LIGULAFLORAE		918.120	0.02526
OXYGEN‰ does not Granger Cause AMBROSIA	14	1.50948	0.55322
AMBROSIA does not Granger Cause OXYGEN‰		17.3135	0.18192
POPULATION does not Granger Cause AMBROSIA	14	0.66536	0.73385
AMBROSIA does not Granger Cause POPULATION		19.6588	0.17095
PICEA does not Granger Cause AMBROSIA	14	1.63841	0.53564
AMBROSIA does not Granger Cause PICEA		3.83845	0.37201
PINE does not Granger Cause AMBROSIA	14	372.205	0.03966
AMBROSIA does not Granger Cause PINE		0.35052	0.85783
POACEAE does not Granger Cause AMBROSIA	14	2.65062	0.43838
AMBROSIA does not Granger Cause POACEAE		0.30604	0.87933
POLYGONACEAE does not Granger Cause AMBROSIA	14	18.6454	0.17545
AMBROSIA does not Granger Cause POLYGONACEAE		0.72645	0.71485
QUERCUS does not Granger Cause AMBROSIA	14	1.14020	0.61484
AMBROSIA does not Granger Cause QUERCUS		2878.73	0.01427
TSUGA does not Granger Cause AMBROSIA	14	0.52609	0.78282
AMBROSIA does not Granger Cause TSUGA		0.08129	0.98729
APIACEAE does not Granger Cause AMBROSIA	14	0.94234	0.65733
AMBROSIA does not Granger Cause APIACEAE		0.58860	0.75980
ASTER does not Granger Cause ARTEMESIA	14	520.011	0.03355
ARTEMESIA does not Granger Cause ASTER		0.82075	0.68803
BETULA does not Granger Cause ARTEMESIA	14	0.23549	0.91503
ARTEMESIA does not Granger Cause BETULA		4.54603	0.34438
CHARCOAL does not Granger Cause ARTEMESIA	14	0.76511	0.70351
ARTEMESIA does not Granger Cause CHARCOAL		3.76363	0.37534
CHENOPODIACEAE does not Granger Cause ARTEMESIA	14	0.47033	0.80492
ARTEMESIA does not Granger Cause CHENOPODIACEAE		3.88134	0.37014
LARIX does not Granger Cause ARTEMESIA	14	0.31136	0.87671
ARTEMESIA does not Granger Cause LARIX		2.69712	0.43509
LIGULAFLORAE does not Granger Cause ARTEMESIA	14	1.09628	0.62358
ARTEMESIA does not Granger Cause LIGULAFLORAE		16.9211	0.18397

Table J.6. Pairwise Granger Causality Tests, Six Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
OXYGEN‰ does not Granger Cause ARTEMESIA	14	1.43819	0.56371
ARTEMESIA does not Granger Cause OXYGEN‰		2.09710	0.48434
POPULATION does not Granger Cause ARTEMESIA	14	1.97935	0.49610
ARTEMESIA does not Granger Cause POPULATION		13.6997	0.20392
PICEA does not Granger Cause ARTEMESIA	14	0.45035	0.81323
ARTEMESIA does not Granger Cause PICEA		2.75806	0.43088
PINE does not Granger Cause ARTEMESIA	14	0.39754	0.83617
ARTEMESIA does not Granger Cause PINE		0.82539	0.68679
POACEAE does not Granger Cause ARTEMESIA	14	133.640	0.06612
ARTEMESIA does not Granger Cause POACEAE		2.16725	0.47771
POLYGONACEAE does not Granger Cause ARTEMESIA	14	7.15406	0.27865
ARTEMESIA does not Granger Cause POLYGONACEAE		4.25749	0.35489
QUERCUS does not Granger Cause ARTEMESIA	14	0.27519	0.89475
ARTEMESIA does not Granger Cause QUERCUS		4.13832	0.35952
TSUGA does not Granger Cause ARTEMESIA	14	20.7477	0.16649
ARTEMESIA does not Granger Cause TSUGA		142.788	0.06397
APIACEAE does not Granger Cause ARTEMESIA	14	54.6190	0.10321
ARTEMESIA does not Granger Cause APIACEAE		2.08439	0.48557
BETULA does not Granger Cause ASTER	14	27.2111	0.14570
ASTER does not Granger Cause BETULA		0.38636	0.84122
CHARCOAL does not Granger Cause ASTER	14	4.35152	0.35136
ASTER does not Granger Cause CHARCOAL		1.78161	0.51793
CHENOPODIACEAE does not Granger Cause ASTER	14	4.82599	0.33503
ASTER does not Granger Cause CHENOPODIACEAE		229.011	0.05054
LARIX does not Granger Cause ASTER	14	77.3636	0.08681
ASTER does not Granger Cause LARIX		1.86731	0.50813
LIGULAFLORAE does not Granger Cause ASTER	14	46.7100	0.11154
ASTER does not Granger Cause LIGULAFLORAE		2320.09	0.01589
OXYGEN‰ does not Granger Cause ASTER	14	20.5534	0.16726
ASTER does not Granger Cause OXYGEN‰		4.89893	0.33272
POPULATION does not Granger Cause ASTER	14	0.42279	0.82502
ASTER does not Granger Cause POPULATION		161.212	0.06021
PICEA does not Granger Cause ASTER	14	23.6536	0.15611
ASTER does not Granger Cause PICEA		2.89867	0.42162
PINE does not Granger Cause ASTER	14	0.52009	0.78512
ASTER does not Granger Cause PINE		2.08000	0.48599
POACEAE does not Granger Cause ASTER	14	113.629	0.07169
ASTER does not Granger Cause POACEAE		0.84711	0.68103
POLYGONACEAE does not Granger Cause ASTER	14	14.8899	0.19582
ASTER does not Granger Cause POLYGONACEAE		9.02807	0.24940
QUERCUS does not Granger Cause ASTER	14	1.54939	0.54760
ASTER does not Granger Cause QUERCUS		1.50744	0.55352
TSUGA does not Granger Cause ASTER	14	3.33645	0.39619
ASTER does not Granger Cause TSUGA		3.33874	0.39607
APIACEAE does not Granger Cause ASTER	14	1.11500	0.61981
ASTER does not Granger Cause APIACEAE		15.1811	0.19398
CHARCOAL does not Granger Cause BETULA	14	1.62713	0.53711
BETULA does not Granger Cause CHARCOAL		3.77071	0.37502
CHENOPODIACEAE does not Granger Cause BETULA	14	4.40120	0.34954
BETULA does not Granger Cause CHENOPODIACEAE		12.0019	0.21744

Table J.6. Pairwise Granger Causality Tests, Six Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
LARIX does not Granger Cause BETULA	14	0.75559	0.70625
BETULA does not Granger Cause LARIX		1.25959	0.59277
LIGULAFLORAE does not Granger Cause BETULA	14	230.868	0.05034
BETULA does not Granger Cause LIGULAFLORAE		13.0142	0.20907
OXYGEN‰ does not Granger Cause BETULA	14	3.09952	0.40936
BETULA does not Granger Cause OXYGEN‰		0.78986	0.69650
POPULATION does not Granger Cause BETULA	14	1.87281	0.50752
BETULA does not Granger Cause POPULATION		2.50277	0.44937
PICEA does not Granger Cause BETULA	14	4.45388	0.34763
BETULA does not Granger Cause PICEA		572.326	0.03199
PINE does not Granger Cause BETULA	14	4.83202	0.33484
BETULA does not Granger Cause PINE		4.08935	0.36147
POACEAE does not Granger Cause BETULA	14	0.83000	0.68556
BETULA does not Granger Cause POACEAE		10.7955	0.22886
POLYGONACEAE does not Granger Cause BETULA	14	2.05107	0.48884
BETULA does not Granger Cause POLYGONACEAE		7.33102	0.27544
QUERCUS does not Granger Cause BETULA	14	14.9491	0.19544
BETULA does not Granger Cause QUERCUS		25.7912	0.14960
TSUGA does not Granger Cause BETULA	14	0.61323	0.75120
BETULA does not Granger Cause TSUGA		57.5441	0.10057
APIACEAE does not Granger Cause BETULA	14	3.29491	0.39841
BETULA does not Granger Cause APIACEAE		0.91542	0.66379
CHENOPODIACEAE does not Granger Cause CHARCOAL	14	1.61352	0.53891
CHARCOAL does not Granger Cause CHENOPODIACEAE		0.65156	0.73834
LARIX does not Granger Cause CHARCOAL	14	239.730	0.04940
CHARCOAL does not Granger Cause LARIX		193.482	0.05498
LIGULAFLORAE does not Granger Cause CHARCOAL	14	329.922	0.04212
CHARCOAL does not Granger Cause LIGULAFLORAE		5.60530	0.31253
OXYGEN‰ does not Granger Cause CHARCOAL	14	15577.9	0.00613
CHARCOAL does not Granger Cause OXYGEN‰		8.91957	0.25085
POPULATION does not Granger Cause CHARCOAL	14	0.65495	0.73723
CHARCOAL does not Granger Cause POPULATION		3.59719	0.38306
PICEA does not Granger Cause CHARCOAL	14	1.10930	0.62095
CHARCOAL does not Granger Cause PICEA		50.2073	0.10761
PINE does not Granger Cause CHARCOAL	14	10.5534	0.23138
CHARCOAL does not Granger Cause PINE		1.92851	0.50145
POACEAE does not Granger Cause CHARCOAL	14	2959.06	0.01407
CHARCOAL does not Granger Cause POACEAE		1.37375	0.57370
POLYGONACEAE does not Granger Cause CHARCOAL	14	0.56207	0.76935
CHARCOAL does not Granger Cause POLYGONACEAE		1.15027	0.61289
QUERCUS does not Granger Cause CHARCOAL	14	19.2117	0.17289
CHARCOAL does not Granger Cause QUERCUS		14.5091	0.19831
TSUGA does not Granger Cause CHARCOAL	14	2.23719	0.47136
CHARCOAL does not Granger Cause TSUGA		6.24381	0.29713
APIACEAE does not Granger Cause CHARCOAL	14	42.9232	0.11631
CHARCOAL does not Granger Cause APIACEAE		1.24165	0.59594
LARIX does not Granger Cause CHENOPODIACEAE	14	5.72163	0.30955
CHENOPODIACEAE does not Granger Cause LARIX		86.5314	0.08210
LIGULAFLORAE does not Granger Cause CHENOPODIACEAE	14	16.7861	0.18470
CHENOPODIACEAE does not Granger Cause LIGULAFLORAE		4.64417	0.34102

Table J.6. Pairwise Granger Causality Tests, Six Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
OXYGEN‰ does not Granger Cause CHENOPODIACEAE	14	49.3447	0.10854
CHENOPODIACEAE does not Granger Cause OXYGEN‰		10.7459	0.22937
POPULATION does not Granger Cause CHENOPODIACEAE	14	6.17052	0.29878
CHENOPODIACEAE does not Granger Cause POPULATION		20.4368	0.16773
PICEA does not Granger Cause CHENOPODIACEAE	14	0.64998	0.73886
CHENOPODIACEAE does not Granger Cause PICEA		37.8896	0.12372
PINE does not Granger Cause CHENOPODIACEAE	14	1.34092	0.57900
CHENOPODIACEAE does not Granger Cause PINE		4002.28	0.01210
POACEAE does not Granger Cause CHENOPODIACEAE	14	3.14212	0.40690
CHENOPODIACEAE does not Granger Cause POACEAE		3.43325	0.39116
POLYGONACEAE does not Granger Cause CHENOPODIACEAE	14	59.9724	0.09852
CHENOPODIACEAE does not Granger Cause POLYGONACEAE		2.01090	0.49287
QUERCUS does not Granger Cause CHENOPODIACEAE	14	15.2941	0.19328
CHENOPODIACEAE does not Granger Cause QUERCUS		7.41763	0.27391
TSUGA does not Granger Cause CHENOPODIACEAE	14	22.8423	0.15881
CHENOPODIACEAE does not Granger Cause TSUGA		202.895	0.05369
APIACEAE does not Granger Cause CHENOPODIACEAE	14	127.990	0.06756
CHENOPODIACEAE does not Granger Cause APIACEAE		12.4270	0.21380
LIGULAFLORAE does not Granger Cause LARIX	14	4.44342	0.34801
LARIX does not Granger Cause LIGULAFLORAE		2239.50	0.01617
OXYGEN‰ does not Granger Cause LARIX	14	24.5397	0.15331
LARIX does not Granger Cause OXYGEN‰		6.13810	0.29952
POPULATION does not Granger Cause LARIX	14	1.63052	0.53667
LARIX does not Granger Cause POPULATION		1.80511	0.51519
PICEA does not Granger Cause LARIX	14	1.02006	0.63965
LARIX does not Granger Cause PICEA		8.70309	0.25382
PINE does not Granger Cause LARIX	14	1.25888	0.59290
LARIX does not Granger Cause PINE		0.92937	0.66042
POACEAE does not Granger Cause LARIX	14	5.58024	0.31319
LARIX does not Granger Cause POACEAE		11.0419	0.22638
POLYGONACEAE does not Granger Cause LARIX	14	35.8052	0.12723
LARIX does not Granger Cause POLYGONACEAE		5.23650	0.32260
QUERCUS does not Granger Cause LARIX	14	1.84299	0.51085
LARIX does not Granger Cause QUERCUS		81.7695	0.08445
TSUGA does not Granger Cause LARIX	14	0.78637	0.69748
LARIX does not Granger Cause TSUGA		4.09494	0.36124
APIACEAE does not Granger Cause LARIX	14	5.19482	0.32380
LARIX does not Granger Cause APIACEAE		1044.22	0.02368
OXYGEN‰ does not Granger Cause LIGULAFLORAE	14	234.402	0.04996
LIGULAFLORAE does not Granger Cause OXYGEN‰		3.00619	0.41492
POPULATION does not Granger Cause LIGULAFLORAE	14	2.69605	0.43516
LIGULAFLORAE does not Granger Cause POPULATION		7.93996	0.26519
PICEA does not Granger Cause LIGULAFLORAE	14	0.90666	0.66593
LIGULAFLORAE does not Granger Cause PICEA		11.6470	0.22062
PINE does not Granger Cause LIGULAFLORAE	14	6.86690	0.28410
LIGULAFLORAE does not Granger Cause PINE		0.46932	0.80534

Table J.6. Pairwise Granger Causality Tests, Six Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
POACEAE does not Granger Cause LIGULAFLORAE	14	9.75188	0.24034
LIGULAFLORAE does not Granger Cause POACEAE		3.38947	0.39341
POLYGONACEAE does not Granger Cause LIGULAFLORAE	14	19.4807	0.17172
LIGULAFLORAE does not Granger Cause POLYGONACEAE		18.1335	0.17785
QUERCUS does not Granger Cause LIGULAFLORAE	14	11.3658	0.22324
LIGULAFLORAE does not Granger Cause QUERCUS		2.23185	0.47184
TSUGA does not Granger Cause LIGULAFLORAE	14	0.52536	0.78310
LIGULAFLORAE does not Granger Cause TSUGA		1.12995	0.61685
APIACEAE does not Granger Cause LIGULAFLORAE	14	1.52988	0.55033
LIGULAFLORAE does not Granger Cause APIACEAE		0.24548	0.90989
POPULATION does not Granger Cause OXYGEN‰	14	2.47739	0.45134
OXYGEN‰ does not Granger Cause POPULATION		0.54600	0.77529
PICEA does not Granger Cause OXYGEN‰	14	0.96371	0.65233
OXYGEN‰ does not Granger Cause PICEA		2.04225	0.48971
PINE does not Granger Cause OXYGEN‰	14	1.48864	0.55623
OXYGEN‰ does not Granger Cause PINE		7.76450	0.26802
POACEAE does not Granger Cause OXYGEN‰	14	1.20522	0.60253
OXYGEN‰ does not Granger Cause POACEAE		3.97820	0.36603
POLYGONACEAE does not Granger Cause OXYGEN‰	14	24.9947	0.15193
OXYGEN‰ does not Granger Cause POLYGONACEAE		15.6125	0.19135
QUERCUS does not Granger Cause OXYGEN‰	14	3.26081	0.40026
OXYGEN‰ does not Granger Cause QUERCUS		0.62424	0.74745
TSUGA does not Granger Cause OXYGEN‰	14	17.0811	0.18313
OXYGEN‰ does not Granger Cause TSUGA		664.902	0.02968
APIACEAE does not Granger Cause OXYGEN‰	14	5.45393	0.31655
OXYGEN‰ does not Granger Cause APIACEAE		40.3928	0.11986
PICEA does not Granger Cause POPULATION	14	0.62781	0.74624
POPULATION does not Granger Cause PICEA		11.4228	0.22270
PINE does not Granger Cause POPULATION	14	0.35309	0.85662
POPULATION does not Granger Cause PINE		0.47041	0.80489
POACEAE does not Granger Cause POPULATION	14	0.41300	0.82930
POPULATION does not Granger Cause POACEAE		1.53983	0.54893
POLYGONACEAE does not Granger Cause POPULATION	14	0.76082	0.70474
POPULATION does not Granger Cause POLYGONACEAE		1.03604	0.63618
QUERCUS does not Granger Cause POPULATION	14	0.47631	0.80248
POPULATION does not Granger Cause QUERCUS		0.62987	0.74555
TSUGA does not Granger Cause POPULATION	14	1.98986	0.49502
POPULATION does not Granger Cause TSUGA		5.50187	0.31526
APIACEAE does not Granger Cause POPULATION	14	2.21098	0.47371
POPULATION does not Granger Cause APIACEAE		2.13895	0.48035
PINE does not Granger Cause PICEA	14	20.2197	0.16861
PICEA does not Granger Cause PINE		1.70449	0.52725
POACEAE does not Granger Cause PICEA	14	5.76452	0.30847
PICEA does not Granger Cause POACEAE		20.8989	0.16590
POLYGONACEAE does not Granger Cause PICEA	14	31.8847	0.13474
PICEA does not Granger Cause POLYGONACEAE		1.23655	0.59685
QUERCUS does not Granger Cause PICEA	14	0.06311	0.99272
PICEA does not Granger Cause QUERCUS		0.65742	0.73642
TSUGA does not Granger Cause PICEA	14	10.6926	0.22992
PICEA does not Granger Cause TSUGA		2.53721	0.44674

Table J.6. Pairwise Granger Causality Tests, Six Lags (Using Data in Appendix H) (cont.)

Null Hypothesis:	Obs	F-Statistic	Probability
APIACEAE does not Granger Cause PICEA	14	61.6006	0.09722
PICEA does not Granger Cause APIACEAE		9.60095	0.24215
POACEAE does not Granger Cause PINE	14	127.366	0.06772
PINE does not Granger Cause POACEAE		3.50236	0.38769
POLYGONACEAE does not Granger Cause PINE	14	12.3241	0.21467
PINE does not Granger Cause POLYGONACEAE		0.34322	0.86129
QUERCUS does not Granger Cause PINE	14	0.46489	0.80716
PINE does not Granger Cause QUERCUS		0.33672	0.86440
TSUGA does not Granger Cause PINE	14	8538.06	0.00828
PINE does not Granger Cause TSUGA		0.31775	0.87358
APIACEAE does not Granger Cause PINE	14	0.42434	0.82434
PINE does not Granger Cause APIACEAE		0.57338	0.76524
POLYGONACEAE does not Granger Cause POACEAE	14	1.82188	0.51325
POACEAE does not Granger Cause POLYGONACEAE		0.43150	0.82125
QUERCUS does not Granger Cause POACEAE	14	0.64995	0.73887
POACEAE does not Granger Cause QUERCUS		0.87873	0.67289
TSUGA does not Granger Cause POACEAE	14	0.23657	0.91447
POACEAE does not Granger Cause TSUGA		0.51305	0.78785
APIACEAE does not Granger Cause POACEAE	14	1.40275	0.56914
POACEAE does not Granger Cause APIACEAE		0.73451	0.71244
QUERCUS does not Granger Cause POLYGONACEAE	14	0.43799	0.81846
POLYGONACEAE does not Granger Cause QUERCUS		14.0918	0.20114
TSUGA does not Granger Cause POLYGONACEAE	14	28.8231	0.14162
POLYGONACEAE does not Granger Cause TSUGA		1841.38	0.01784
APIACEAE does not Granger Cause POLYGONACEAE	14	7.07831	0.28005
POLYGONACEAE does not Granger Cause APIACEAE		1.95222	0.49894
TSUGA does not Granger Cause QUERCUS	14	0.98325	0.64785
QUERCUS does not Granger Cause TSUGA		6.02113	0.30224
APIACEAE does not Granger Cause QUERCUS	14	20.3825	0.16795
QUERCUS does not Granger Cause APIACEAE		4.01390	0.36455
APIACEAE does not Granger Cause TSUGA	14	2.01941	0.49201
TSUGA does not Granger Cause APIACEAE		62.9169	0.09621

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