Geochemical and lithologic response of an upland watershed over the past 800 years to landscape changes in Southern Burgundy, France.

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Tamara Janelle Misner

University of Nebraska-Lincoln, 1998

University of Pittsburgh. 2003

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This dissertation was presented

by

Tamara Misner

It was defended on

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and approved by

Dr. Patrick Manning, Associate Professor, Department of History

Dr. Mark Abbott, Associate Professor, Department of Geology & Planetary Science

Dr. Thomas Anderson, Emeritus, Department of Geology & Planetary Science

Dr. Emily Elliott, Assistant Professor, Department of Geology & Planetary Science

Dissertation Advisor: Dr. Daniel Bain, Assistant Professor, Department of Geology & Planetary Science

Geochemical and lithologic response of an upland watershed over the past 800 years to landscape changes in Southern Burgundy, France.

Tamara Janelle Misner, PhD

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This study is an integrated analysis of the interaction between human and environmental systems within a small watershed in Southern Burgundy, France. The main objectives for this study were to understand the key environmental drivers for sediment erosion and nutrient availability in the watershed, and how those drivers were recorded in the pond sediment over the past 800 years. Future climate variability, interacting with land-use changes (e.g. intensification of agriculture) may have detrimental impacts on water quality, water availability, and crop yields in the Burgundy region. Thus, the examination of historical human landscape changes and interactions with climate in Burgundy can provide scientific data that policy makers and farmers can use to move toward sustainable land-management policies and practices, developing resilient systems, more robust in the face of future challenges.

Records of high-resolution geochemical, biological, and lithological data were reconstructed from the sediments of two small, Medieval-aged reservoirs. Geochemical proxies including scanning X-ray Fluorescence, stable isotope ($\delta13C$ and $\delta15N$), and elemental analyses (carbon, nitrogen, and phosphorus) were used to understand changes in erosion and productivity. Additionally, pollen analysis provided a record of changes in plant abundance and land cover through time. This reconstructed history was directly compared with historically documented changes in land-use within Burgundy using historical maps, parish/civil records, and agricultural reports.

Results from this study suggest humans have driven most of the changes recorded in the pond sediment. In particular, changes in agricultural practices, such as increased livestock

production, resulted in increased erosion to the ponds. Further, activities such as hemp processing and chemical fertilization both resulted in episodes of eutrophication. Ultimately, this work provides a framework for predicting future impacts of agricultural policies on the Burgundian landscape, and utilizes a multiproxy approach to landscape history that may be applied to other regions. Furthermore, this study documents landscape history within a paleoenvironmental context, and in a geographic area where studies on environmental archives (i.e. reservoir sediments, tree rings, etc.) are scarce. Therefore, these data are particularly important to formulating sustainable land-management practices and policies to create a more resilient Burgundy in the face of future climate change.

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PREFACE

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1.0 INTRODUCTION

Burgundy, in east-central France (Fig. 1.1) is a key agricultural region of the world (Crumley and Green, 1987; Crumley, 2000), and has been occupied by small farms and light industry for at least 2500 years. The Burgundy landscape has remained productive despite nearly continuous agricultural use for thousands of years. Infrastructure from the earliest recorded regional agrarian activity (e.g., Celtic and Roman roadways and hedgerows) have endured over the millennia, and were incorporated into numerous Medieval Period and modern features. Regional farm reservoirs and millponds record a detailed local and regional-scale sedimentary archive of changing climate, hydrology, and land use. The history of land use is important to understand, as human activities (i.e. agriculture, construction, urbanization, deforestation, etc.) result in persistent changes in the structure of catchment hydrology that influences the evolution of landscape function over time (Pringle, 2003). Moreover, the region has a rich written history that provides important information on social, political, and economic practices. Furthermore, mill and pond sediments can provide continuous high-resolution records of natural and human activities impacting the catchment over time (Battarbee, 2005; Oldfield, 2005: Dearing et al., 2006). Thus, the synthesis of historical records with pond sediment data can be used to reconstruct the impact of humans on the landscape and pond systems over time. Hence, this landscape contains a long and comprehensive record of human activity, environmental change, and human-environment interaction that is critical to better understand and predict future landscape responses to natural and human influences. Future climate variability, interacting with land-use changes (e.g. intensification of agriculture or livestock production) may have detrimental impacts on water quality, water availability, and crop yields in the Burgundy region (Fink et al., 2004; Poumadere, et al., 2005). The examination of historical human landscape changes and interactions with climate variability in Burgundy can provide scientific data that policy makers and farmers can use to move toward sustainable land-management policies and practices, developing resilient systems, more robust in the face of future challenges.

This dissertation focuses on the Commune of La Chapelle-au-Mans, located in the Canton of Gueugnon in the Department of Sâone-et-Loire (Fig. 1.1). Sedimentary records of high-resolution geochemical, biological, and lithological data were reconstructed from the sediments of two small, Medieval-aged reservoirs. Geochemical proxies arising from these data including scanning X-ray Fluorescence (XRF), stable isotope ($\delta^{13}C$ and $\delta^{15}N$), and elemental analyses (carbon, nitrogen, and phosphorus) are used to understand changes in erosion and productivity, particularly how changes in sediment and nutrient availability have impacted the pond systems over time. Additionally, biological proxies, such as pollen analysis, provide a record of changes in plant abundance and land cover through time. Furthermore, pollen data also clarifies changes in land use/ land cover and cropping practices during time periods when historical documentation is lacking.

This reconstruction of history from the sediment record can be directly compared with nearly three decades of historical changes in land-use within Burgundy using data sources including historical maps (dating from ~1650, and ranging in scale from regional to individual land parcels) (Fig. 1.2), parish/civil records, and agricultural reports detailing the local economy and land-use (e.g., crop type, distribution, and yields, and numbers of animals) (Table 1.1) (Jones, 2006, 2009; Jones et al., 2010). Additionally, aerial photography and satellite imagery provide contemporary environmental GIS data (geology, elevation, slope, aspect, hydrology etc.). The integration of historical data with sediment geochemistry data provides a powerful tool for examining the impact of human activities on catchment sediment dynamics and pond system geochemistry over time.

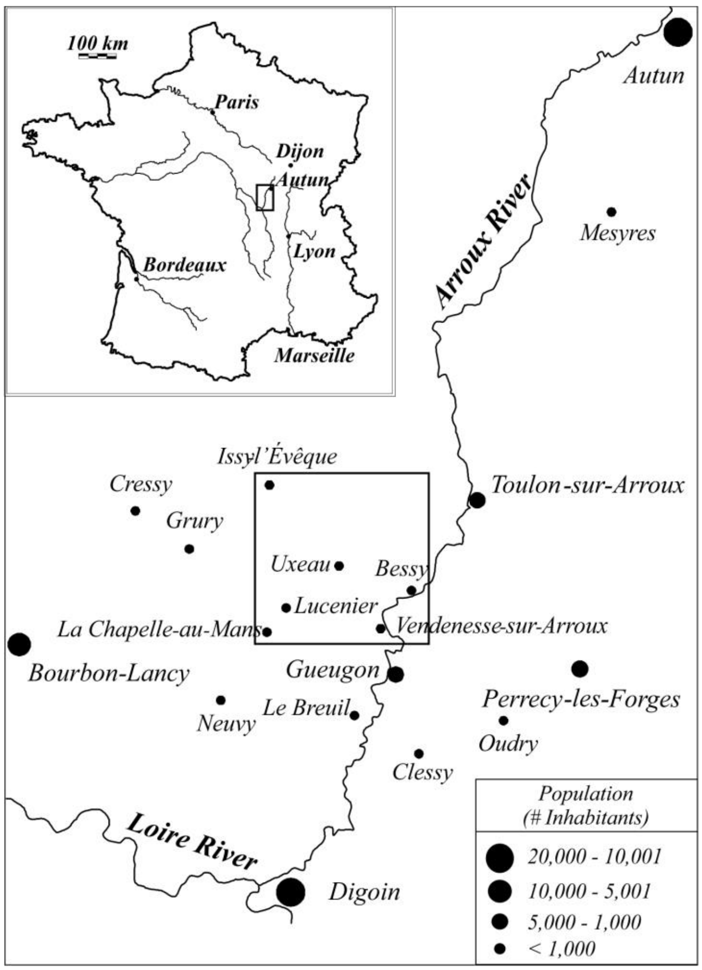


Figure 1.1. Map of the study region within Burgundy, Saône-et-Loire, France highlighting local population centers and the valleys of the Loire and Arroux Rivers.

Figure 1.2. Land-use map of the Commune of Uxeau, Canton Gueugnon, Arrondissement of Charolles, Saône-et-Loire, dating from 1881 (M2472, Macon Archives). The map, denotes woodlands (bois), meadows (prés), cropland (terres), and vineyards (vignes).

Table 1.1. Cropland type and extent within the commune of Uxeau, Department of Saône-et-Loire. Data from Mâcon archives document M2260.

Cultures et Patûrages	Étendue de Chaque Culture en Hectares [a]	Produit Totale [b]	Prix Moyens en Francs et Centimes [c]	Quantité de Semences par Hectare [d]	Poids Moyen de l'Hectolitre des Diverses Espèces de Céréales [e]	Quantité de la Consummation Totale dans la Commune [f]
Froment (wheat)	100	800	17, 50 f, c	200	75	200
Méteil (maslin)	0	0	0	0	0	0
Seigle (rye)	1000	6000	11, 25 f, c	2000	75	2000
Orge (barley)	40	600	10, 15 f	180	60	600
Avoine (oats)	40	1200	6, 25 f, c	200	42	1000
Sarrasin (buckwheat)	5	200	6, 25 f, c	250	42	200
Maïs et millet (corn and millet)	0	0	0	0	0	0
Pommes de terre (potatoes)	500	5000	1, 50 f, c	5000	75	5000
Légumes sec (dried peas, beans)	15	200	11, 25 f, c	n/a	n/a	200
Betteraves (beets)	0	0	0	0	0	0
Colza (huile) , navette (rapeseed oil, turnips)	15	100	25, 0 f, c	n/a	n/a	100
Vignes - Vin (vineyards - wine)	41	1000	15, 0 f, c	n/a	n/a	500
Vignes - Eau-de-vie (vineyards - brandy)	n/a	8	30, 0 f, c	n/a	n/a	8
Prairies artificielles	8	32000	0, 04 f, c	n/a	n/a	n/a
Prairies naturelles	334	85000	0, 04 f, c	n/a	n/a	n/a
Lin (flax)	0	0	0	0	0	0
Chanvre (hemp)	15	6000	0, 70 f, c	n/a	n/a	6000
Mûrier (mulberry)	0	0	0	0	0	0
Bois (woods)	667	2000	5, 0 f, c	n/a	n/a	1000
Jachères (fallow land)	500	n/a	n/a	n/a	n/a	n/a
Jardins (gardens)	7	n/a	n/a	n/a	n/a	n/a

a Areal extent of each crop type in hectares.
b Total weight (currently an unknown measure) produced by crop type.
c Average price in francs and centimes.
d Quantity of seeds per hectare.
e Average weight per volume (hectoliter) of the various cereals.
f Quantity consumed (by weight) within the commune.

Furthermore, the multi-disciplinary approach taken in this study provides the framework for an integrated analysis of human and natural systems change at spatial scales that vary from local to regional, and at annual, decadal, and century time scales for a region that is currently lacking local paleoclimatic data (Etien, 2007). This data can be used to answer questions such as: how have these ponds responded to changes in sediment and nutrient availability in the watershed? How have these ponds responded to changes in temperature, precipitation, and land cover/land use, etc. over time? This type of information is important for establishing baseline or reference data in order to identify thresholds and ensure the persistence or sustainability of these systems in the landscape. Moreover, the data collected here can be used to predict how the pond systems might respond to future changes in human activities and climate within the catchment.

In general, the dissertation is laid out as follows: Chapter 2, is a detailed examination of an 800-year sedimentary record of reservoir response to changes in land use during pronounced fluctuations in climate throughout the Medieval Warm Period (MWP) and Little Ice Age (LIA), and is in revision for the *Journal of Quaternary Research*. Chapter 3 expands on Chapter 2, comparing the changes in sediment dynamics recorded at the upland pond site (Lucenier) with the record from a lowland reservoir (Valette) at the base of the watershed. Chapter 4 investigates organic matter sources and the eutrophic history of both ponds through time in response to changing human activities (i.e. row cropping, livestock production, deforestation, etc.) within the catchment. Finally, Chapter 5 summarizes the major findings.

More specifically, Chapter 2 focuses on the geochemical, biological, and lithological characteristics of sediments in a 3.5 m long sediment core from a small catchment in the Saône-et-Loire region of southern Burgundy, France. These characteristics were measured and compared with historical records. Results indicate that human activity drove more of the changes in sediment dynamics relative to dynamics driven by climate in the pond catchment over the last 800 years. Pollen and lithological data combined with historical documentation suggest that continuous row cropping and pond management coincided with periods of low and stable sediment yield throughout most of the LIA a period of strong climate variability (Lamb, 1965, 1977; Grove, 1988; Mann, 2002, 2009). Sediment yield does vary with agricultural practice. For example, increased production of beef cattle yielded more sediment than the previous hundreds of years of cereal production.

Chapter 3 examines fluctuations in XRF ratio data combined with elemental carbon and nitrogen data to compare the history of sediment transport and erosion for the two sites. Low relative concentrations of detrital elements (Si, K, Rb, Sr, and Zr) derived from XRF imaging indicate that during a majority of the record there was limited detrital input to the pond, suggesting relative landscape stability. Additionally, a sediment mixing model analysis was used to explore the varying concentrations of XRF Al/Ti and Zr/Ti in the Valette pond sediment related to contributions from changing sources of sediment. Mixing model results suggest there were three main sources of sediment to Valette that include coarse rocky materials, shallow soils and deep soils. Furthermore, the mixing model was also used to help distinguish human activities that were causing erosion in the watershed. For example, during the Medieval Warm Period sediment deposition in the pond was dominated by a deep soil source, suggesting farming activities (i.e. plowing) were supplying sediment to the pond. Additionally, periods of increased erosion were detected based on increased relative concentrations of detrital elements. The identified episodes of erosion corresponded with periods of intensification in livestock production and mechanization of agriculture.

In Chapter 4 a mixing model was developed to identify the major sources of organic material to the ponds, and the eutrophication history of the ponds was documented through the examination of elemental carbon, nitrogen and phosphorous data, in conjunction with stable carbon and nitrogen isotope data over the past 800 years. Episodes of eutrophication and increased primary productivity were likely related to human activity such as livestock production, hemp processing, and fertilizer use in the watershed. Valette, draining the larger watershed, was influenced by more frequent and prolonged episodes of pollution. Additionally, changing land use practices in the watershed have shifted the importance of nitrogen versus phosphorous as limiting nutrients at each pond over time.

Chapter 5 is a summary of the major findings from each chapter. In summary, each chapter provides a unique opportunity to examine the couplings between human activities, natural environmental changes, and long-term watershed dynamics within the La Chapelle-au-Mans watershed. Over time the pond systems were negatively impacted by changes in nutrient and sediment loading that resulted from changes in human activities (i.e. row cropping, livestock production, deforestation, etc.) within the catchment. The data presented here indicate there were time periods of relative landscape stability in the catchment that were interrupted by episodes of increased erosion and eutrophication that led to degradation of the landscape and pond systems. Identifying time periods of instability and observing fluctuations in pond sediment lithology and geochemistry is an important step towards recognizing thresholds that are driving changes in trophic state within the system, and leading to water quality impairments. If this landscape is to persist in production for future generations, it is important to identify the historical mechanisms for change to understand how the landscape will respond to future environmental changes.

2.0 GEOCHEMICAL AND LITHOLOGIC RESPONSE OF AN UPLAND WATERSHED OVER THE PAST 800 YEARS TO LANDSCAPE CHANGES IN SAÔNE-ET-LOIRE, FRANCE.

2.1 INTRODUCTION

The modern landscape in continental Europe has been shaped by thousands of years of human activities (Doyen, et al., 2013). Many of these activities are driven by changes in climate and socio-economic factors (i.e. population density, wars, economic policies, technological advances, etc.), which dictate the needs of society and result in major expansion and collapse of certain agricultural practices through time (i.e. row cropping, tree farming, livestock production, etc.) (Mercuri, 2011; Dearing and Jones, 2003; Tinner et al., 2003; Gaillard and Digerfeldt, 1991). Therefore, an understanding of landscape history is fundamental to recognizing the environmental factors that have driven the evolution and sustainability of European landscapes over time (Ballut, et al., 2012).

Studies of lake and reservoir sediments commonly focus on the use of lithological, biological, and geochemical data to develop proxy records of climate change for a given region or to unravel environmental changes within a surrounding watershed. The main objective of many of these studies is the characterization of the potential impacts from future environmental changes (both climatic and human-driven) and thereby the development of more effective strategies for adaptation and mitigation. However, many lake and reservoir studies lack corresponding historical records that can be used to refine interpretations of past environmental change based on sediment data alone (Birks and Birks, 2006). Such detailed reconstructions of climate/human/landscape interactions are especially important for agricultural regions that may disproportionally feel the impact of climatic and land use changes (Harington, 1992; Rivers, 1995).

Lake and reservoir sediments are useful for environmental reconstructions because they provide continuous high-resolution records of natural and human activities (McKenzie 1985; Last and Smol 2001; Battarbee 2005; Oldfield 2005; Dearing et al., 2006). Reservoirs can be particularly sensitive to climate and land use changes within a watershed, and the relatively rapid and continuous accumulation of sediment within reservoir systems can provide high-resolution (inter-annual to decadal scale) records of environmental change (Battarbee, 2000; Shotbolt et al., 2005). Furthermore, reservoir sediments can provide important information regarding erosion and soil degradation resulting from changes in past land use and climate (Dearing, 1991; Walling, 1998; Dearing and Jones, 2003).

Sediment eroded from a catchment can be trapped in a reservoir and quantified as sediment yield (Foster et al., 1985, 1990; Walling 1998). Sediment yield is dependent on erosion and sediment delivery processes in the reservoir (Verstraeten and Poesen, 2001). Thus, sediment yield can be used as a proxy to document and understand the effect of past changes in land use and climate on erosion (Dearing, 1991; Walling, 1998) and reservoir response to these changes. Sediment yield combined with historical records of land use can provide an even more detailed framework for understanding the evolution of landscapes and reservoirs over time (Dearing and Jones, 2003).

In addition to sediment erosion data, biological proxies such as pollen can be used to document changes in the vegetation adjacent to and within the pond, which can also be used to infer human activities within the catchment (Gaillard, et al., 1991; Gaillard, et al., 1992; Laine, et al., 2011; Jouffroy-Bapicot, et al., 2013). For example, Doyen et al., (2013) analyzed pollen assemblages from a small lake in the upper Rhône Valley of France that documented major shifts in agricultural activities since Neolithic times that included: crop cultivation, hemp cultivation and retting, and tree farming. Another study in the Morvan region of France, utilized pollen proxies recorded in a small lake to document tree farming (i.e. chestnut cultivation) and tree harvesting activity for fuel during Medieval and Modern times (Jouffroy-Bapicot, et al., 2013).

This study combines a rich historical data set with high-resolution geochemical, biological (i.e. pollen), and lithological data from the sediments of a small, Medieval-aged reservoir at the Château de Lucenier in the Saône-et-Loire region of Burgundy, France. Burgundy is a key agricultural region (Crumley and Green, 1987; Crumley, 2000), and ideal for landscape history analyses as tree ring data and grape harvest records provide nearly a millennium of regional reference climate data (Le Roy Ladurie, 1967; Serre-Bachet, 1978; Le Roy Ladurie and Baulant, 1980; Briffa et al., 1986; Frenzel et al., 1992; Lamarque, 1994; Pfister, 1992, 1999; Chuine et al., 2004). Historical meteorological measurements and roughly 500 years of documented land use information (tax records, historical maps, agricultural reports, parish records, census data, etc.) specific to the area are also available (Crumley and Green, 1987; Crumley, 1994; Jones, 2006, 2009; Madry, et al., 2011, 2012), as are numerous reservoirs, some of which have persisted for hundreds of years (Cassini 1759, Fig. 2.1, upper panel, left).

2.2 STUDY AREA

The study focuses on a small moat and farm pond located within the Commune of La Chapelle-au-Mans, in the Canton of Gueugnon, within the Department of Sâone-et-Loire. The watershed drains 1.7 km^2 and is largely rural (Fig. 1, lower panel, left). The dominant land cover is pasture (76%). The remaining land cover includes cropland (11%, primarily wheat and corn), and forest (11%) (European Environmental Agency, 2006). Soils in the region are weakly developed on granitic rocks, and are typically thin (Crumley and Green, 1987). Average annual precipitation is 850 mm, generally occurring as rain in the late fall and early winter. Average annual temperature is 11^o C (range -7 to 23^o C (Météo, France, 2012).

More generally, in Burgundy France, human impacts to the landscape began, at the latest, during the Iron Age, with mixed agrarian/industrial communities centered in upland settings. Celtic land-use during the Iron Age included mining of iron, tin, copper, and coal, with extensive trade routes developed along some roads and rivers. With the conquest of Gaul in 52 B.C., Roman land use practices were introduced including extensive use of valley roads and river transport and an intensive agrarian economy. Following the Roman period, civil upheaval in the seventh, ninth, and tenth centuries resulted in the reoccupation of fortified hilltops, thus shifting land-use between upland and valley settings (Berry, 1987). The Cassini maps of AD 1759 document the final vestiges of the Medieval landscape and provide an early cartographic record for the study area. The reservoir included in this study is depicted on Cassini maps for the area (Figure 2.1). Moreover, Celtic roads and hedgerows present during medieval times have persisted as significant geomorphological elements on the modern landscape.

The pond at Lucenier is a small (0.014 km^2), shallow (mean depth ~1.4 m), well-mixed, open basin reservoir surrounding a château (ca. 13^{th} century) (Fig. 2.1). It is ice-covered during the winter months and is hypereutrophic during the summer. Lucenier is located in the headwaters of a small catchment (1.7 km^2) at an elevation of 306 m, and is filled from a single inflow that emanates directly from another small reservoir (0.031 km^2) located ~50 m upstream of the pond. The main pond at Lucenier (surrounding the château) was originally constructed as a moat (Maison de pays du canton de Gueugnon, 1996), and later utilized as a millpond. The mill was likely used to process locally grown grain (per comm. E.A. Jones). Based on historical documents, the mill was no longer in use after the mid AD 1800's, and the pond is currently maintained for landscaping and recreation (Fig. 2.1, photograph, middle panel, left). Lucenier was chosen as a coring location because it existed since at least AD 1759 as indicated by Cassini (Fig. 2.1, upper panel, left). Both ponds have persisted since construction, as documented by historical and modern maps and air photos.

Figure 2.1. Study area maps. A portion of the study region from the 1759 Cassini map, Institut Geographique National, Paris (upper panel, left), the 1834 Cadastre, Archives Départementales de Saône-et-Loire, Mâcon (upper panel, center), the 1895 Carte de la France, Librairie Hachette et Compagnie, Paris (upper panel, right), and the 2003 topographic map, Institut Geographique National, Paris (middle panel, right). The Lucenier basin and watershed and the Château de Lucenier is centered in each map. The Château de Lucenier (photograph, middle panel, left) is a castle complex dating to the 14th century. Forested areas are evident in each of the maps, and artificial dams, ponds, and water mills (stars at the base of dams in the Cassini map, for example) are clearly marked. Aerial photograph, Institut Geographique National, Paris (lower panel, left) shows the watershed outlined in black, and illustrates the modern land cover surrounding the pond (pond is labeled Lucenier). Forest appears dark green, crops appear brown to light yellow, pastures are medium to light green (IGN, 2005). A bathymetric map (lower panel, right) showing the general reservoir morphometry and depth. The core site is labeled with a triangle, and the inflow and outflow to the pond are noted.

2.3 CLIMATE BACKGROUND

Regional variations in climate and corresponding hydrological regimes, driven by upstream controls in the Atlantic, define the Maritime-, Mediterranean-, and Continental- climatic regimes that all influence the study area. Locally, microclimates, resulting from orographic effects produced by the elevation of the Morvan Plateau and the Massif Central, dominate the climate of the study area. The high areas impede westerly flow and result in increased precipitation.

The paths of storms across Western Europe are controlled by the position and strength of the Azores high atmospheric pressure system and Icelandic low atmospheric pressure system (Hurrell, 1995). The principal centers of activity expand and contract seasonally (Barnston and Livezey, 1987), as well as on longer time-scales. These changes produce spatial shifts in temperature and precipitation across the European continent from summer to winter, and over millennia (van Loon and Rogers, 1978; Rogers and van Loon, 1979; Gunn and Crumley, 1991; Trouet, et al., 2009; Yiou et al., 2012).

In general, as hemispheric temperatures increase the Azores high atmospheric pressure system expands northward, increasing the pressure gradient and causing increased zonal flow. The expansion results in less north-south mixing of air masses, the displacement of storm tracks to more northern latitudes, the development of barotropic conditions in southern Europe, and the potential for isolated, convective thunderstorms within the southern Burgundy region. Periods of cooling result in southerly contraction of the Azores high, increased meridionality and mixing of air masses, increased storminess and climatic variability. This results in a maritime climactic regime in Southern Burgundy. The Little Ice Age and the Younger Dryas, for example, have been attributed to meridional flow patterns in the northern hemisphere, as have cool episodes within the period of instrumental monitoring (Moses et al., 1987; Lamb, 1982; 1984; Olsen et al., 2012). Warm periods such as the Medieval Warm Period (MWP) resulted from more zonal flows, and the establishment of a high-pressure system over central France (Trouet et al., 2009). For southern Burgundy, the expansion of the Azores high fosters a Mediterranean or continental type climate, forcing zonal flow and increased cyclonic activity to more northerly positions. Transitional seasons result in more meridional circulation and include large storms, creating highly variable weather as the position of ridges and troughs shift with the phase of planetary waves. Variations in meridional or zonal flow patterns between winter and summer result in a spatially varied climatic influence within those seasons as well. Climatic history for the Burgundy region suggests that climate has been highly variable, with a tendency for one of the three major climatic regimes (maritime, continental, Mediterranean) to dominate for extended periods of time over the landscape (Crumley and Green, 1987).

A considerable amount of regional-scale historic information and paleo-environmental data exists for the Northern Hemisphere, including Europe. Much of this data have been used to characterize the magnitude of climate change over the last millennium (Overpeck et al., 1997, Jones et al., 1998, Mann et al., 1998 and 1999, Pfister et al., 1999, Crowley, 2000, Briffa, 2000, Briffa et al., 2001, Esper et al., 2002, Jones et al., 2002, Mann and Jones, 2003, Chuine et al., 2004, Luterbacher et al., 2004, Moberg, 2005; Krieger et al., 2010; Wetter and Pfister, 2012). The regional European studies are mainly based on a combination of high latitude or altitude tree ring indices, documentary evidence, and early instrumental data. Mann et al. (1998, 1999, 2007) reconstructed mean annual Northern Hemisphere surface temperatures back to AD 1400 based on tree ring, ice core, ice melt and historical records. Their results showed increased warmth in climate at the end of the 20th century and that the increases are anomalous for the last millennium. Their record has been contrasted with other studies that have found warmer than present air temperatures at various times in the past. For example, Chuine et al. (2004) used a process-based phenology model developed for the Pinot Noir grape in Burgundy, France, to reconstruct mean spring-summer air temperatures from 1370 to 2003. Their record shows numerous decadal time periods during the past that were warmer than present. Their results were also significantly correlated with other proxy records for mean summer air temperatures in the region (Paris, Central England, and the Alps). Wetter and Pfister (2012) compared a long Swiss grape harvest date (GHD) record with other GHD series in Burgundy. Their study discovered a severe drought that occurred in AD 1540 that was much more severe and lasted longer than the heat wave in AD 2003. Jones et al. (2002) found a slight long-term warming trend with growing seasons being warmer pre-1860 based on a 200 – 250 year long record of temperature, precipitation and drought for northern and central Europe. They also found that most of the warming documented in their record was experienced in the cold season. Etien et al. (2007) combined Burgundy GHD with $\delta^{18}O$ data of tree cellulose from living trees and timbers collected from a castle and forest in Fontainebleau, France to reconstruct maximum growing temperatures in northern France from AD 1596 - 2000. They calibrated the grape harvest records and tree cellulose data with twentieth century instrumental data. This analysis produced a reference data set for the variability of growing temperatures in Western Europe over a 400 year time period. The contrasts in finer-scale climate variability point to the importance of reconstructing landscape dynamics at finer temporal and spatial scales.

Climate reconstruction in the sixteenth century has been a major focus of research in the region because of the Little Ice Age (LIA). The LIA is associated with a documented shift towards cooler temperatures and increased climate variability, including more frequent and extreme changes in temperature and precipitation in Europe from AD 1400 – 1700 (Lamb, 1965, 1977; Grove, 1988; Mann, 2002, 2009). The impact of the LIA has been recorded throughout Europe in sediment records from lakes at high elevations often associated with glacial activity. Most of these records suggest the LIA was characterized by increased storminess (Dearing and Jones, 2003). Pfister and Brazdil (1999) reconstructed seasonal and annual precipitation and temperature trends for sixteenth century Europe based on a composite long-term tree ring series (Briffa, 1999) and documentary evidence. Their data showed an increase in mid-summer wetness and cooling during the last three decades of the sixteenth century that resulted in Alpine glacial advances, increased storminess, and increased flooding (Brazdil, 1999). The deterioration in climate had a huge impact on society as crops failed and wine production also declined (Landsteiner, 1999). For many people, the worsening climate at the end of the sixteenth century was suspected as evidence that the world was ending (Behringer, 1999). Reconstruction of catchment dynamics from sediments in the Lucenier pond provides the opportunity to gather additional data on human and landscape responses to these substantial climatic changes.

2.4 METHODS

2.4.1 Core Collection and Sampling

In July 2006, a 3.5 m sediment core was collected from a central location in the Lucenier pond using a sediment-water interface corer and modified square-rod piston coring system (Fig. 2.1, lower panel, right). The upper 35 cm of the surface piston core was extruded in the field at 1.0 cm intervals until the sediment became firm enough to ensure undisturbed transport. Core sections were extruded in the field and packaged for transit. All packaged core material was transported to the University of Pittsburgh where it was split, described, and photographed. Core sections were sampled in the laboratory at 5-cm intervals for bulk density, grain size, organic carbon, inorganic carbon, pollen, elemental carbon, and nitrogen analyses. Samples were also collected for radiocarbon, ^{137}Cs, and ^{210}Pb dating.

2.4.2 Core Chronology

Sediment ages and accumulation rates were determined by radiocarbon accelerator mass spectrometry (AMS) of both macroscopic and microscopic charcoal and terrestrial organic matter (wood, seeds) (Table 2.1; Fig. 2.2). Samples were pretreated at the University of Pittsburgh following standard acid/base/acid pretreatment protocols (Abbott and Stafford, 1996) and measured at the William M. Keck Carbon Cycle AMS Facility at the University of California, Irvine. Calibrated dates and calendar ages were calculated using the CALIB 5.0 calibration (Stuiver and Reimer, 1993; Reimer et al., 2004). Radioisotope (^{210}Pb, ^{226}Ra, ^{137}Cs) activities were also measured in surface piston core samples by direct gamma counting at the University of Florida using an EG&G Ortec® GWL high-purity germanium well detector (Appleby et al., 1983; Schelske et al., 1994). Pb-210 dating was attempted, but was of limited utility given measured Radium-226 excess relative to Pb-210. As a result, the sediment chronology is based on ^{14}C AMS measurements and ^{137}Cs dating.

Table 2.1. Accelerator Mass Spectrometry radiocarbon dates from samples from Lucenier pond, La Chapelle-au-Mans, France.

Core Section	Material	Field Depth (cm)	Composite Depth (cm)	Radiocarbon age (BP)	±	Calibrated age (AD)		
						Median	Lower	Upper
Sediment-Water Interface Core	Macros	67 - 68	67 - 68	195	25	1780	1765	1800
Square-Rod Piston Core "Drive" 1	Seed	140-142	140-142	185	20	1770	1735	1805
Square-Rod Piston Core "Drive" 2	Wood	180-181	177-178	355	15	1495	1465	1525
Square-Rod Piston Core "Drive" 2	Wood	233-235	230-232	475	20	1430	1415	1450
Square-Rod Piston Core "Drive" 2	Wood	237-238	234-235	600	20	1335	1300	1370
Square-Rod Piston Core "Drive" 3	Charcoal	266-267	263-264	670	15	1295	1280	1305

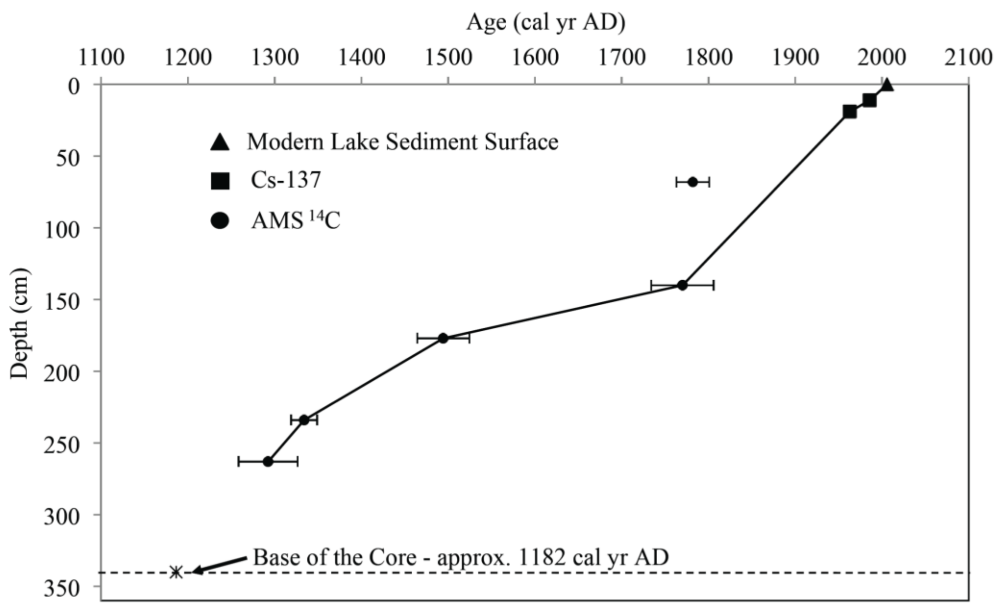


Figure 2.2. The age model was constructed using linear interpolation through successive radiocarbon dates. The triangle represents the modern pond surface, squares are ^{137}Cs data points, and the circles are AMS ^{14}C dates plotted with error bars representing the 1-sigma age range. Linear sedimentation rates were extrapolated to the base of the sampled sediment profile. The dashed line represents the bottom of the core with an asterisk for an extrapolated date in calendar years AD. The outlier is the date collected from plant macrophytes.

2.4.3 Sediment Accumulation Rate, Flux, and Sediment Yield

Sediment accumulation rates (SAR gm $cm^{-2}yr^{-1}$) were determined by multiplying dry bulk density (BD gcm^{-3}) with calculated sedimentation rates (SR $cmyr^{-1}$). The values for SAR were used to calculate sediment yield by multiplying SAR (tons $km^{-2}yr^{-1}$) by the pond surface area (km^2) and dividing the product by the pond catchment area (km^2) (Cisternas et al., 2001).

Organic carbon flux was calculated by multiplying the percent organic matter (OM %) by the SAR ($gcm^{-2}yr^{-1}$).

2.4.4 Core Lithology

Sediment magnetic susceptibility (MS) was measured at 0.5 cm intervals using a Tamiscan-TS1 automated surface-scanning sensor and Bartington® susceptibility meter at the University of Pittsburgh.

Grain size analysis was completed on a Coulter® LS 100 laser diffractometer at Edinboro University of Pennsylvania. The measurement range for this instrument is 0.04 μm to 1 mm; therefore, prior to analysis samples were wet sieved to separate the greater than 1 mm fraction from the finer fractions and avoid excessive obscuration. Samples were prepared for grain size analysis using a four step pre-treatment process (Vaasma, 2008). The laser diffractometer was calibrated periodically throughout the analysis with 500 μm glass spheres, and duplicate samples were run every fifth sample to test for reproducibility of particle size fractions. Linear regression analysis of the original samples with duplicate samples demonstrated low inter-sample variability with r^2 values >0.94.

2.4.5 Sediment Geochemistry

Elemental composition of the Lucenier sediment core was analyzed using scanning X-ray fluorescence (XRF) on an Avaatech (now a subsidiary of Doeschot) XRF core scanner at the University of North Carolina – Chapel Hill. Details of the XRF scanning methods are outlined in Chapter 3 Section 3.3.

Weight percent organic matter was determined at 5-cm intervals in the Lucenier core by loss-on-ignition (LOI) after 4 hours at 550°C (Dean 1974; Heiri et al., 2001). Weight percent $CaCO_3$ was similarly calculated by LOI after 2 hours at 1000°C (Boyle, 2004). Inorganic carbon (IC) was measured by coulometric titration (Engleman et al., 1985) with a UIC/Coulometrics Model 5011 coulometer and a coupled automated acidification preparation system (AutoMate FX, Inc.).

Total carbon (TC) and nitrogen (TN) in the sediments were measured with a Eurovector high temperature elemental analyzer with autosampler at the University of Pittsburgh. Organic carbon (OC) was estimated by subtraction of IC from TC.

2.4.6 Pollen

Pollen samples were collected using a constant volume sampler (2 cm^3) every 5 cm, which is roughly equal to a ten-year time interval, for a total of 72 samples. Pollen processing followed standardized procedures (Berglund and Ralska Jasiewiczowa, 1986). Clubmoss (*Lycopodium*) spores were added for calculation of pollen concentrations and pollen accumulation rates (Stockmarr, 1971). At least 500 pollen grains per sample were counted and identified with the aid of standard keys (Moore et al., 1991; Beug 2004; Punt et al., 1976-2003) and by comparison with reference materials housed at the Linnaeus University's Department of Biology and

Environmental Science. The separation of cereal pollen from grasses (*Gramineae*) pollen was achieved using Beug's criteria (2004). Grains with a diameter > 37 µm and a pore diameter and annulus thickness > 2.7 µm are ascribed to the pollen morphological type *Cerealia*. Further separation into rye (*Secale cerale*), barley (*Hordeum* type), wheat (*Triticum* type) and oats (*Avena* type) is performed with a careful analysis of the exine's surface (size and distribution of papillae) (Beug 2004). Joly et al., (2007) investigated pollen from wild *Poaceae* in western France and examined grain and annulus diameters. They concluded that the grain and annulus sizes should be > 47µm and > 11µm, respectively, for a secure separation of cereals from wild grasses in their study area. There are few common species of *Gramineae* in NW Europe with grains > 37 µm (except water mannagrass *Glyceria fluitans*). Therefore, cereal identifications that rely on the analysis of the exine surface combined with the grain and annulus size thresholds of Beug (2004) are more accurate than separation based solely on size criteria.

Pollen diagrams were constructed using TILIA and TGView software (Grimm, 1991). PARs (number of pollen grains $cm^{-2}yr^{-1}$) were calculated by dividing the pollen concentrations (number of pollen grains cm^{-3}) by the number of years it took to accumulate one centimeter of sediment. PARs provide a record of pollen loading and more clearly reveal changes in local plant abundance relative to pollen percentages (Davis and Deevey, 1964). The pollen taxa are grouped in vegetation/land-use types according to Gaillard (2007, 2013). This grouping primarily aims to facilitate interpretation of pollen records in terms of human impact and includes ten groups of pollen indicators of human-induced vegetation units. Each group is designated by an abbreviation on the pollen diagrams, and are defined as follows: *TSDS,* Trees and shrubs of damp soils; *STTS,* Shade-tolerant trees and shrubs; *LDTS,* Light demanding trees and shrubs; *CUTS,* Cultivated trees and shrubs; *FOHF,* Forest herbs and ferns; *DPME,* Dry pastures and meadows; *FMEP*, Fresh meadows and pastures; *WMLP*, Wet meadows, lake/pond shores, *RUCO*, Ruderal communities; *CULA*, Cultivated land. Pollen percentages were calculated from the total sum of terrestrial pollen types (trees and shrubs plus cultivated land taxa). Microscopic charcoal particles (an indication of regional fire activity) were counted on the pollen slides following Berglund (1991).

2.4.7 Historical Data

Historical data for the region spanning the past ˜300 years (Fig. 2.3) were collected and compiled from regional archives, and local village offices in Burgundy. These records include tax- and parish-records containing land-use and population data, as well government agricultural reports with detailed crop and animal information. This documentary evidence was integrated with information on land cover derived from the GIS analysis of a series of 14 historical maps of the area dating from AD 1759 – 2003, and aerial photos dating to AD 1945 (Fig. 2.1), to determine general trends in land cover and land use over the last ˜350 years (Fig. 2.3) (Jones, et al., 2012; Madry et al., 2011).

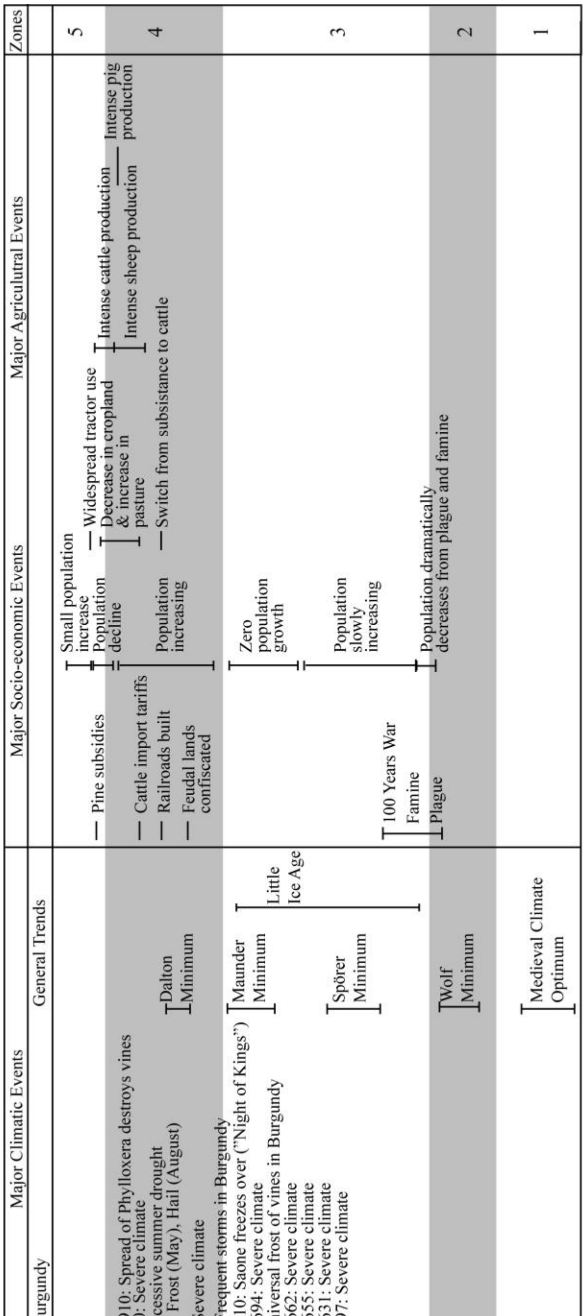


Figure 2.3. Major historical, economic, and climatic events compared with sediment yield for the study area. Shaded areas refer to zones that are delineated based on major changes in sediment yield. Zone 1 is pre-pond sediment. Zones 2 and 4 are time periods of high sediment yield, and Zones 3 and 5 are periods of low yield.

2.5 RESULTS

2.5.1 Core Chronology

Age-depth values were determined by linear interpolation through successive radiocarbon dates, and ^{137}CS dated horizons (Fig. 2.2). The activity of ^{137}CS was < 4 $dpmg^{-1}$ and displayed two distinct peaks. A peak at 19 cm corresponds to the 1963 Nuclear Test Ban Treaty, and a secondary peak at 11 cm to the 1986 nuclear disaster at Chernobyl. Additionally, linear sedimentation rates were extrapolated to the base of the sampled sediment profile. An AMS date collected from plant macrophytes was not included in the age model, as these materials are often considered less reliable than dates collected from wood, charcoal and seed material (Geyh et al., 1974; Colman et al., 1996; and Wohlfarth et al., 1998).

There was a high degree of stratigraphic correlation between overlapping core sections allowing for the construction of core composites using Analyseries software (Paillard et al., 1996) based on magnetic susceptibility profiles. Tie points were chosen between a reference core section and overlapping core section. The resulting correlation analysis then rescaled the overlapping section with new depths.

2.5.2 Core Lithology

Lithologically the base of the core from AD 1190 - 1230 is coarse-grained light colored alluvium, likely pre-pond sediment. From AD 1230 – 1240, there is a mottled buried A horizon that is likely a buried paleosol. From AD 1240 – 2006, the sediment is characterized by brown (10 YR 4/2) homogenous silt. There are 3 distinct gravel layers (> 20% gravel) that occur at AD

1250, AD 1290, and AD 1325. The percentage of clay (˜15%) and silt (˜72%) is consistent through these sediments, except for the base of the core during the pond establishment period (Fig. 2.4). The sand fraction fluctuated throughout and in general is high at the base (>20%), decreased through the middle (˜6%), and increased again at the top (up to 17%).

Magnetic susceptibility (Fig. 2.4) varied from 0 to 5 x 10^{-5}SI with a mean of 1 x 10^{-5}SI. In general, values increased from AD 1240 to their maximum value in AD 1890 (5 x 10^{-5}SI), and then decreased to AD 1940 (0.5 x 10^{-5}SI).

Sediment yield (Fig. 2.4) was generally high in basal sediments (> 20 tons km^{-2} yr^{-1}), with distinct maxima centered at approximately AD 1260, AD 1300, and AD 1330. Thereafter, sediment yield steadily declined (< 5 tons km^{-2} yr^{-1}) to ca. AD 1750. After AD 1750 sediment yield increased markedly to a maximum of 40 tons km^{-2} yr^{-1}near AD 1790. High sediment yield values declined slightly thereafter and peaked again near AD 1900 (˜30 tons km^{-2} yr^{-1}). Sediment yields declined from AD 1900 to the present (2 tons km^{-2} yr^{-1}).

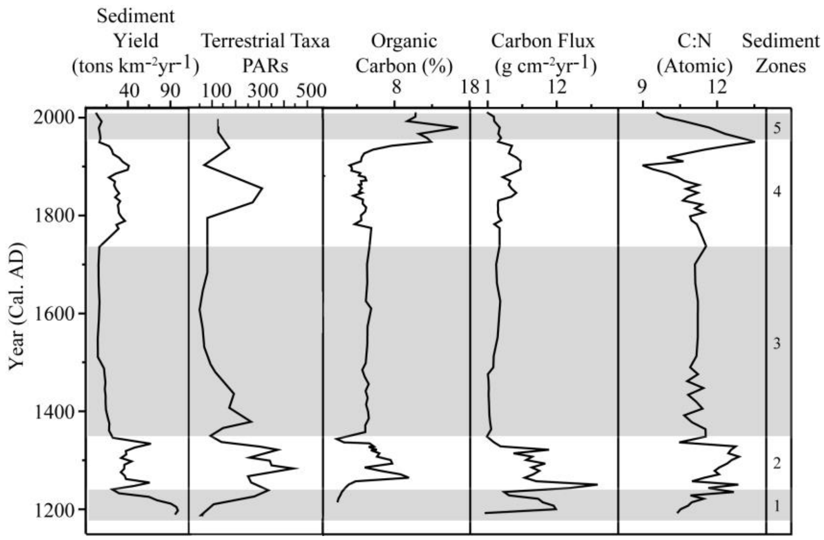


Figure 2.4. Core lithology and chemistry data plotted versus time. The extruded sections of the core were not analyzed for magnetic susceptibility and grain size (the upper 0 – 35 cm or post AD 1935). The gray shading denotes areas that correspond to the 5 sediment zones, which are based on major changes in sediment yield. Sediment zone 1 delineates the pre-pond sediment. Zones 2 and 4 are time periods of high sediment yield, and Zones 3 and 5 are periods of low yield.

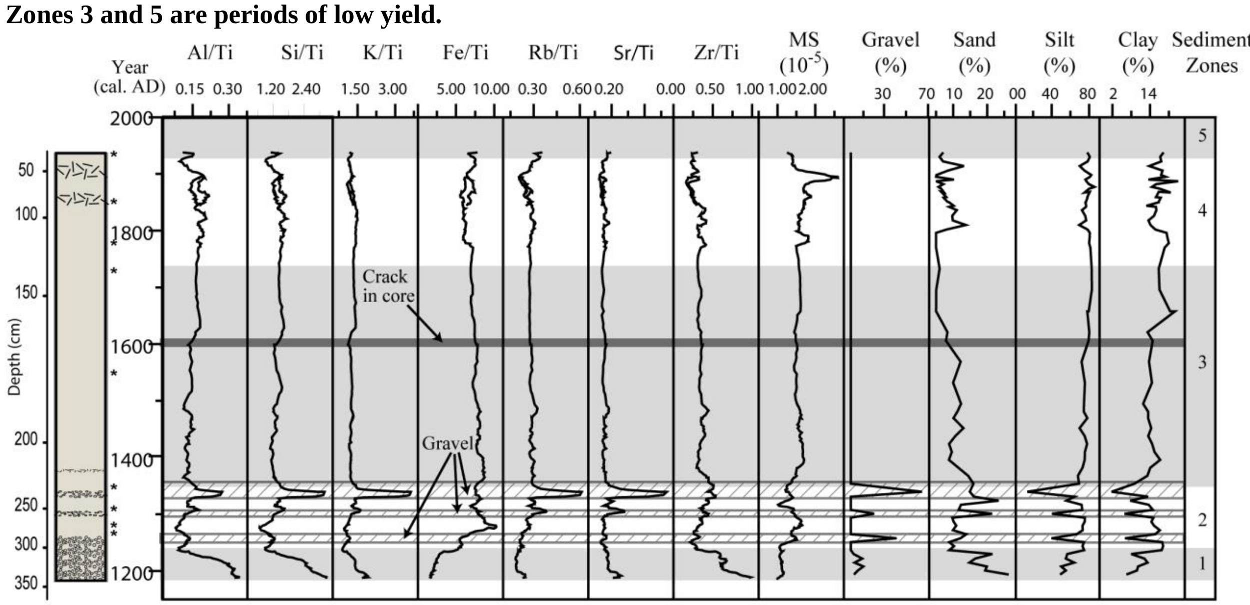


Figure 2.5. XRF data showing relative changes in elemental concentration throughout the core. The data are presented as ratios of counts (fluorescence intensity of elements), and are smoothed with a 5-point moving average. Core sections are plotted separately (not composited) because there was a disagreement in values between overlapping sections. This disparity in values is particularly evident for Fe/Ti from AD 1850 – 1900. The shaded gray area around AD 1600 marks a crack in the core causing a distinct dip in data. The light gray shading denotes areas that correspond to the 5 sediment zones, which are based on major changes in sediment yield. Sediment Zone 1 delineates the pre-pond sediment. Zones 2 and 4 are time periods of high sediment yield, and Zones 3 and 5 are periods of low yield. The record stops in the AD 1900's because the upper 35 cm of the core was extruded in the field, and could not be scanned. A generalized description of the core lithology is also shown. Organic horizons are noted as well as gravel layers, and woody material.

2.5.3 Sediment Geochemistry

Organic carbon (OC) content (Fig. 2.4) ranged from a minimum of 0.3% to a maximum of 17%. The OC remains relatively constant for most of the core until after ca. AD 1900, when it increased to 17% in AD 1975 and then decreased to 10% at present. Organic carbon flux ranges from 1 g cm^{-2} yr^{-1} to 14 g cm^{-2} yr^{-1}, and generally increased through time to the early AD 1900's (˜6 g cm^{-2} yr^{-1}), and decreased to the present (˜1 g cm^{-2} yr^{-1}). There are distinct time periods when the flux is low and relatively stable (< 5 g cm^{-2} yr^{-1} from mid AD 1300's to early l800's), as well as intervals with significant peaks (> 12 g cm^{-2} yr^{-1} during the mid AD 1200's to early 1300's). C:N ratios (Fig. 2.4) ranged from 9 – 14 with an average of 11. There is one peak in C:N ratios during the late AD 1900's (14), and then values declined toward the top of the core (˜9).

All element ratios have a distinct peak centered near AD 1330 (Fig. 2.5). Values for K/Ti and Sr/Ti remain relatively unchanged for the remainder of the core. Similarly, Rb/Ti is relatively unchanged except for around AD 1900 it decreased to 0.2 and then increased to 0.4 in AD 1940. Values of Al/Ti, Si/Ti, and Zr/Ti are consistent through most of the core except around AD 1770 they increased to 0.2, 1.2, 0.4 respectively and stayed roughly at these levels until AD 1840. Subsequently, they decreased to 0.1, 1.2, and 0.2 until AD 1890. Values increased again to 0.2, 1.5, and 0.3 around AD 1900, and decreased again in AD 1930 to 0.1, 0.9, and 0.2. Around AD 1935 values for Al/Ti and Si/Ti increased to 0.2 and 1.5 respectively, while Zr/Ti remains unchanged. Finally in AD 1940 the values for Al/Ti and Si/Ti decline to 0.1 and 1.1 respectively, while Zr/Ti increases to 0.3.

2.5.4 Pollen

Percentages for major taxa are presented in Figs. 2.6 and 2.7, and PARs for major taxa are presented in Figs. 2.8 and 2.9. Rare pollen types are presented in Table 2.2 with their attribution to plant-ecological groups and land-use types. Taxa composition and changes are specified in PARs only when they are significantly different from the percentage record.

Pollen from AD 1190 - 1240, is dominated by woodland taxa such as: Oak (*Quercus*), beech (*Fagus*), hazel (*Corylus*), birch (*Betula*), and alder (*Alnus*). Increased Alder and fern pollen percentages suggest they were likely most abundant (Figure 2.6). There is also a regular occurrence of grasses (*Gramineae*), Ribwort Plantain (*Plantago lanceolata*), sorrel (*Rumex acetosa/acetosella*), hawkweeds/chicory (*Compositae SF Cichorioideae*), perennial knawel (*Scleranthus perennis*), cereals (*Cerealia* type), barley (*Hordeum* type) and rye (*Secale cereale*).

After AD 1240, aquatic taxa such as reeds (*Phragmites* type), lesser marshwort (*Apium inundatum*), marsh buttercups (*Ranunculus sceleratus* group) and spores of algae (primarily *Pediastrum* ssp.,) are abundant. Water chestnut (*Trapa natans*) was introduced ca. AD 1290 and still occurs today. Additionally, after AD 1240, new taxa characteristic of arable and ruderal land, dry and fresh meadows, and pastureland appear (Table 2.2). The percent values of rye and chestnut increased while grasses, ribwort, plantain, and heather decreased from ca. AD 1460 – 1900. Hemp (*Cannabis* type) pollen is found from AD 1240 – 1950. After AD 1900 the pollen data are characterized by a general increase in tree taxa (alder) and a decrease in cultivated taxa.

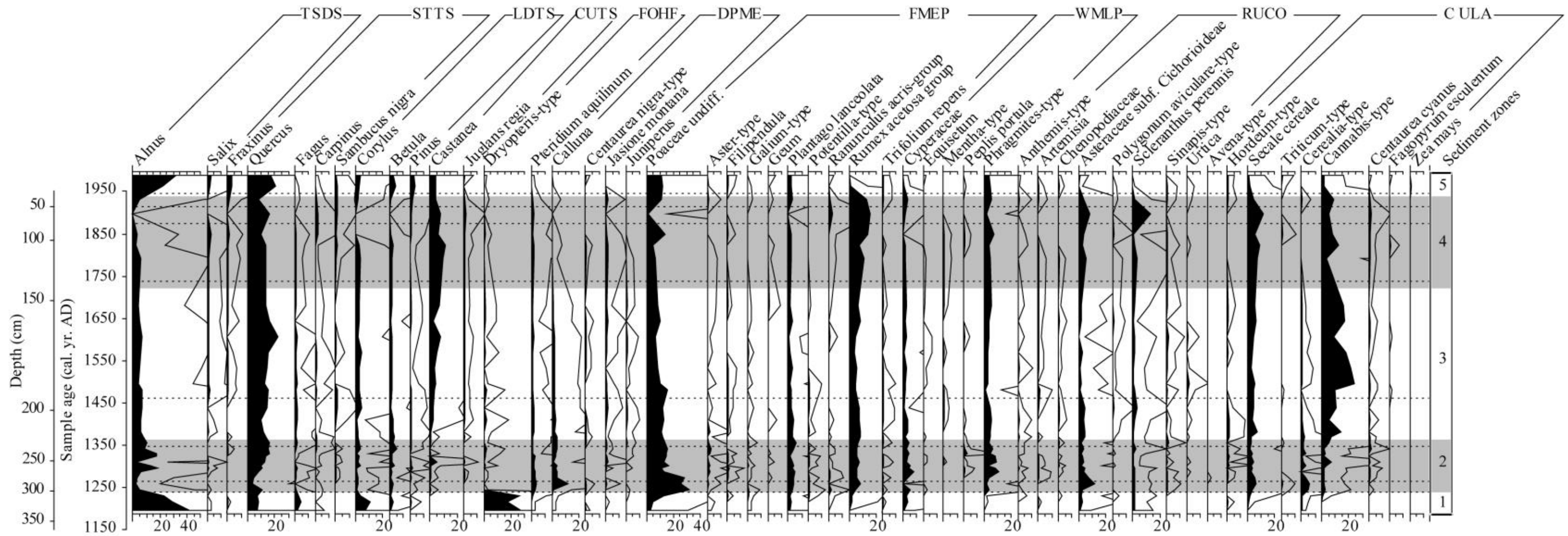


Figure 2.6. Pollen percentages of individual terrestrial taxa grouped into plant ecological groups (PEG) and land-use types (LUT) following Gaillard (2007, 2013). The calculation sum includes all pollen and spores from plants growing on drained land and excludes those from lakeshore plants and aquatics except for the group WMLP (see below). The percentages are plotted against time in calendar years AD following the chronology inferred from the age-depth model in Figure 2. *Abbreviations*: *TSDS* Trees and shrubs of damp soils; *STTS* Shade-tolerant trees and shrubs; *LDTS* Light demanding trees and shrubs; *CUTS* Cultivated trees and shrubs; *FOHF* Forest herbs and ferns; *DPME* Dry pastures and meadows; *FMEP* Fresh meadows and pastures; *WMLP* Wet meadows, lake/pond shores (excluded from the calculation sum of the other groups) *RUCO* Ruderal communities; *CULA* Cultivated land. Shaded areas correspond to the 5 sediment zones.

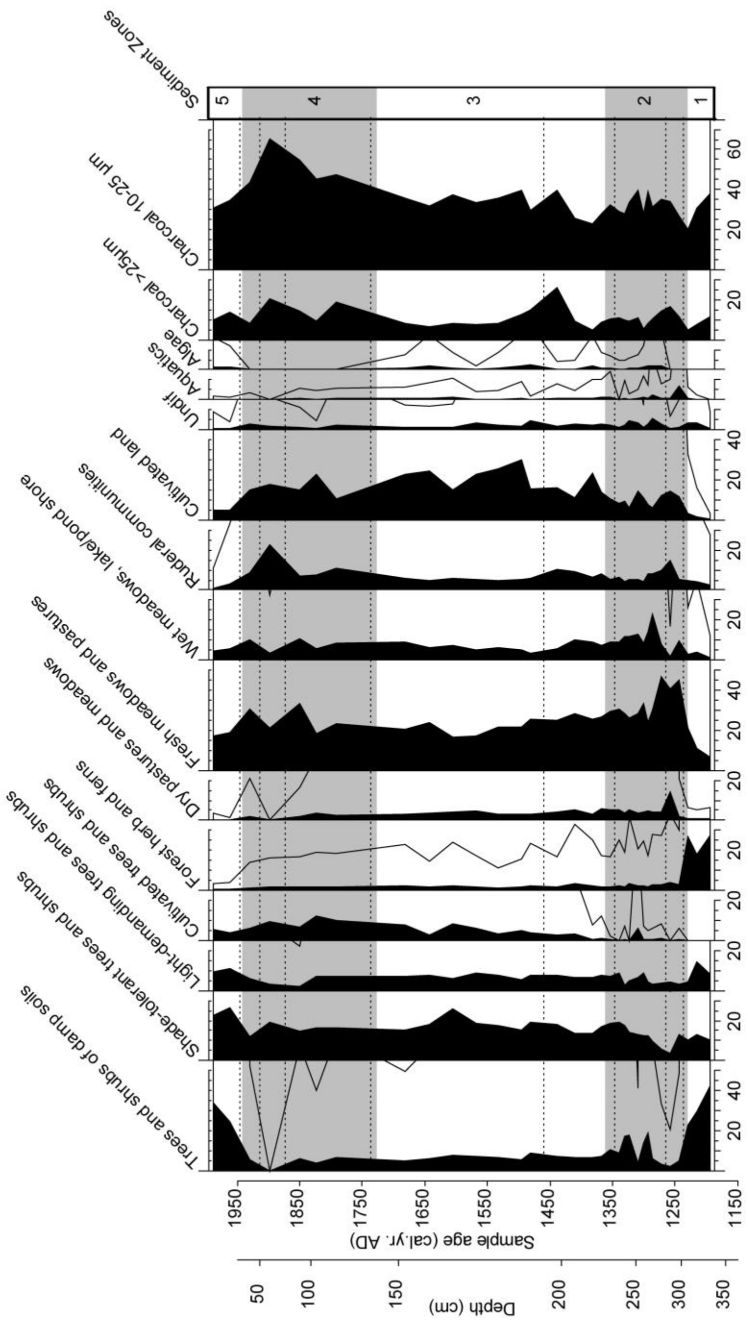


Figure 2.7. Pollen percentages of all plant ecological groups (PEG) and land-use types (LUT) following Gaillard (2007, 2013). The calculation sum includes all pollen and spores from plants growing on drained land and excludes those from lakeshore plants and aquatics except for the groups WMLP, Aquatics and Algae for which the calculation sum includes the taxa in WMLP. The percentages are plotted against time in calendar years AD following the chronology inferred from the age-depth model in Figure 2.

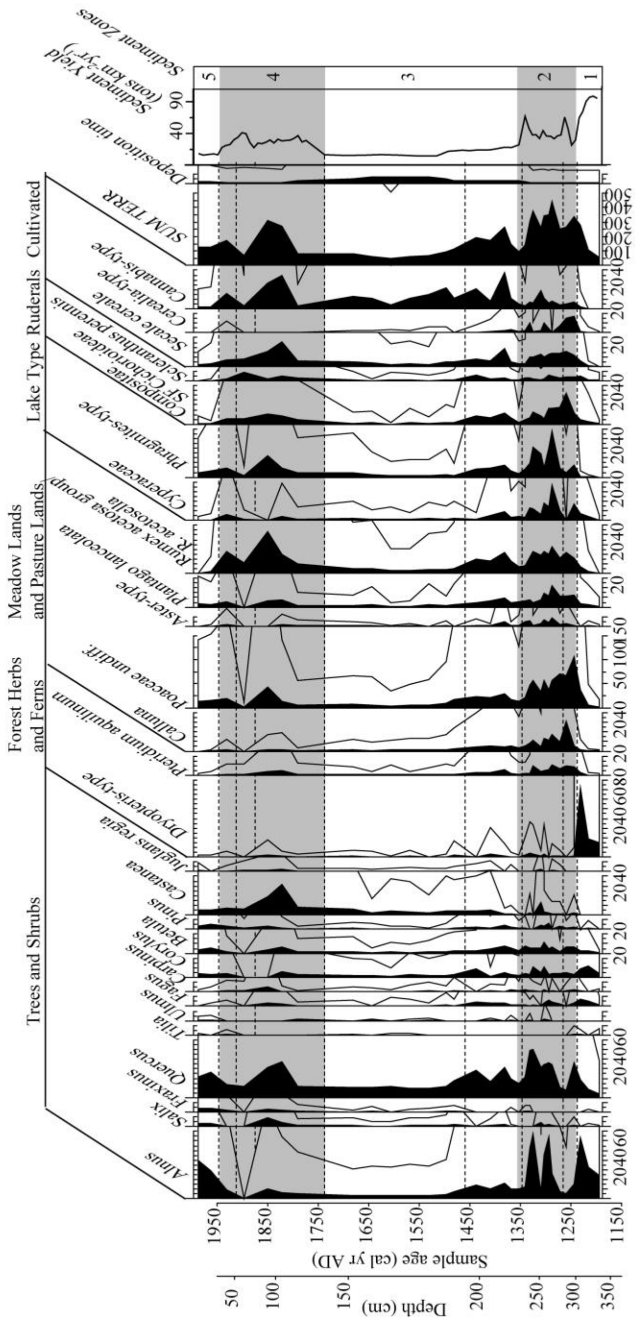


Figure 2.8. Pollen accumulation rates (PARs, number of grains cm^{-2} yr^{-1}; scale: 1= 10^3) for terrestrial taxa. Shaded areas refer to zones based on changes in sediment yield.

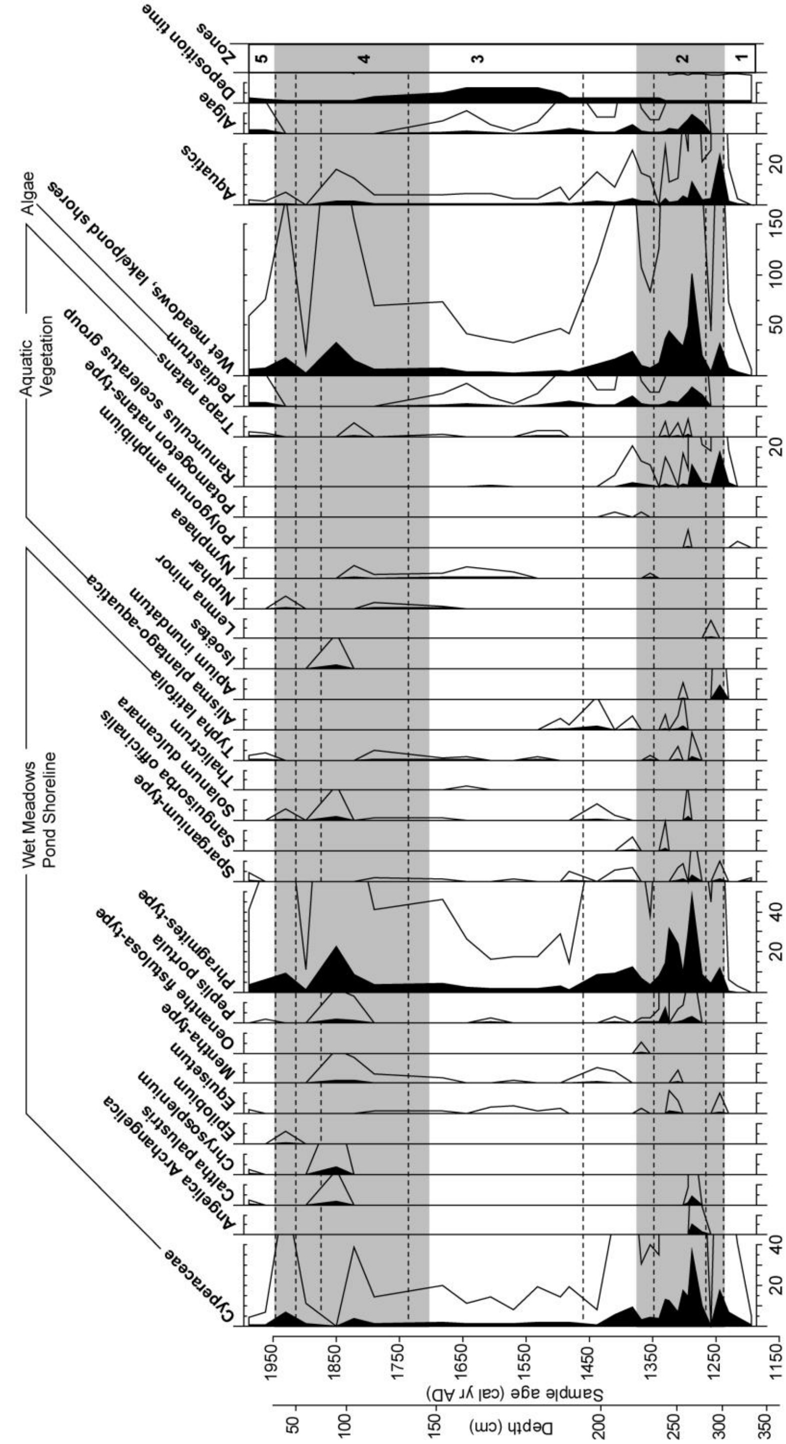


Figure 2.9. Pollen accumulation rates (PARs, number of grains cm^{-2} yr^{-1}; scale: 1= 10^3) for lakeshore and aquatic taxa. Shaded areas refer to zones based on changes in sediment yield.

Table 2.2. Less common or rare pollen types not presented in the pollen diagrams of Figs 2.6, 2.7, 2.8, and 2.9 with their attribution to plant ecological groups and land-use types following Gaillard (2007, 2013).

Taxa/zone	**1**	**2a**	**2b**	**2c**	**3a**	**3b**	**3c**	**3d**	**4**
Trees and shrubs									
Frangula alnus			x						
Acer					x	x			
Tilia	x	x			x			x	x
Ulmus			x	x	x	x			x
Hedera helix					x			x	x
Picea abies		x				x			x
Lonicera caprifolium-type			x						
Taxus			x	x					
Viburnum					x				
Populus tremula			x	x	x	x		x	x
Prunus				x	x	x			
Rosaceae			x	x	x	x			x
Sorbus aucuparia	x		x	x	x	x	x		x
Aesculus hippocastanum				x	x			x	x
Buxus sempervirens									x
Ribes alpinum				x					
Forest herbs and ferns									
Dryopteris filix-mas								x	
Polypodium vulgare			x		x				
Dry meadows and pastures									
Dianthus type			x			x			
Erica tetralix				x					
Ericaceae undiff.			x						
Genista type				x					
Ononis-type			x	x	x				
Plantago media-type		x	x		x				
Vaccinium			x		x	x			

2.6 DISCUSSION

2.6.1 General interpretation of the pollen record, PARs versus pollen percentages

The changes in PARs of most taxa and total PARs through time closely follow the fluctuations in sediment yield (Figs. 2.8 and 2.9) with both having low values ca. AD 1250, 1300, 1350-1500, 1800-1900, and particularly low values ca. AD 1500-1750. However, there is no clear correspondence in the sediment yield record to the very low PARs around AD 1900. Additionally, the increased PARs ca. AD 1800 occur later than the increased sediment yield after

AD 1750. The close correlation of PARs with sediment yield over most of the profile implies that pollen deposited in the pond was mainly transported by water (from the pond's inlet and run-off from the catchment area) rather than from the air. Therefore, the pollen record of land taxa should primarily represent the vegetation cover in the pond's hydrological catchment rather than in the "relevant source area of pollen" (Sugita, 1994). Fluctuations in PARs of individual taxa not corresponding with changes in sediment yield are potentially a qualitative measure of changes in plant abundance, in particular for plants growing in the pond or at its margin (Fig. 2.9). In this case, pollen percentages might better reflect proportional changes among taxa through time, in particular during shifts in sediment yield. Therefore, we combine the information from both percentages and PARs to interpret the pollen record.

2.6.2 Sedimentologic changes within a climatic and land-use context

Sedimentation in the pond as recorded in the core can be divided into 5 distinct zones based on sediment yield. Zones 2 and 4 exhibit relatively high and variable sediment yields, and Zones 3 and 5 have relatively low, stable yields. The following discussion highlights major sedimentologic changes for each zone within a climatic and human historical context (Fig. 2.3) integrating the land-use history inferred from the pollen record (Figs. 2.6, 2.7, 2.8, 2.9 and Table 2.2).

2.6.3 Zone 1: Pre-pond phase: before AD 1240

Before AD 1240, gravel and buried soils define the pre-pond sediment at the core bottom. The pollen in this sediment is predominantly woodland taxa (Figs 2.6 and 2.7). Spores of ferns are also common. Alder pollen and fern spores distinctly decreased just before pond creation, suggesting the pond might occupy a historic alder swamp. Agrarian activity occurred before the existence of the pond, as evidenced by the regular occurrence of pollen indicators of cereal cultivation, meadows, and grazing land (Figs. 2.6 and 2.7).

2.6.4 Zone 2: AD 1240 - 1360

The oldest sediments from clearly lacustrine (open water) conditions suggest that the pond began filling by approximately AD 1240. This date is similar to historical data that indicated construction of the chateau occurred ca. AD 1300 (Gueugnon et son Canton, 1996). Additionally, it is also consistent with pollen data (Fig. 2.6) that indicate pond establishment ca. AD 1240. For example, pollen of reeds, aquatics (lesser marshwort, marsh buttercups) and spores of algae (primarily *Pediastrum*) become abundant. Water chestnut pollen suggest it was introduced in AD 1290 and is still abundant today.

Human activities related to chateau construction resulted in increased erosion and deposition of sediment in the pond. Sediment yields during this time period were generally high, averaging ~39 tons km^{-2} yr^{-1}. Additionally, there are distinct gravelly horizons, and the highest sand content for the entire core (Figs. 2.4 and 2.5). Furthermore, elemental C:N ratios also increased, indicating elevated contribution of terrestrial material to the pond sediment (Fig. 2.4). The increased sediment yield and grain size, in addition to the increased contribution of terrestrial material to the pond sediment, suggest human activities caused an influx of minerogenic material to the pond. Simultaneous increased magnetic susceptibility and all elemental ratio values suggest these sediments were also relatively less weathered.

Sharply decreased PARs and percentage of alder pollen and fern spores also suggest human disturbances, such as tree clearing, occurred in preparation for pond and château construction. Additionally, high PAR values of bracken fern and increased charcoal particles from AD 1240 suggest fire was used in clearing. Hazel and beech PAR values are lower from AD 1240 and never recover earlier to PAR values. Oak exhibits very low pollen percentage and PAR values ca. AD 1260, but regains high percentage values from ca. AD 1300, and is the most common tree in the area besides chestnut through the remainder of the record. This shift in pollen data from alder to oak also supports the timing of landscape transformation from an alder swamp to a chateau estate.

Starting in AD 1240, common and rare taxa characteristic of anthropogenic activities increased significantly, and a large number of new herb taxa characteristic of arable and ruderal land, dry and fresh meadows, and pastureland appeared (Fig. 2.6; Table 2.2). Trees and shrubs indicating more open landscapes, such as willows, ash, and elderberry, are also regularly present in these sediments (Fig. 2.6). Hemp is found from AD 1240 with high percentages (5 – 25%) and PARs (5 – 40 pollen grains $cm^{-2}yr^{-1}$), indicating hemp was being grown locally and potentially processed in the pond. Previous studies showed that hemp pollen percentages greater than 10% could be attributed to retting (soaking done to soften and separate the hemp fibers), Edwards and Whittington, 1990; Gaillard et al., 1991; Lotter, 2001). Furthermore, the byproducts of hemp retting can pollute water bodies, leading to acidification and eutrophication (Cox, et. al, 2001; Riera et. al, 2006; Laine et al., 2010). The presence of *Pediastrum* associated with hemp (Figs. 2.8 and 2.9) suggests Lucenier may have been more eutrophic from AD 1240, as a result of hemp processing. *Pediastrum* is commonly associated with nutrient rich waters, and can be used as an indicator for eutrophic conditions (Fredskild, 1983; Warner et al., 1984). Pollen data analyzed by Laine et al., (2010) from a marsh in the Dijon area of Burgundy, also document hemp cultivation and retting by Cistercian monks during the same time period at Lucenier. Additionally, similar to Lucenier, they document the presence of *Pediastrum* in their record, which also potentially indicated eutrophication of the pond as a result of the retting process.

During this period of pond and château construction agricultural tree species were introduced as indicated by the first appearance of chestnut and walnut pollen ca. AD 1240 and AD 1270 respectively. A study of vegetation history and land use change reconstructed from peat cores in the Morvan region of France also document chestnut cultivation during the Middle Ages (Jouffroy-Bapicot, et al., 2013). The presence of these domesticated tree pollen is consistent with a shift from an alder and wetland vegetation dominated landscape.

Climatically, this period represents the tail end of the MWP (Fig. 2.2). The MWP is characterized by mild climatic conditions, in which winters were less severe, and summers drier than previous and subsequent climatic episodes (Mann, 2002). The mild weather conditions were favorable for agricultural production.

2.6.5 Zone 3: AD 1360 - 1730

Pollen, sediment, and geochemistry data suggest the landscape adjacent to the pond is stable relative to the previous time period. Sediment yield remains relatively low throughout this time period, between 5 – 15 tons $km^{-2}yr^{-1}$ (Fig. 2.4). In addition to decreased sediment yield, the grain sizes suggest limited extreme events, as coarse sediments are absent. Furthermore, XRF ratio data such as K/Ti are relatively stable, suggesting limited variation in pond sediment sources. The percentage pollen values indicate increased cultivation (rye and chestnut, in particular) at the expense of pasture (grasses, ribwort plantain and heather decrease) ca. AD 1450 (Fig. 6a). The low PARs of most plant taxa also reflect low sediment yields during this period. In general, the pond's flora was similar to the previous period. However, there is one exception that had higher pollen percentages. Hemp pollen increased from AD 1450, which suggests regular processing (soaking and/or rinsing of hemp fibers) occurred again in the pond during this period.

Cooler temperatures and increased climate variability, including more frequent and extreme changes in temperature and precipitation, characterize the LIA in Europe from AD 1400 – 1700 (Lamb, 1965, 1977; Grove, 1988; Mann, 2002, 2009). The impact of the LIA has been recorded throughout Europe in sediment records from lakes at high elevations often associated with glacial activity. Most of these records suggest the LIA was characterized by increased storminess (Dearing and Jones, 2003; Fig. 2.10), and is often associated with a series of flooding events, for instance at Lac d'Annecy (Thorndycraft et al., 1998; Dearing, et. al, 2003) and Le Bourget (Chapron, 2002) located in the foothills of the Alps NW of our study region. In most studies of sediment from lakes with no or small inlets, it is challenging to separate human-induced changes to the landscape from those caused by natural climate variability during the LIA (e.g. Berglund et al., 1991; Lotter, 1999). Data from this study suggest that human activity over the last 800 years drove more of the changes in sediment dynamics relative to climate in the Lucenier catchment.

Although rivers draining the study area, such as the Arroux and the Loire, also had more frequent, large magnitude floods during this time period (Straffin, 2000; Straffin and Blum, 2002), the sediment record at Lucenier does not indicate dramatic changes in sediment composition characteristic of increased storminess. Given the series arrangement of ponds, it is possible that storm-related deposition could have been trapped in the upper pond and, therefore been absent from the lower Lucenier pond. However, even with substantial sediment trapping, some episodic coarsening of the sediments would be expected during extreme events. The stability of XRF ratio data such as K/Ti and Zr/Ti, and MS data are consistent with no increase in minerogenic sediment influx during this period indicating episodic influxes of sediments during expected extreme events were not recorded (Fig. 2.5).

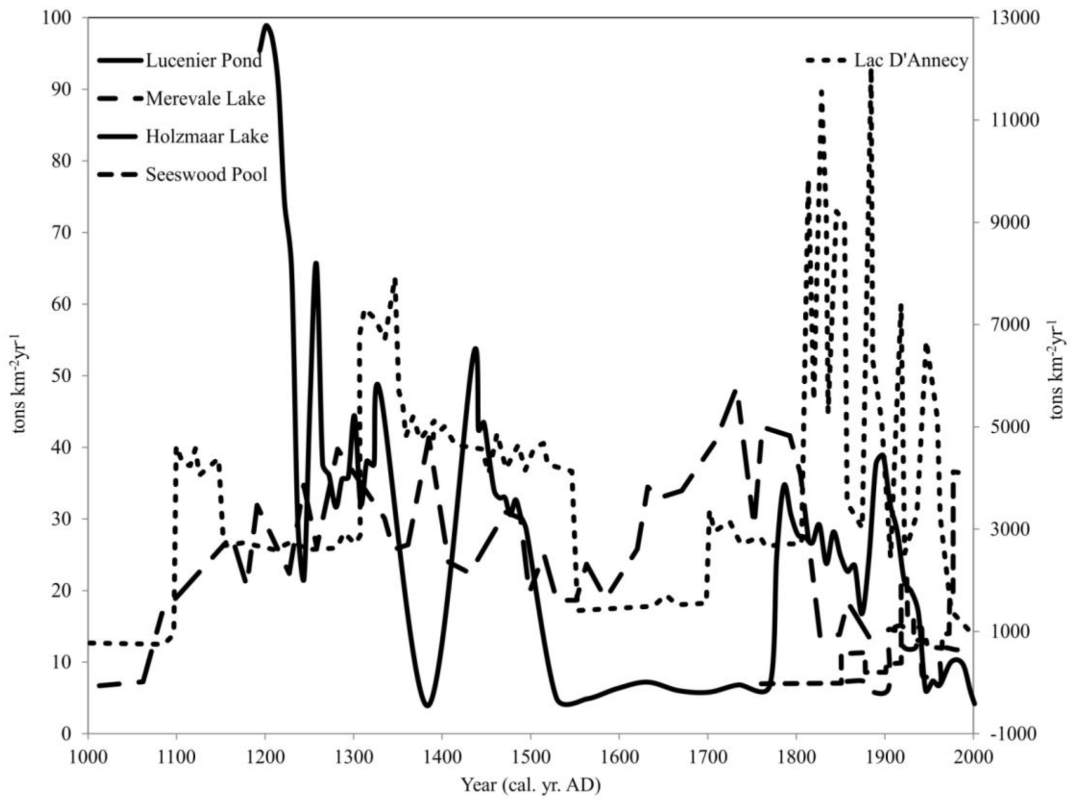


Figure 2.10. Comparative sediment yield records from various study sites in Western Europe. Sediment yield data from Midland England (Seeswood pool and Merevale Lake) illustrating changes in sedimentation from AD 1750 – 1990 (taken from Foster, et al., 1985). Sedimentation rates documented at Lac d'Annecy, France from AD 1100 – 2000 (taken from Dearing, et al., 2003). Changes in sediment yield recorded at Lake Holzmaar, Germany (taken from Zolitschka, 1998).

2.6.6 Zone 4: AD 1730 - 1945

Beginning in ~AD 1730, the transition from a highly-controlled feudal tenure to an agricultural regime where farmers selected crops resulted in increased sediment yields (~6 to 37 tons km^{-2} yr^{-}

^{1}). Pollen percentages (Figs. 2.6 and 2.7) record decreased alder and fern pollen, while chestnut and ruderal taxa increase gradually, particularly hawkweeds/chicory and perennial knawel (Fig. 2.6). These changes suggest that cereal and chestnut production increased. Chestnut peak percentages and PARs occur ca. AD 1820. Heather had lower percentages than earlier periods, suggesting that grazing on poor soils diminished. Decreased percentages of arboreal taxa, and increased charcoal particles (Figs. 2.7) may represent additional land clearance for agrarian purposes. The pollen flora at this time is similar to that of the previous time period (before AD 1730), indicating the landscape diversity in general had not changed.

After AD 1870, changes in transportation (especially the railroad network), mechanization, and intensification of agriculture for market (Clout 1983; Moulin, 1991) resulted in a second episode of increased sediment yield (from 20 to 40 tons km^{-2} yr^{-1}). Between AD 1836 – 1934 livestock production intensified in the neighboring Commune of Uxeau: cattle for sale (19% increase), horses for pulling farm machinery (1850% increase), and goats for cheese production (86% increase) (Jones et al., 2012). At the same time, there were significant increases in pollen percentage of taxa indicating pastureland, such as sorrel and ruderal plants, coincident with decreased chestnut, suggesting increased pasturing in the pond's catchment.

Soil erosion increased during this time period as a result of increased livestock production. Sediment sand content increased noticeably and MS values peaked, ca. AD 1900, suggesting an influx of sediment or soil to the reservoir, and therefore increased erosion in the uplands. This rapid sedimentation also caused low PARs (Fig. 2.8). Carbon flux and C:N ratios both increased during this period, suggesting greater terrestrial contributions to pond organic matter. Other studies in Western Europe also document increased sediment yield to reservoirs as a result of sheep grazing and livestock production (Dearing et al., 1987; Van der post et al., 1997). Thus, the increased soil disturbance at Lucenier, as evidenced by increased sediment yield, grain size, MS, a shift in C:N ratios, and PAR's, seems likely due to increased livestock production that occurred during this time period.

Dramatic decreases in sediment yield (40 tons $km^{-2}yr^{-1}$ to an average of 6 tons $km^{-2}yr^{-1}$) after ca. AD 1900 appear coincident with decreased pollen percentages and PARs of all taxa characteristic of cereal cultivation, particularly rye and rye weeds (e.g., corn flower). Alder and birch pollen increased and returned to percentages and PARs comparable to periods before AD 1350 (Figs. 2.6 and 2.8). This may suggest expanded tree cover on wet soils around the pond and along the inlet. Additionally, detrital indicators from XRF ratio data such as Zr/Ti and K/Ti have lower values during this time period than any other time in the record (Fig. 2.5), suggesting a stable landscape.

There were a number of socio-economic factors that influenced the human activities in the watershed at this time. For example, this period corresponds to a significant decline in population due to World War I and the rural exodus to cities (there was a 25% decline in population in the reservoir's Commune of la Chapelle-au-Mans between 1891 and 1936) (Archives Départmentales de Saône-et-Loire, 1891-1936). Additionally, there was decreased crop production due to the disruptions of WWI, the market disturbances of the 1920's, and economic depression of the 1930's (Moulin, 1991).

During this time there was more stable, warm, and wet maritime climate compared to the LIA, which was favorable for agriculture. Decreased human disturbance likely lowered the amount of sediment delivered to the pond system, manifesting in the sediment record as decreased sediment yield. Thus, the significant decline in sediment yields, pollen percentage, and PARs of indicators of cereal cultivation at the end of this period (ca. AD 1900-1950) is most likely due to decreased crop production. Increased alder and birch pollen values are likely a result of abandonment of agricultural land and subsequent overgrowth with pioneer tree species. Increased tree cover resulted in greater landscape stability and decreased sediment yields to the pond.

2.6.7 Zone 5: AD 1945 - 2006

The sediment record is characterized by low (< 20 tons $km^{-2}yr^{-1}$) and relatively stable sediment yield throughout this zone (Fig. 2.4). The decreased sediment input to the reservoir is likely related to a combination of continued increases in tree cover and French and European Union water management and land conservation policies (initiated in the early AD 1960's) such as pine subsidies (Bruckmeier, et al., 2002). Other studies in Europe report subsurface draining and conservation policies contribute to lower modern sediment yields (Dearing et al., 1987, 2003).
The pollen record suggests that the stable land use pattern in the pond's catchment beginning ca. AD 1400 ceased between AD 1900 and 1950, and the catchment transitioned to intensive cattle grazing. Grasses and a few ruderals, such as white clover and ribwort plantain, dominate a much less diverse pollen flora and other taxa become rare or locally extinct (Fig. 6, Table 2). A major transition in farming policy occurred at the close of World War II with a push by the French Government to convert small rural farms from subsistence producers to larger, more mechanized farms to feed France (Duby and Wallon, 1977; Keeler, 1987). In AD 1950, there were 140,000 tractors in France. This number rose to 305,000 in AD 1955, and almost a million by AD 1963, representing a tractor for more than one-half of all farms (Moulin, 1991). This time period, referred to as the "Rural Crisis" (Hervieu, 1989), saw a 70% decline in farm jobs in southern Burgundy (Van Deventer, 2001). Therefore population in Burgundy decreased during this period (Jones et al., 2012). Nationally, between the censuses of AD 1954 and AD 1962 the active rural

population decreased from 3.5 to 2.6 million. Following that, between AD 1955 and AD 1963, another 400,000 farmers ceased farming (Moulin, 1991). Additionally, the remaining farmers were encouraged by government subsidies to buy small unproductive farms to increase their production potential (Van Deventer, 2001).

Government policies enacted during this time period likely influenced changes in land cover and land use. Pine reaches its highest percentage and PAR values from ca. AD 1960, which may result from the pine subsidies after AD 1964 that encouraged the conversion of cropland or pasture to woodlands. Further, in the last two decades, the European Union's Common Agricultural Policy emphasizes environmentally-sound farming practices requiring mitigation of many ecological impacts, including water runoff and water quality impairments, for direct-payment subsidies from the government (Bruckmeier and Wiking 2002).

Climatic conditions during this time period continued to be stable, warm, and mild. Erosion and sediment deposition to the pond were low during this time period; despite increased farm sizes, and continued row cropping and livestock production. Low erosion likely resulted from improved farming practices that were a consequence of modern conservation policies.

2.6.8 Impact of livestock production on the landscape

Previous land-use practices can result in persistent impacts to the landscape. Burgundy relies on an agricultural economy, making regional soil conservation important. The sediment yield record at Lucenier is directly related to basin sediment dynamics, and can be used to evaluate the impact of historical land-use practices on soil erosion. There are two periods in the Lucenier record characterized by low, stable sediment yields. From AD 1340 to 1740 and from AD 1950 to 2006 yields ranged from 2 – 20 tons $km^{-2}yr^{-1}$ (Fig. 2.4). During the first time period the land was being used predominantly for cereal production. Despite the agricultural activity, sediment yields were low. Climate during this time was highly variable (e.g., severe cold temperatures, frequent flooding) and therefore a period where increased episodic sediment delivery to the pond might be expected. The low sedimentation rates suggest that farming practices during this time period (predominantly row cropping) did not cause significant erosion from the landscape, and therefore did not increase the sediment yield to the pond relative to adjacent periods. From AD 1950 to 2006, low sediment yield most likely resulted from conservation policies and best management practices restricting animal access to waterways that mitigated erosion (e.g. Trimble and Lund, 1982).

Episodes of increased sediment yield were driven by human activities such as construction and agricultural practices. There were also two time periods with high sediment yields in the Lucenier record. From AD 1240 to 1340 and AD 1740 to 1950, sediment yields ranged from 17 to 67 tons $km^{-2}yr^{-1}$ (Fig. 2.4). During the earlier time period, the pond and chateau were newly constructed, and high yields were likely related to the construction and establishment of the estate and reservoir. The second time period follows a change in land use from estate agriculture to market production with an emphasis on livestock, and the introduction of mechanized farming (Moulin, 1991). Sediment yields were nearly 8 times higher between AD 1740 and 1950, relative to the preceding 250 years. This increase coincided with a nearly 3-fold increase in livestock production, suggesting that increased grazing pressures, and areas of open pastureland, significantly influenced soil-erosion rates in the watershed. Animal grazing impacts on sediment yields to lakes throughout Western Europe are well-documented (Dearing et al., 1987; Van der Post et al., 1997). Several studies also indicate that cattle grazing on upland slopes results in soil and sediment compaction and concomitant increases in runoff, soil erosion, and sediment delivery (Trimble and Mendel, 1995). Other studies note a 30% increase in runoff on grazed versus ungrazed pastures (Lusby, 1970), and even a 12-fold increase in surface runoff from heavy grazing (Heathewaite et al., 1990). Additionally, if animals are permitted access to waterways, they can increase erosion by physical disturbance of the banks, modification of stream and pond banks, reducing vegetative cover (Hoffman and Ries, 1991), and loosening sediment (Trimble and Mendel, 1995).

The maximum sediment yield at Lucenier (67 tons $km^{-2}yr^{-1}$) is close to the amount of sediment that was produced (85 tons $km^{-2}yr^{-1}$) at a small creek, in south central Tennessee U.S.A., as a result of cattle grazing on stream banks (Trimble, 1994). This suggests the dramatic increase in sediment yield to the pond from AD 1740 - 1950 resulted at least in part from increased livestock activity, particularly in and around waterways (Van der post, 1997).

2.7 CONCLUSIONS

Direct comparison of sediment core data from the pond at the Château de Lucenier with known local land-use histories provides a unique opportunity to examine the couplings between human activities, natural environmental changes, and long-term watershed dynamics. The sediment record at Lucenier pond suggests that people maintained crop production during the LIA despite pronounced fluctuations in climate. Lucenier pond was more heavily impacted by changes in land use (i.e. switch from major crop production to livestock production) within the catchment relative to changes in climate. Furthermore, certain agricultural practices were more detrimental to the landscape than others. For example, the pollen record demonstrates that the vegetation covering the landscape became drastically less diverse after AD 1950, as evidenced by a decrease in species diversity in the following plant ecological groups: ruderal land/weeds, pastureland, meadow and pond vegetation (Table 2.2). The decreased diversity suggests the landscape was degraded by land-use changes after World War II, consistent with many areas of Europe (e.g. Berglund et al., 1991). The decrease in species diversity resulted from chemical fertilization (Moulin, 1991) and industrialization of agriculture (larger fields, less wetlands, etc.), as well as from the abandonment of practices such as hemp processing and cultivation of water chestnut.

Additionally, high sediment yields coupled with the XRF and elemental ratio data suggest that livestock production and early agricultural mechanization resulted in higher erosion rates compared to centuries of row cropping. Despite the landscape impacts following intensification of livestock production, the area has remained productive, although with substantial chemical fertilizer input (Moulin, 1991). Even though crop and cattle production continue in the region, French and European Union water management and land conservation policies have had a positive impact on the landscape and resulted in relatively low modern sediment yields after AD 1945.

3.0 COMPARISON OF GEOCHEMICAL AND LITHOLOGIC RECORDS OF LANDSCAPE CHANGE OVER THE PAST 800 YEARS FROM TWO SHALLOW RESERVOIRS IN SAÔNE-ET-LOIRE, FRANCE.

3.1 INTRODUCTION

Valette is a millpond located in the Saône-et-Loire region of southeast Burgundy, France. The pond is at the base of a small watershed (14.4 km^2) that has been in agricultural production for thousands of years (Crumley and Green, 1987). Legacy sediment (LS) can be defined as sediment that is episodically deposited following production by anthropogenic processes (i.e. agriculture, construction, urbanization, deforestation, etc.) (Walter and Merritts, 2008; Hale, et al., 2010; James, 2013). Legacy sediment imparts structural legacy effects (Bain, et al., 2012), by persistently changing the structure of catchment hydrologic flow paths and influencing the evolution of landscape function over time. As a structural legacy, LS are trapped in stream channels and on floodplains interrupting the transfer of materials across the landscape (Pringle, 2003; Tetzlaff et al., 2007). In agriculturally based economies such as Burgundy, it is particularly important to identify practices that increase soil erosion to inform efforts to sustain soil quality, allowing continued landscape productivity.

Pond sediments can provide continuous high-resolution records of natural and human activities impacting the landscape over time (Battarbee, 2005; Oldfield, 2005: Dearing et al., 2006).

Therefore, an examination of the pond sediment records can be used to study periods of increased erosion, which can then be compared with historical records to reconstruct the impact of humans on sediment dynamics in the watershed. This long-term analysis of the sediment record allows incorporation of erosion trends not detectable in short-term studies into our understanding of catchment sediment dynamics (Dearing, 1991). For example, numerous lake studies in Europe and North America show increased erosion during modern times (Duck and McManus, 1990; Foster et al., 1990; Dearing, 2005), while other studies in Europe show more significant impacts from early agricultural practices (Dearing, 1991). Many of these studies document sediment yields increasing by a factor of ten following disturbance in the catchments (Binford et al., 1983; Foster et al., 1985; Zolitschka, 1998; Dearing, et al., 2003). However, increased erosion does not necessarily increase sediment yields at the mouth, particularly of larger catchments (Walling, 1983). This non-linearity is known as the sediment delivery problem, in which only a small proportion of sediment eroded within a catchment will be transported through the basin outlet (Trimble, 1976; Walling, 1983).

The catchment can be conceptualized based on the main environmental processes controlling sediment transfers within the catchment (Fig. 3.1). In general, sediments can be stored on hillslopes as colluvium, in stream banks, channels, floodplains, and wetlands as alluvium and in reservoirs (Dearing, 1991; James, 2013). Sediment sinks (e.g., wetlands, hillslopes and floodplains) create the potential for substantial lag times between the activity that caused erosion, and increased sediment yield (Trimble, 1983, 2009; Jain and Tandon, 2010). This lag time, which creates the sediment delivery problem, depends on the availability of sediment sources and the continuity of transport across the landscape (Benda et al., 2004; Brierly et al., 2006; Meals et al., 2009; Fryirs, 2013).

This study relies on changes in sediment geochemistry to reconstruct periods of increased sediment delivery from the catchment draining to Valette. These changes were measured using core-scanning XRF that provides rapid, non-destructive, and high-resolution profiles of sediment chemical composition. Scanning X-ray fluorescence is used carefully to avoid the wide variety of potential signal interferences. Additionally, the results from this study are used to characterize the observed changes in lithologic and geochemical proxies recorded in the pond sediments at multiple scales, and infer the influence of environmental drivers on sediment dynamics across the watershed (i.e. local versus regional). The set of nested catchments provides an opportunity to examine the movement of sediment through the landscape, and the effect of scale on the sediment dynamic processes (i.e., Valette's catchment is nine times larger Lucenier's). Ultimately, variations in total organic carbon (TOC), C/N molar ratios, XRF element/Ti ratios, and pollen data are synthesized with historical data to reconstruct the influence of human and geophysical drivers on sediment dynamics across the watershed.

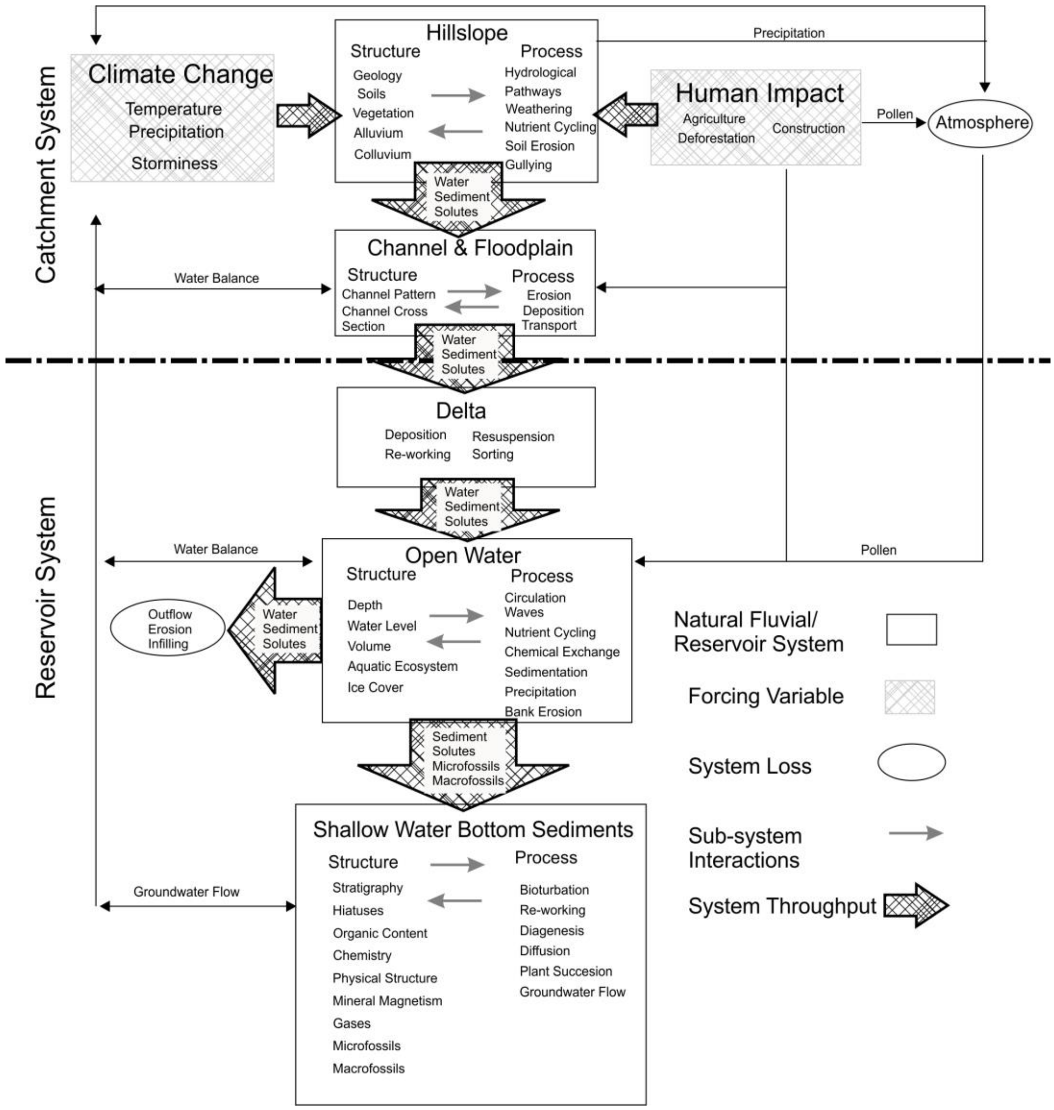


Figure 3.1. Simple conceptual model illustrating the main sources and sinks for sediment within the study catchment (modified from Dearing, 1991).

3.2 STUDY AREA

A detailed description of the study region and Lucenier pond is presented in Chapter 2. The pond at Valette is a small (0.029 km^2), shallow (<3 m), well-mixed, open basin reservoir, with one inflow and outflow stream (Fig. 3.2). The reservoir was used as a mill pond until the mid-1800's, and is currently used for recreational purposes. Valette pond experiences ice cover during the winter months and is hypereutrophic during the summer. Valette is located 3.2 km downstream of Lucenier, and thus drains a larger catchment (14.4 km^2). On the AD 1759 Cassini map there are 5 ponds mapped in the watershed above Valette, but since AD 1848 there have been only 4 ponds mapped (Fig. 3.3).

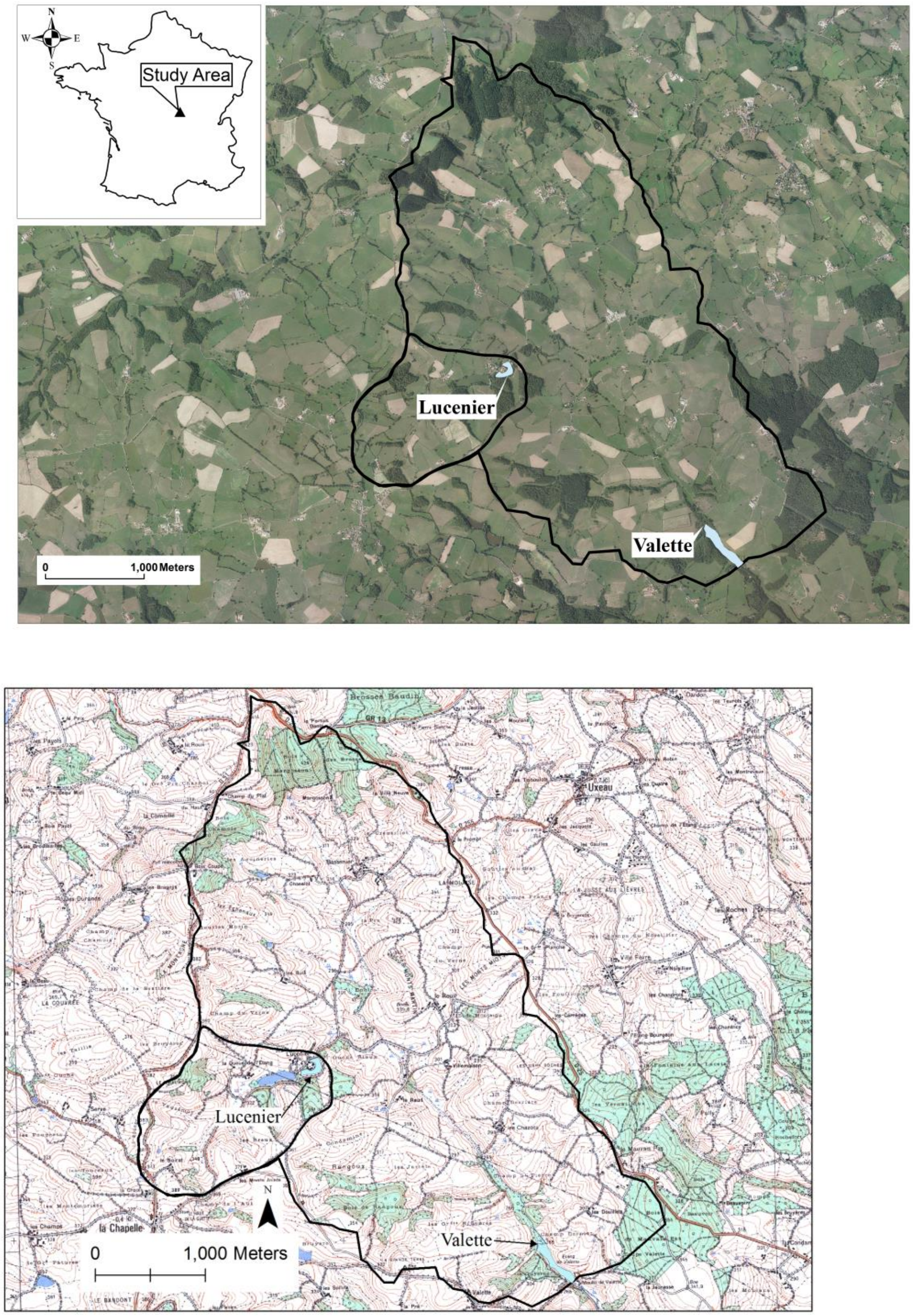


Figure 3.2. (Upper panel) Aerial photo of the region showing study location and land cover across the study area; lower panel) Topographic map of the study area. Green shaded areas are forested, and blue areas are lakes and streams. Both panels show the catchments for each pond are outlined in black, and the lakes are highlighted blue.

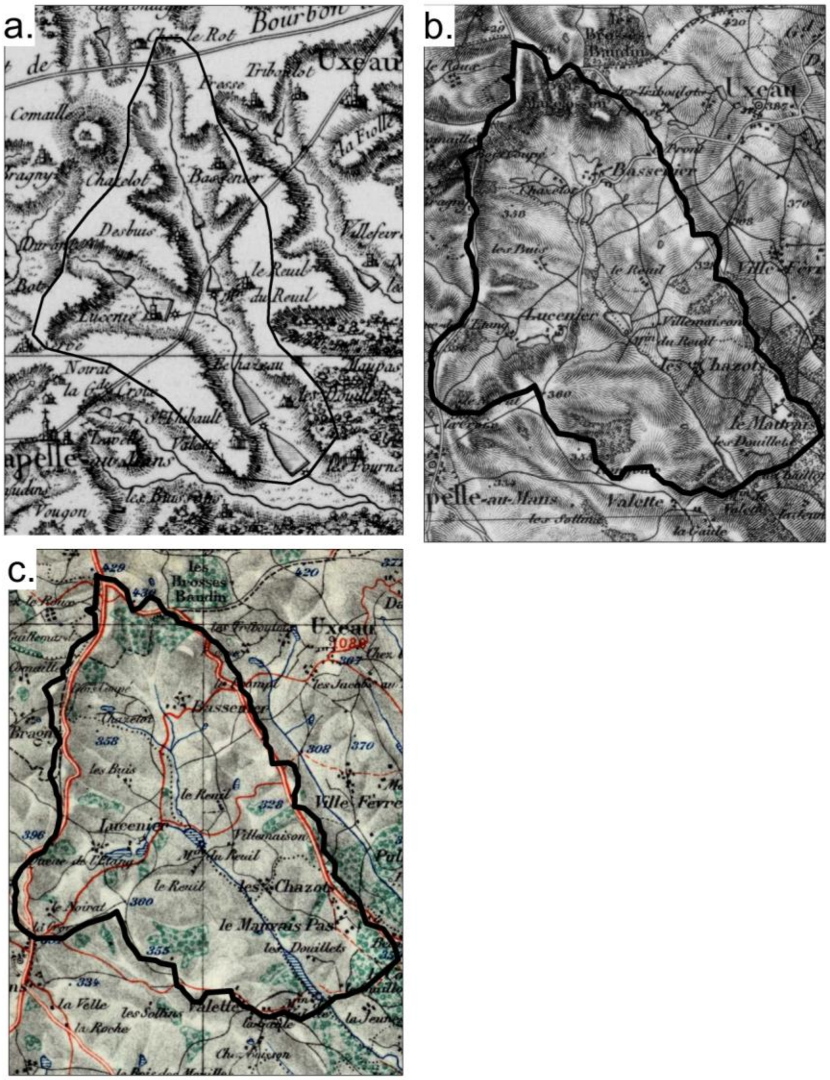


Figure 3.3. Historical maps for the Valette watershed. The watershed is outlined in black. a) 1759 Cassini map; b)1848 cadastral map; c) 1895 cadastral map.

3.3 METHODS

3.3.1 Core Collection and Sampling

In July 2006, a 3.2 m sediment core was collected from near the dam in Valette pond using a sediment-water interface corer and modified square-rod piston coring system. The upper 25 cm of the surface piston core was extruded in the field at 1.0 cm intervals until the sediment became firm enough to ensure undisturbed transport. All packaged core material was transported to the University of Pittsburgh where it was split, described, and photographed. Core sections were sampled in the laboratory at 5-cm intervals for bulk density, grain size, organic carbon, inorganic carbon, pollen, elemental carbon, and nitrogen analyses. Samples were also collected for radiocarbon, ^{137}Cs, and ^{210}Pb dating.

3.3.2 Sediment Chronology

Sediment ages were determined by radiocarbon accelerator mass spectrometry (AMS) of both macroscopic and microscopic charcoal and terrestrial organic matter (wood, seeds, and leaf material) (Table 3.1). Samples were pretreated at the University of Pittsburgh following standard acid/base/acid pretreatment protocols (Abbott and Stafford, 1996) and measured at the William M. Keck Carbon Cycle AMS Facility at the University of California, Irvine. Calibrated dates and calendar ages were calculated using the CALIB 5.0 calibration (Stuiver and Reimer, 1993; Reimer et al., 2004). Radioisotope (^{210}Pb, ^{226}Ra, ^{137}Cs) activities were also measured in surface piston core samples by direct gamma counting at the University of Florida using an EG&G Ortec® GWL high-purity germanium well detector (Appleby et al., 1983; Schelske et al., 1994). Radium-226 activity was measured at each depth to estimate supported ^{210}Pb activity.

Table 3.1. Accelerator Mass Spectrometry radiocarbon dates for samples from Valette pond, La Chapelle-au-Mans, France.

Core	Material	Field Depth (cm)	Radiocarbon age (BP)	±	Calibrated age (AD) Median	Lower	Upper
Sediment-Water Interface Core	Seed	73-74	135	25	1833	1879	1856
Square-Rod Piston Core “Drive” 1	Leaf	98-99	145	20	1727	1764	1746
Square-Rod Piston Core “Drive” 2	Seed	215-216	470	20	1429	1443	1436
Square-Rod Piston Core “Drive” 3	Leaf	239-240	530	20	1406	1425	1416
Square-Rod Piston Core “Drive” 3	Leaf	244-245	560	20	1395	1412	1404
Square-Rod Piston Core “Drive” 4	Wood	301-302	805	20	1222	1254	1238

3.3.3 XRF core scanning

Multi-element geochemical analyses of Lucenier and Valette sediment cores were completed using scanning x-ray fluorescence (XRF) on an Avaatech (now a subsidiary of Doeschot) XRF core scanner at the University of North Carolina – Chapel Hill. This scanning system measures elemental variations within split sediment cores at millimeter-scale resolution. Digital geochemical information is acquired by sequentially moving a focused X-ray beam across the surface of the sediment core. The beam window dimensions were 10 mm X 16 mm, and depending on the physical characteristics of the core sediment (i.e. grain size, surface roughness, etc.), the elemental response depth was < 500 μm into the sediment. Interaction of the X-ray beam with the sediment causes elements to fluoresce at unique wavelengths that are dependent upon their atomic number. Heavier elements emit relatively higher fluorescence energies, and also have larger response depths. For example, aluminum (27 amu) has a response depth of ~8 μm compared to iron (56 amu), which has a response depth of 180 μm (Potts, 1987). The resultant fluorescence is measured in counts per second (cps), and permits the determination of the relative concentration of select major, minor, and trace elements (aluminum to uranium) within the irradiated area.

Traditional chemical analysis of sediment cores is destructive, typically involving freeze-drying, grinding, and acid digestion of the sample prior to analysis, and normally requires significant quantities of material for accurate measurement. In contrast, core-scanning XRF provides non-destructive, high-resolution profiles of chemical composition prior to any further destructive sampling. However, as core-scanning XRF measures fluorescence from the surface of sediments, the elemental intensities can be impacted by particle size, density differences or any mineral coatings (i.e. calcite, iron, etc.) on the sample that can cause scatter or absorption of the radiation beam. Traditional techniques avoid these surface affects by completely homogenizing and digesting the sample for analysis. While there are many advantages to using the core scanning XRF technique (i.e. non-destructive, high resolution, and rapid analysis), care must be taken to account for any potential surface affects that may impact the results of the analysis.

The cores in this study were continuously scanned at 1-mm intervals with a 30 second scan time using a Rh X-ray source set to 10 kV and 500μA for the following elements: Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe. Heavier elements (Zn, Br, Rb, Sr, Y, Zr, Mo, Pb, and U) were also measured and scanned at 30 kV and 1000μA for 30 seconds. In order to assess data reliability, a duplicate measurement was collected every 10 cm. Additionally, in order to account for the effects of variation in bulk density and mineral content on the elemental concentrations, all elements were normalized with respect to Ti. Titanium was used for normalization because it is weathering resistant, not biologically utilized, and has no significant anthropogenic sources.

3.4 RESULTS

3.4.1 Valette Chronology

An age model was constructed for Valette by linear regression through successive radiocarbon dates, and Cesium-137 dates where available (Fig. 3.4 and Table 3.1). Cesium-137 activity was < 4 $dpmg^{-1}$ and displayed two distinct peaks at each core site. Valette displayed a peak at 9 cm corresponding to the 1986 Chernobyl disaster, and another peak at 48 cm resulting from the 1963 peak in fallout from above ground nuclear testing.

Sedimentation rates are low (0.5 cm yr^{-1}) at the beginning of the core record until ~ AD 1400 (Fig. 3.5). Rates increased to the highest values of the record (0.9 cm yr^{-1}) and remained high for a 30 year time period before decreasing to 0.4 cm yr^{-1}. Rates declined to the lowest values (0.2 cm yr^{-1}) from AD 1750 to 1850. Subsequently, rates increased to 0.6 cm yr^{-1} in AD 1860 and remained at this level until the end of the record.

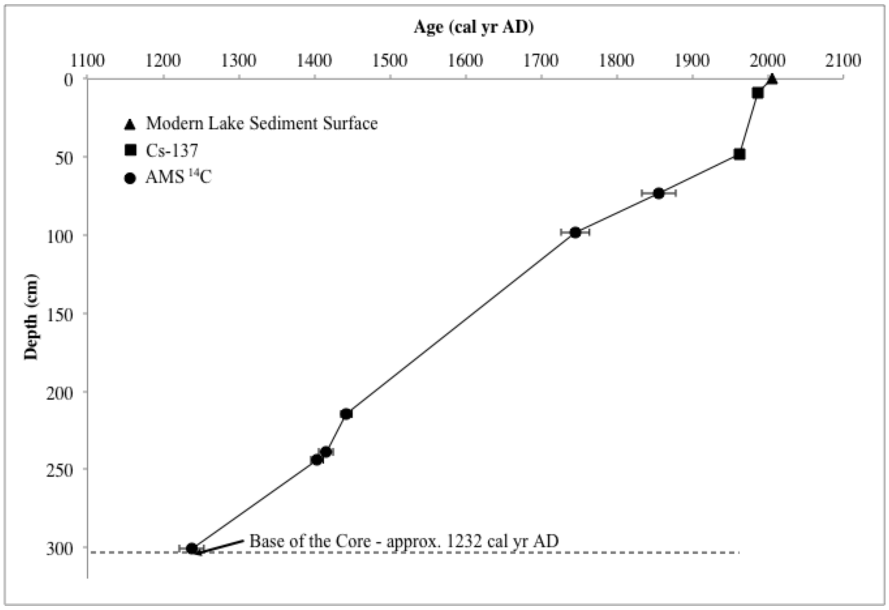


Figure 3.4. Age model for Valette Pond.

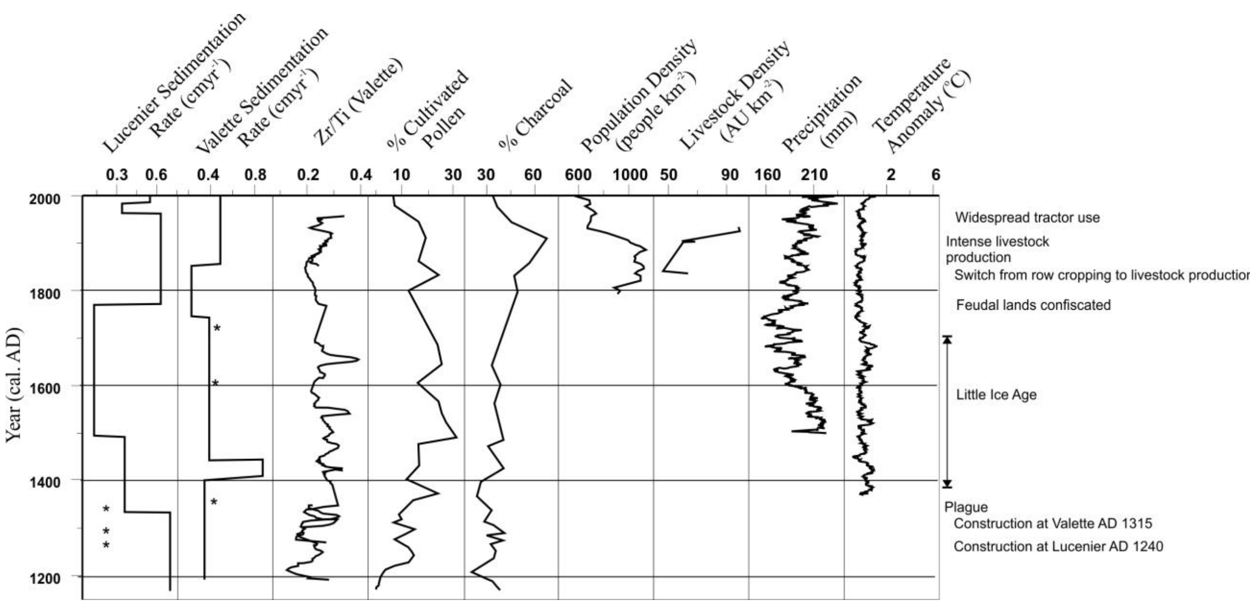


Figure 3.5. Comparative plot of select proxies for the watershed showing: Sedimentation rates for both ponds that were calculated from age models, XRF Zr/Ti ratio data plotted over periods without the gravel intervals, % cultivated pollen taxa (Lucenier Pond), % charcoal (Lucenier Pond), population density (for neighboring commune Uxeau), animal unit normalized livestock density (for neighboring commune Uxeau), precipitation for Burgundy (Pfister, unpublished data), and temperature anomalies (Chuine, et al., 2004). The text on the right side of the graph indicates major historical events that have occurred through time (Jones, et. al, 2012). Asterisks denote the location of significant gravel layers in the cores.

3.4.2 Valette Sediment Geochemistry

Total organic carbon content (Fig. 3.6) ranged from 0.7% – 5.6% and total nitrogen values vary from 0.1% - 0.6%. At the base of the Valette record from AD 1280 – AD 1355, the carbon and nitrogen content are low (average values of 1.7% C and 0.2% N). There is a minimum in values around AD 1620 (0.75% C and 0.1% N), corresponding to a gravel layer in the core. Percentages increased and peaked around AD 1690 (2.9% C and 0.32% N), and then decreased once again in a sandy and gravelly interval deposited around AD 1740 (1.0% C and 0.13% N). Values steadily increased towards the top of the core with maximums occurring (5.6% C and 0.6% N) around AD 1913.

C:N ratios (Fig. 3.6) ranged from 9 – 12 in the Valette core with an average of 10. Starting in AD 1285 values vary around 10, and then increased to 12 around AD 1425. From there they decreased to the lowest value on record of 9 in AD 1630. Subsequently, they fluctuated from 9 – 10.5 until AD 1900. There are several peaks at 11.3 from AD 1900 to AD 1935. Values declined at the top of the core to around 9.

All element/Ti ratios peak in intervals dominated by sand and gravel (around AD 1363 and AD 1738 at Valette (Fig. 3.6)). The following XRF element ratios Si/Ti, K/Ti, Rb/Ti Sr/Ti, and Zr/Ti varied minimally through most of the core, except during sand and gravel intervals. Fe/Ti is low from AD 1215 to AD 1350. Values increased rapidly from 5 to 11 around AD 1365. They remained high until AD 1415 when they declined to 6 and then fluctuated from 6 to 9 until AD 1860. From there Fe/Ti increased rapidly to the highest value of 12 around AD 1920, and then declined to around 9 at the top of the core.

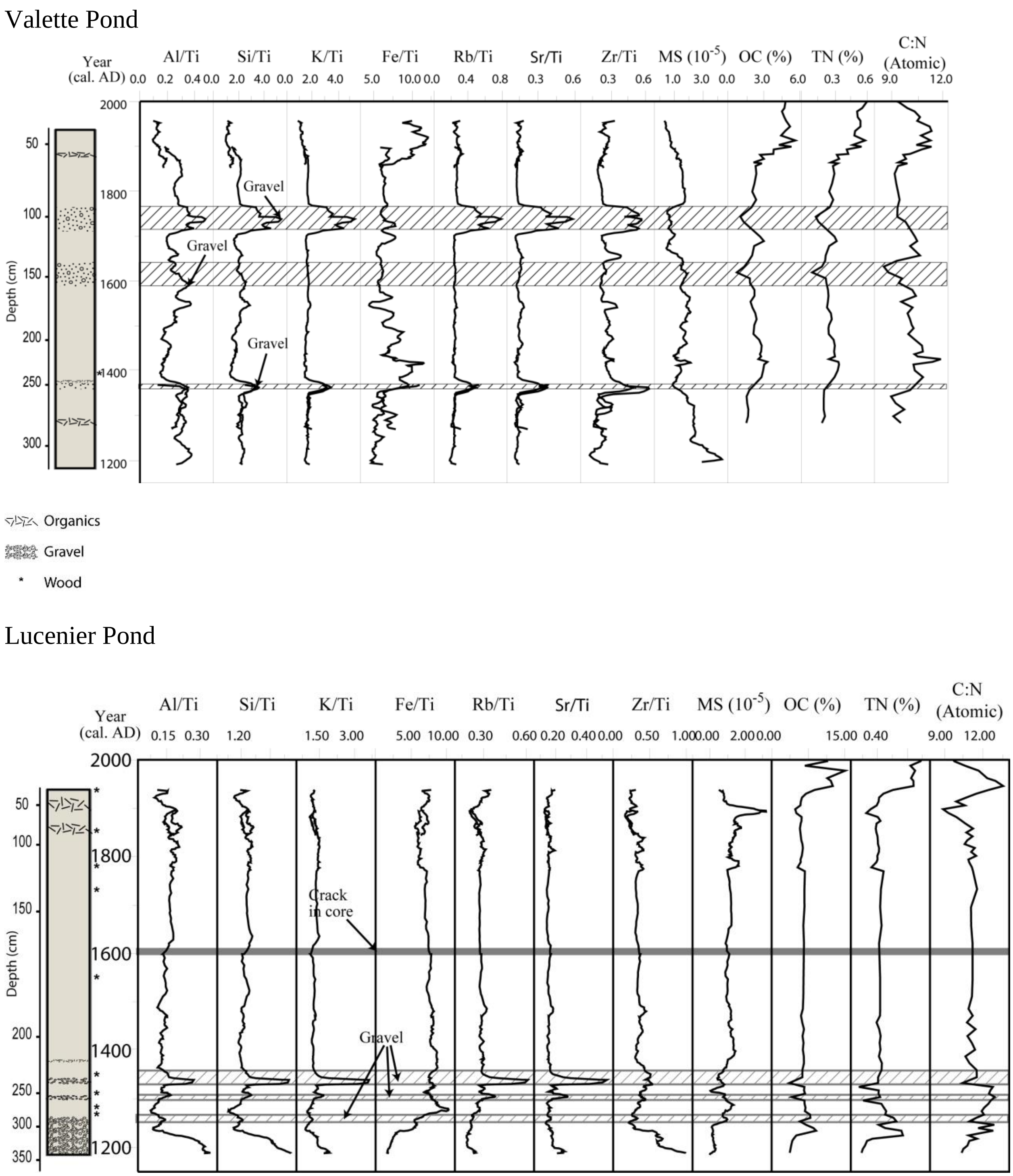


Figure 3.6. (Upper panel) Geochemical and lithologic data for Valette Pond. Lower panel) Geochemical and lithologic data for Lucenier Pond.

3.4.3 Scanning XRF Reproducibility Results for Both Ponds

Scanning XRF data reproducibility was investigated by least squares linear regression analyses of the duplicated measurements for both pond sites. The following 8 elements had r^2 values greater than 0.7 at both ponds: Al, Si, K, Ti, Fe, Rb, Sr, and Zr (Table 3.2), and thus were determined to be the most appropriate to include in analyses.

Table 3.2. Results of linear regression analysis of XRF main scan versus duplicate data.

Valette Pond	
Element	r^2
Al	0.92
Si	0.91
K	0.90
Ti	0.97
Fe	0.99
Rb	0.80
Sr	0.76
Zr	0.96

Lucenier Pond	
Element	r^2
Al	0.73
Si	0.84
K	0.89
Ti	0.93
Fe	0.99
Rb	0.83
Sr	0.87
Zr	0.97

In addition to the reproducibility analysis, 25 core sediment samples (including both fine and coarse grained intervals) from Lucenier pond were sent to SGS Minerals Services for inductively coupled plasma atomic emission spectrometry (ICP-AES) analysis. A multi-acid (hydrofluoric, hydrochloric, nitric, and perchloric) solution digested the sediment for ICP-AES analysis. The elemental concentrations from ICP-AES were compared with scanning XRF count data by linear regression. The resulting r^2 values for most of the elements of interest in this study were greater than 0.6 (Fig. 3.7). This suggests that the scanning XRF count data is a decent representation of the concentration of relevant elements (except K) within the core material. Potassium had relatively poor r^2 values (0.3). The outliers from the regression line on the plot of ICP-AES K concentration vs. XRF K count data (Fig. 3.7) are all associated with gravel intervals. This suggests that the poor correlation for K is due to a combination of increased radiation scatter on rougher sediment surfaces, and shallow response depth that likely resulted in poor count values. Therefore, potassium XRF data for coarse increments should be examined with particular caution.

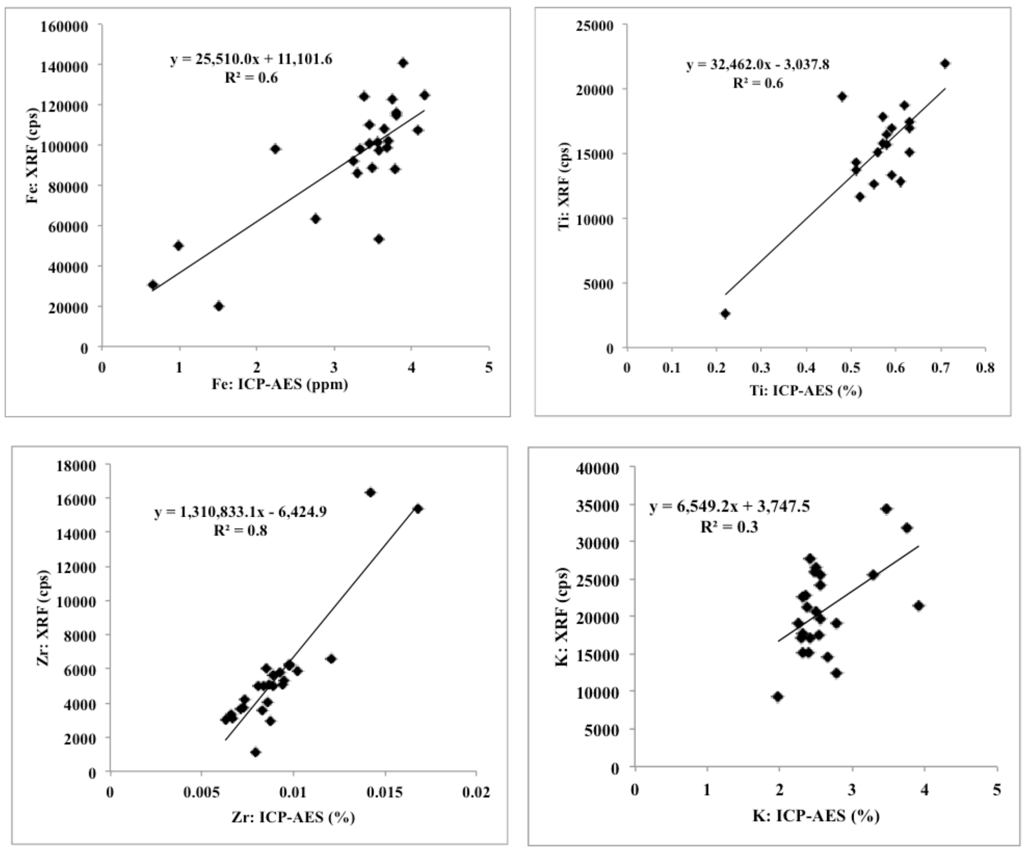


Figure 3.7. Scatterplots of XRF count data versus ICP-AES data at Lucenier pond.

3.4.4 Valette Sediment Lithology Results

The core is characterized by massive clayey mud that is most organic rich within the top 75 cm (~AD 1850), and has distinct intervals of sand and gravel (Fig. 3.6). The organic content at the top of the core is less than 6%, and is therefore not excessively organic rich and should not impact the scanning XRF results. There are three major sand and gravel layers that occurred at Valette: around AD 1360, AD 1590 – 1640, and AD 1715 – AD 1765.

Magnetic susceptibility (Fig.3.6) varies from 0.1 to 4.5 X 10^{-5} SI with a mean of 1.5 X 10^{-5} SI. Values reached their highest point early in the record around AD 1205, and then declined to 1.0 X 10^{-5} SI around AD 1365. From there values fluctuated between 2.0 X 10^{-5} SI to 0.4 X 10^{-5} SI to the top of the core. In general, values less than 1.0 X 10^{-5} SI correspond with sand and gravel layers.

3.4.5 Correlation Analysis and Mixing Model Results for Both Ponds

In order to examine the association between pairs of element/Ti ratios at both ponds, a Pearson correlation of XRF intensities was calculated for each climatic regime with the gravel intervals omitted. The gravel intervals were removed to minimize the grain size effects on the scanning XRF data (see Section 3.6.1.1). The associations among elements for the various climatic periods are summarized in Tables 3.3 and 3.4.

Table 3.3. Pearson correlation tables of XRF element/Ti ratio data at Valette Pond.

Medieval Warm Period (n=86)

	Al/Ti	Si/Ti	K/Ti	Fe/Ti	Rb/Ti	Sr/Ti	Zr/Ti
Al/Ti	1.000						
Si/Ti	0.835	1.000					
K/Ti	0.123	0.595	1.000				
Fe/Ti	-0.859	-0.773	-0.138	1.000			
Rb/Ti	-0.371	0.053	0.784	0.295	1.000		
Sr/Ti	-0.170	0.298	0.792	0.049	0.827	1.000	
Zr/Ti	-0.445	0.000	0.580	0.247	0.663	0.732	1.000

Little Ice Age (n=123)

	Al/Ti	Si/Ti	K/Ti	Fe/Ti	Rb/Ti	Sr/Ti	Zr/Ti
Al/Ti	1.000						
Si/Ti	0.968	1.000					
K/Ti	0.894	0.937	1.000				
Fe/Ti	-0.722	-0.734	-0.670	1.000			
Rb/Ti	0.474	0.478	0.630	-0.317	1.000		
Sr/Ti	0.528	0.623	0.644	-0.517	0.672	1.000	
Zr/Ti	-0.038	0.074	0.115	-0.109	0.063	0.420	1.000

Modern Period (n=86)

	Al/Ti	Si/Ti	K/Ti	Fe/Ti	Rb/Ti	Sr/Ti	Zr/Ti
Al/Ti	1.000						
Si/Ti	0.993	1.000					
K/Ti	0.932	0.935	1.000				
Fe/Ti	-0.948	-0.955	-0.877	1.000			
Rb/Ti	0.006	0.037	0.178	-0.048	1.000		
Sr/Ti	-0.344	-0.300	-0.347	0.313	0.611	1.000	
Zr/Ti	-0.722	-0.680	-0.648	0.691	0.301	0.649	1.000

Table 3.4. Pearson correlation tables of XRF element/Ti ratio data for Lucenier pond.

Medieval Warm Period (n=84)

	Al/Ti	Si/Ti	K/Ti	Fe/Ti	Rb/Ti	Sr/Ti	Zr/Ti
Al/Ti	1.000						
Si/Ti	0.940	1.000					
K/Ti	0.841	0.910	1.000				
Fe/Ti	-0.259	-0.153	0.142	1.000			
Rb/Ti	0.573	0.643	0.853	0.474	1.000		
Sr/Ti	0.657	0.699	0.835	0.033	0.826	1.000	
Zr/Ti	0.470	0.653	0.724	0.343	0.690	0.568	1.000

Little Ice Age (n=62)

	Al/Ti	Si/Ti	K/Ti	Fe/Ti	Rb/Ti	Sr/Ti	Zr/Ti
Al/Ti	1.000						
Si/Ti	0.822	1.000					
K/Ti	0.760	0.698	1.000				
Fe/Ti	-0.648	-0.724	-0.535	1.000			
Rb/Ti	-0.587	-0.408	-0.179	0.469	1.000		
Sr/Ti	-0.520	-0.296	-0.274	0.445	0.886	1.000	
Zr/Ti	-0.476	-0.412	-0.249	0.564	0.708	0.809	1.000

Modern Period (n=145)

	Al/Ti	Si/Ti	K/Ti	Fe/Ti	Rb/Ti	Sr/Ti	Zr/Ti
Al/Ti	**1.000**						
Si/Ti	**0.969**	**1.000**					
K/Ti	**0.704**	**0.810**	**1.000**				
Fe/Ti	**-0.859**	**-0.848**	**-0.721**	**1.000**			
Rb/Ti	**-0.390**	**-0.235**	**0.215**	**0.253**	**1.000**		
Sr/Ti	**-0.267**	**-0.113**	**0.272**	**0.181**	**0.817**	**1.000**	
Zr/Ti	**0.225**	**0.372**	**0.771**	**-0.229**	**0.461**	**0.631**	**1.000**

3.5 DISCUSSION

For a detailed discussion of the Lucenier pond chronology, geochemistry, and lithology see Chapter 2. This discussion will focus on the response of Valette pond to human and climate inputs, as well as compare the similarities and differences between the sediment records at both ponds over the past 800 years within the context of major European climactic regimes. Increased erosion in the watershed should be recorded as increased sedimentation rates and increased XRF Zr/Ti. If the increased erosion is due to climatic input, then both ponds should be impacted and generally show relatively synchronous changes in sediment chemistry and lithology. If the erosion is due to land use change, depending on the location and magnitude of the event (i.e., the potential sediment storage between the event and the pond), records may diverge between ponds. Additionally, sediment can be stored before reaching the lower pond, and therefore it may not be incorporated in the sediment record at Valette. For example, pastureland that is converted to row cropping would be tilled before planting. However, hedgerows separate many of the fields in the study area, and can be zones of sediment deposition. Therefore, sediment produced from fields that are plowed for agricultural production may first be trapped at the edge of the field in hedgerows before eventually being transferred into a stream channel or pond. A delay in the transfer of sediment from the fields to the stream channel would create a lag time in the sediment record between the actual change in land use, and the variation in pond sediment lithology/geochemistry that signals erosion resulting from land use change (i.e. increased sedimentation rates and/or increased Zr/Ti values).

In summary, if both ponds exhibit similar changes in lithology and geochemistry synchronously, this might suggest that climate is the driving mechanism for sediment dynamics in the basin, as climate should influence both sites concurrently. However, if the timing of variations in lithology and chemistry are different between sites, this might suggest that people are the main driver of changes in the sediment record.

3.5.1 Issues with scanning XRF

There are several sediment characteristics that are particularly problematic when using scanning XRF techniques, as mass attenuation and particle size are the major contributors to bias and errors in data interpretation (Norrish and Hutton, 1969; Weltje and Tjallingii, 2008). Excessive organic matter and silica can interfere with x-ray absorption because the fluorescence from atoms deeper in the sample must pass through overlying sediment that absorbs energy during the signals return to the detector. This results in an apparent but false reduction of concentration (Löwermark et al., 2011). Grain size impacts the ability of the instrument to detect lighter elements (i.e. the coarser the sediment the more difficult it is to detect light elements due to scattering of the instrument radiation beam). High calcium concentrations dominate the signal by absorbing most of the x-ray beam when scanning for light elements in calcareous sediments (Boyle, 2000). The cores being analyzed for this study do not have excessive organic matter, iron, or silica, and are calcareous poor. A majority of the sediment for this study is fine grained (silt and clay) and therefore not impacted by grain size affects. Therefore other than a few distinct intervals containing coarse sediment that have been carefully interpreted, XRF analyses of these cores are assumed to reasonably reflect core sediment geochemistry.

3.5.2 Valette Pond Mixing Model

A mixing model based on XRF Al/Ti and Zr/Ti ratios of Valette pond sediments was developed. The mixing model shows a triangular relationship suggesting three distinct sources of sediment to the pond (i.e., the pond sediment is a mixture of three end members, Fig. 3.8). Zirconium/Ti is a geochemically stable elemental ratio that has been used in previous studies to infer erosion in catchments (Koinig, et al., 2003; Croudace, et al., 2006). Zirconium is considered stable, due to low solubility (Brookins, 1988; White, 1995) and its host mineral zircon, is typically stable in a soil environment (Milnes and Fitzpatrick, 1989). Here it is assumed that the source of Al/Ti and Zr/Ti to the pond is from either granitic bedrock or a continuum of sedimentary material that results from weathering of granitic bedrock. These sources are assumed to be 1) deep soils (e.g., B horizons); 2) Shallow soils (e.g., A horizons), and 3) rocky material (e.g., bedrock or coarse sediments stored in the catchment sediment sinks) (Fig. 3.8). The end members in this analysis were determined by dividing the mixing model space based upon the mean values for Al/Ti (mean = 0.24) and Zr/Ti (mean = 0.25) (Fig. 3.8). Values with high Al/Ti (> 0.24) and low Zr/Ti (< 0.25) are considered representative of a deep soil (e.g., a B horizon) where Al is able to accumulate. Aluminum enrichment of deeper soils occurs over time as a result of physical and chemical weathering of the topsoil and translocation of mobile ions and clays into the subsoil over time. Values with low Al/Ti (<0.24) and low Zr/Ti (<0.25) are interpreted as shallow soils (Fig. 3.8), zones where both Al and Zr have been depleted. The last end member consists of high values of Al/Ti (>0.24) and high values of Zr/Ti (>0.25), which likely represents a relatively rocky source (e.g., bedrock), particularly coarse sediments where Zr is enriched by density sorting (e.g., mobilized point bar sediments).

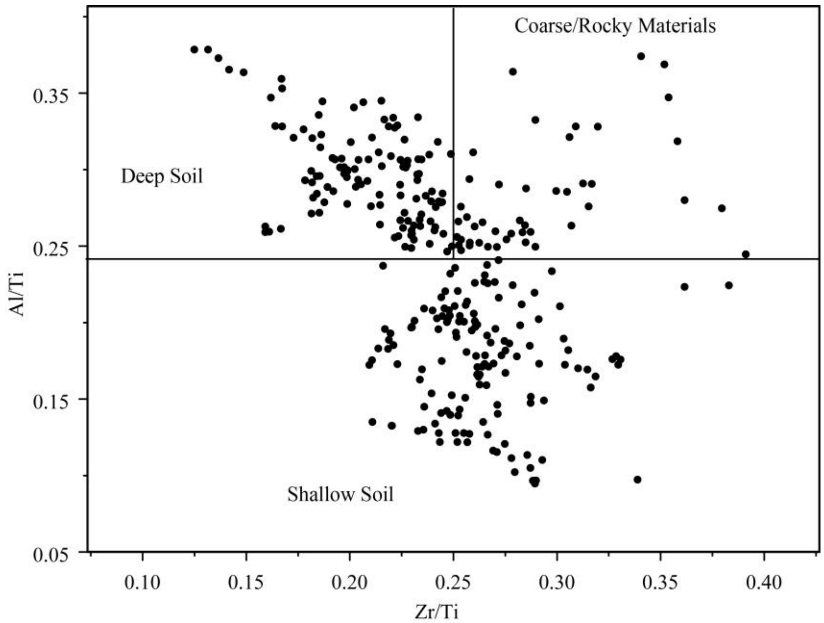


Figure 3.8. Mixing model plot of XRF Al/Ti versus Zr/Ti to explore the potential contribution of well weathered versus less weathered sediment sources to the pond sediment.

XRF concentration measurements are sensitive to changes in grain size (Das and Haake, 2003; Koinig et al., 2003; Tabaoda, et al., 2006). In particular an XRF analysis by Kylander, et al., (2011) determined that Zr is associated with coarser silt and sand size particles. There is no grain size data available for Valette pond, however data from the Lucenier pond allows linear regressions of sediment grain size and XRF ratio values. Resulting r^2 values were 0.2 or less for all XRF element ratios except for Zr/Ti, which was positively associated with percent sand (r^2 =0.5) and negatively with percent silt and percent clay (r^2 values of 0.4 for both). These data are consistent with assigning the high Zr/Ti, high Al/Ti sediments to coarse, rocky sources. The mixing model is used to characterize the main sources of sediment to the pond during the three climatic regimes.

3.5.3 Medieval Warm Period (MWP) AD 1190 – AD 1400

The sediment record suggests that the buildings at Valette were constructed around AD 1300, which corresponds well with historical records. Sediment dynamics at Valette during this time are dominated by the input of deep soil from the catchment. Increased values of XRF Al/Ti and decreased values of Zr/Ti indicate the sediment reaching the pond came from a deep soil source (Fig. 3.9). Additionally, both Al/Ti and Si/Ti and Rb/Ti and Sr/Ti are positively associated ($r > 0.8$; $p<0.01$) during this period, and may result from the clay minerals inputs during this period. Climate during this time period was favorable for agriculture, and cultivated pollen data from Lucenier pond was high relative to adjacent time periods (Fig. 3.10). Together, these data suggest that the sediment inputs to Valette during this period were arising from increased agriculture disturbance of soils during this period, particularly row cropping.

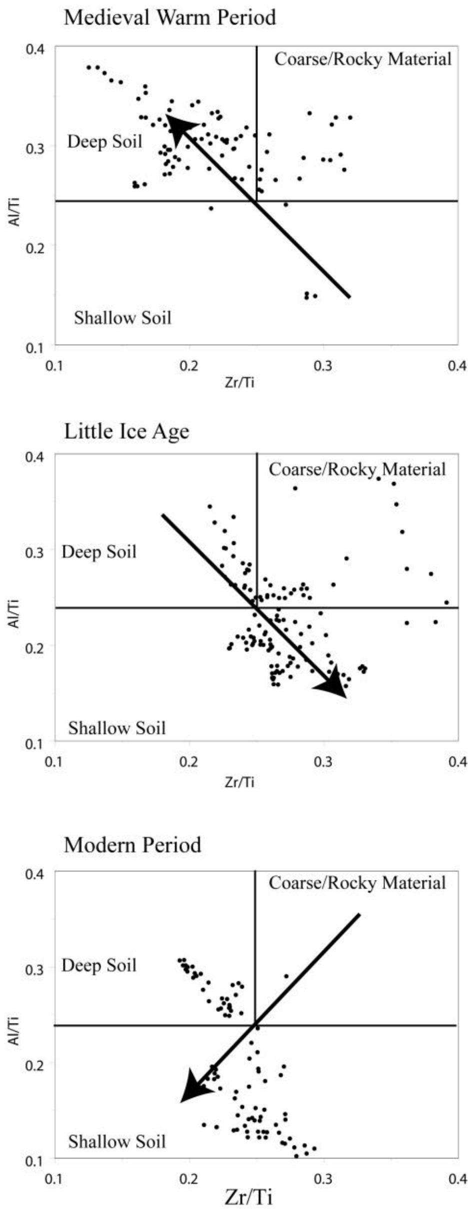


Figure 3.9. Mixing model plot of XRF Al/Ti and Zr/Ti (without the gravel intervals) to highlight the major shifts in sediment source material during each climatic episode. The arrows indicate the major shifts in source material during each time period. For example, during the Medieval Warm Period, the main sediment source to the pond was well weathered/deep soil (B horizon) material; there was relatively little moderately weathered/shallow soil (A horizon) material, and some relatively less weathered/rocky material being input to the pond. During the Little Ice Age the main source of sediment shifted to shallow soil, while input of deep soil material decreased, and coarse/rocky material input remained relatively unchanged.

During this period there were two time periods (AD 1300 – 1340 and AD 1345 – 1380) with enriched Zr/Ti ratios (> 0.25) in the pond sediment (Fig. 3.9). The first time period is coincident with building and dam construction at Valette, with both activities potentially introducing sands and gravels directly to the pond. Local histories estimate that the reservoir and buildings were completed in ~AD 1315 (Lucien D'Auvergne, 2006, per comm.). This also demonstrates that the pond has existed prior to this construction, as the bottom of the core dates to AD 1190 and appears to be a continuous accumulation of pond mud. This is further supported by C/N values that range from 9 – 11(Fig. 3.6), suggesting that the carbon inputs in these pre-mill sediments were dominated by a mix of terrestrial and algal sources (Kendall, 2001).

At the very end of the Medieval Warm Period (~AD 1370) there is a shift in sediment source to the pond, indicated by increasing Zr/Ti and decreasing Al/Ti (Fig. 3.9), near one of the gravel deposits identified in the core (Fig. 3.6). Simultaneously, C:N ratio values increased during this period, suggesting an influx of shallow soil material to the pond (Kendall, 2001). It is possible that climatic events (i.e. increased precipitation intensity) increased sediment delivery during this period. The XRF Zr/Ti values also increased at Lucenier pond during this period, suggesting climatic events increased sediment input during the late MWP and potentially mobilized coarse silts and sands from channel storage.

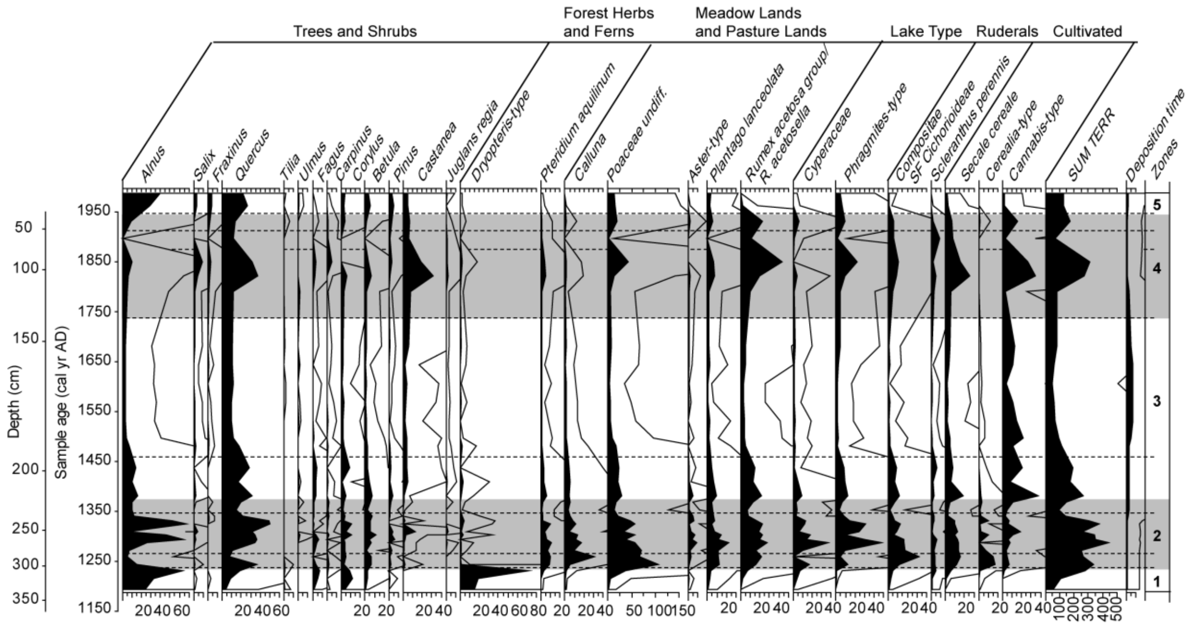


Figure 3.10. Pollen accumulation rates from Lucenier pond.

3.5.4 Little Ice Age: AD 1400 – AD 1700

The shift in the relative importance of sediment sources to the pond continues at the beginning of the LIA. The LIA was a period of decreased agricultural activity and increased deforestation. Increases in % OC, % TN, C/N, and Fe/Ti values in the sediment, combined with a dramatic increase in sedimentation rate and mixing model results suggest increased inputs of shallow soil material to the pond. During this period, the pollen data at Lucenier shows a decreased percent-cultivated pollen taxa, a decrease in the pollen accumulation rate of tree taxa, and increased percent charcoal. Together this suggests changes in in forest clearance and burning mobilized predominantly shallow soils to the pond. The relatively low sediment yields during this period are consistent with limited erosion and a predominance of shallow soil sources.

After ~AD 1550, erosion in the watershed shifted back to a coarse, rocky source, coincident with renewed agricultural activity in the catchment. Pollen data from Lucenier indicate increased percentages of cultivated pollen (*Poaceae, Secale, Rumex, Cannabis, and Cerealia* – type pollen) during this period (Fig. 3.10). While the LIA is often associated with extreme climatic events in this region, these sediment yield data predominantly reflect the influence of agricultural activities.

In addition to the influence of agricultural activities on sediment source to Valette, climate may have influenced in-pond geochemistry during the LIA. Distinct increases in XRF Fe/Ti at the beginning of the LIA may result from prolonged ice cover creating anoxic conditions in the pond. There are several peaks in Fe/Ti: AD 1415, AD 1471 – AD 1487, AD 1526, and AD 1562 potentially resulting from increased Fe precipitation onto sediment during this time period (Fig. 3.5). Iron is negatively correlated with all other elements during the LIA (Table. 3.4) suggesting that Fe/Ti variability is not related to detrital inputs. Moreover, the percent OC at Valette was steady and not associated with Fe/Ti variability during early portions of the LIA suggesting that biological activity and organic matter decomposition are not driving the Fe concentrations.

Since XRF Fe/Ti is negatively correlated with detrital elements, and percent OC values do not fluctuate and are relatively low during this time period, the most likely explanation for changes in Fe/Ti concentrations during the LIA is increased ice cover that contributed to anoxic bottom water conditions. Anoxia could result in changing redox conditions that would increase the mobility of Fe and cause the observed fluctuations in the XRF Fe/Ti values. Moreover, similar variability in Fe/Ti occurred at Lucenier during this time period suggesting a catchment wide mechanism driving redox conditions at both ponds.

3.5.5 Modern Climate: AD 1700 – AD 2006

At the beginning of this time period (AD 1700) the sediment mix in Valette is dominated by shallow soil sources. A significant gravel deposit (~AD 1740) and peaks in Zr/Ti values between ~AD 1705 – 1765 suggest a major erosional event during this period mobilizing stored sediments. This event corresponds to an anomalous period of low precipitation and low temperatures, and poor pollen preservation (Fig. 3.5). Otherwise, sedimentation rates (Fig. 3.5) remain low and consistent throughout the period (0.4 $cmyr^{-1}$ at the beginning and (0.5 $cmyr^{-1}$) at the end), and is predominantly shallow soils throughout. Declining percent of cultivated pollen taxa recorded in Lucenier and population density recorded in human demographies are consistent with the stable sediment dynamics at the end of this time period.

Despite an intensification of livestock production (starting in AD 1900), and an increase in widespread tractor use (~AD 1950) these activities did not increase sedimentation rates or change the mix of sediment sources. The insensitivity of the sediment record to these significant changes in agricultural activities could indicate that all of the easily erodible material has been removed and the catchment has shifted to supply limitation in sediment yield. However, the European Union's Common Agricultural Policy (introduced in AD 1962) emphasized environmentally sound farming practices requiring mitigation of many ecological impacts, including water runoff and water quality impairments (Bruckmeier and Wiking 2002). Improved farming practices likely decreased erosion in the watershed simultaneously with intensification in agricultural activities.

During the Modern time period, increased fertilizer use and resulting nutrient inputs increased pond productivity and organic matter concentrations. This results in a moderate positive correlation (r^2 = 0.7; $p<0.01$) of the redox sensitive Fe/Ti with percent OC. In addition, C:N values declined to 9 near the end of the record during a period of increased percent OC and percent TN(Fig. 3.6). This suggests that the pond carbon sources are dominated by algae and in turn the increased productivity causes eutrophication.

The distinct increase in Fe/Ti that occurs during this time period may result from FeS precipitation (note: sulfidic odors were detected during core extrusion in the field). Anoxic conditions would result in a low redox potential causing FeS to precipitate as a layer on the sediment surface or as coatings on the sediment (Parker and Rae, 1998; Koinig, 2003). This process would impact the sediment Fe concentration, and indicate changes in redox status. Therefore the changes in XRF Fe/Ti ratio data seem to reflect changes in redox condition of the pond, changes likely associated with eutrophication.

3.5.6 Comparison of Valette and Lucenier Core Sediment Records

Sediment delivery processes that operate at varying spatial scales influence sedimentation in each pond. Valette pond core sediment geochemistry was more variable than Lucenier. Specifically, Valette elemental %OC, %TN, and C/N as well as scanning XRF ratio data Al/Ti, Si/Ti, Fe/Ti, and Zr/Ti is more variable than values recorded at Lucenier.

This contrast in variability might suggest that Valette records a wider variety of landscape disturbances than Lucenier. However, the increased fluctuations observed in the XRF data at Valette could also indicate that the additional opportunities to store sediment in the larger Valette catchment create opportunities for more geochemical differentiation during sorting and storage. For example, the XRF ratio data at Lucenier shows very little fluctuation in sediment geochemistry throughout most of its record, with major changes in XRF element/Ti ratio data associated with local events such as construction. Given the relatively fewer opportunities for sediment storage, resulted in less zircon enrichment.

Multiple gravel layers at Lucenier Pond during the MWP could be related to the location and construction of the Chateau with respect to the pond, as compared to Valette. Sediment and pollen data at Lucenier pond support construction disturbances occurring in AD 1300 as evidenced by decreased alder pollen, increased grain size data, and increased concentrations of XRF ratio data (Figs. 3.6 and 3.10). In contrast, the sediment record at Valette does not record coarse sediment deposition (gravels) during construction of the local mill. Instead construction at Valette corresponds with increased XRF Zr/Ti values. Since Lucenier pond was originally constructed as a moat, the Chateau and farm buildings are built out into the middle of the pond (Fig. 3.11), making construction activities more likely to contribute sediment directly to the middle of the pond. The mill and other buildings at Valette are built on the backside of the dam (Fig. 3.11). As a result, it is more likely that coarse sediment produced during construction was deposited in the outflow or on the floodplain below the dam, rather than directly into the reservoir. The difference in construction location of buildings at the ponds could explain the lack of gravel observed at Valette.

Figure 3.11. Aerial photographs of Lucenier (left panel) and Valette (right panel) showing building placements with respect to the ponds and dams.

3.6 SUMMARY AND CONCLUSIONS

Geochemical and lithologic data from Valette pond was used to reconstruct periods of increased erosion in the watershed over the past ~800 years. Low relative concentrations of XRF ratio data such as: Si/Ti, K/Ti, Rb/Ti, Sr/Ti, and Zr/Ti, indicate that the Valette record, experienced very little detrital input during the LIA as compared to the MWP and the Modern Climatic Regime. This suggests that the watershed was fairly stable during that time period. There were two significant erosional events that were indicated by sand and gravel layers in the core and increased concentrations of all XRF ratio data. The gravels are likely related to climate or mill activity that would have disturbed coarse sediment along the stream banks or shorelines of the pond.

Comparison of variations in XRF Zr/Ti data, and sedimentation rates indicated periods of disturbance to and relative stability of the landscape, and time periods when both ponds were responding to similar environmental factors over the past ~800 years. Instability was related to erosion caused mostly by human controlled environmental factors such as: agricultural practices (i.e. row cropping and livestock production), construction, mill operations, and dam maintenance. The large gravel deposits found in both ponds were likely related to construction activity at Lucenier, and fluctuating pond water levels at Valette.

Scale appears to influence sedimentation rates seen at both ponds. Since Valette has a larger contributing area, the amount of sediment that reaches the pond was significantly lower during some time periods at Valette, as compared to Lucenier. This is likely related to trapping of sediment as it is being transported down through the watershed (Walling, 1983; Vente, et al., 2007).

Additionally, the impact of increased livestock production and mechanization of agriculture that occurred around AD 1870 resulted in a weaker signal in the XRF ratio data at Valette. For example, most of the XRF ratio detrital elements (Zr/Ti, K/Ti, Si/Ti, Al/Ti) at Lucenier increased during this time period (Figs.3 and 7). However the XRF ratio data at Valette only slightly increased for Rb/Ti, Sr/Ti and Zr/Ti (Fig. 3.6). This suggests that mechanization and livestock production was clearly recorded at Lucenier and may have impacted this system more than Valette, where it was barely documented in the sediment record.

Results from this study indicate that fluctuations in concentrations of XRF Zr/Ti in reservoir sediment seem to be more sensitive to human (i.e. construction and agricultural practices) versus climate (i.e. precipitation and temperature) impacts on the watershed. In general, the variability and magnitude of change in the Zr/Ti signal was higher at Valette as compared to Lucenier. This is likely related to periodic remobilization of legacy sediment stored in stream channels and valley bottoms, and the larger catchment area supplying sediment to Valette.

The fluctuations in Zr/Ti seemed to be controlled by processes/erosional events that occurred locally at each pond. For example, the Zr/Ti data recorded the initial construction of buildings at each pond site. Another example, is increased livestock production in AD 1870 was recorded as greater Zr/Ti concentrations in Lucenier, but not in Valette. In contrast to the Zr/Ti record, sedimentation rates seemed to give a broader or more regional picture of sediment availability and landscape stability in the watershed.

4.0 AN 800-YEAR SEDIMENTARY RECORD OF EUTROPHICATION FROM SHALLOW RESERVOIRS IN SOUTHERN BURGUNDY (SÂONE-ET-LOIRE), FRANCE.

4.1 INTRODUCTION

This chapter focuses on the eutrophication history of two small ponds located in the Saône-et-Loire region of Burgundy, France (Fig. 4.1). These ponds have existed for nearly 800 years, and are economically and recreationally important to the community (Jones, per. comm.). Human activities (i.e. agricultural practices, construction, etc.) can negatively impact the water quality of pond systems leading to impairment and loss of function. Therefore, understanding the pond geochemical history and human activities driving water quality impairment can enhance pond management, and provide a framework for predicting future ecosystem response to environmental change (i.e. land use and climate) (Bragée et al., 2013).

Lithological and geochemical data preserved in pond sediment can provide a record of environmental change in the catchment, and associated impacts on the pond system (Last and Smol, 2001; Dearing, et al., 2006). More specifically, pond productivity can be investigated by analyzing the changes in elemental carbon (C), nitrogen (N), phosphorous (P), and stable isotopes of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) (Hodell and Schelske, 1998; Teranes and Bernasconi, 2000; Woodward et al., 2012; Braig et al., 2013). Human activities such as agriculture and deforestation often result in excess sediment and nutrients that are exported from the landscape into waterways. This frequently results in enhanced pond productivity and eutrophication that can be recorded by changes in the concentrations of elemental C, N, P and stable isotopes ($\delta^{13}C$, and $\delta^{15}N$) within the pond sediments. The molar ratio of total organic carbon to total nitrogen (C/N) can indicate the sources of organic matter to the sediment. A majority of organic matter in lake sediments is sourced from plant-derived material (Meyers et al., 1999). Furthermore, non-vascular (algae and macrophytes) and vascular (trees, shrubs, grasses, etc.) plants are the main contributors of organic matter to the pond system, and differ in their biochemical compositions. As a result they have a distinct C/N ratio that can be recorded in the sediment record. Analyzing the changes in the C/N ratios within the pond sediment can provide valuable information about the sources of organic matter and changing trophic status of the pond over time.

C/N ratio analyses often result in overlapping values for lake sediments, and so it is common to analyze the stable $\delta^{13}C$ and $\delta^{15}N$ isotopes to aid in source identification and interpretation of changes in productivity in lake systems (Hodell and Schelske, 1998; Mayer et al., 2005; Meyers, 2006; Braig, et al., 2013). The values of $\delta^{13}C$ and $\delta^{15}N$ in sediment organic matter are influenced by the source of organic material, and carbon and nitrogen cycling within the catchment and lake systems (Woodward, et al., 2012). For example, during photosynthesis algae preferentially assimilate the lighter isotope (^{12}C) leaving the dissolved inorganic carbon pool (DIC) enriched in ^{13}C (Farquhar et al., 1989). If productivity continues to increase, the DIC becomes more enriched in ^{13}C, and the phytoplankton discriminate less and assimilate more of the heavier isotope (Teranes and Bernasconi, 2005). Therefore, shifts in $\delta^{13}C$ values are related to changes in primary productivity of algae within the pond, which is then recorded in the organic matter preserved in the pond sediment (Meyers 1994; Schelske and Hodell 1995; Hodell and Schelske 1998; Teranes and Bernasconi, 2005). Similar to $\delta^{13}C$, variations in $\delta^{15}N$ values occur as a result of changes in $\delta^{15}N$ of DIN sources to organic matter, and biological processes (i.e. assimilation, mineralization, denitrification, etc.) that impact the nitrogen isotope values through discrimination against the heavier isotope, which results in relative isotopic enrichment in phytoplankton that consume the nitrogen in the water column (Talbot, 2002). Thus, the variations in $\delta^{13}C$ and $\delta^{15}N$ in the pond sediment can also be used to interpret changes in productivity and source over time.

This study utilizes elemental concentration data (C, N, P) and stable isotopic data ($\delta^{13}C$ and $\delta^{15}N$) in combination with local historical and climatological data sets to: 1) Document changes in reservoir productivity over the past 800 years; 2) compare increases in anthropogenic nutrient inputs with shifts in reservoir primary productivity; and 3) relate changing organic matter sources to the reservoir with changes in land use/land cover.

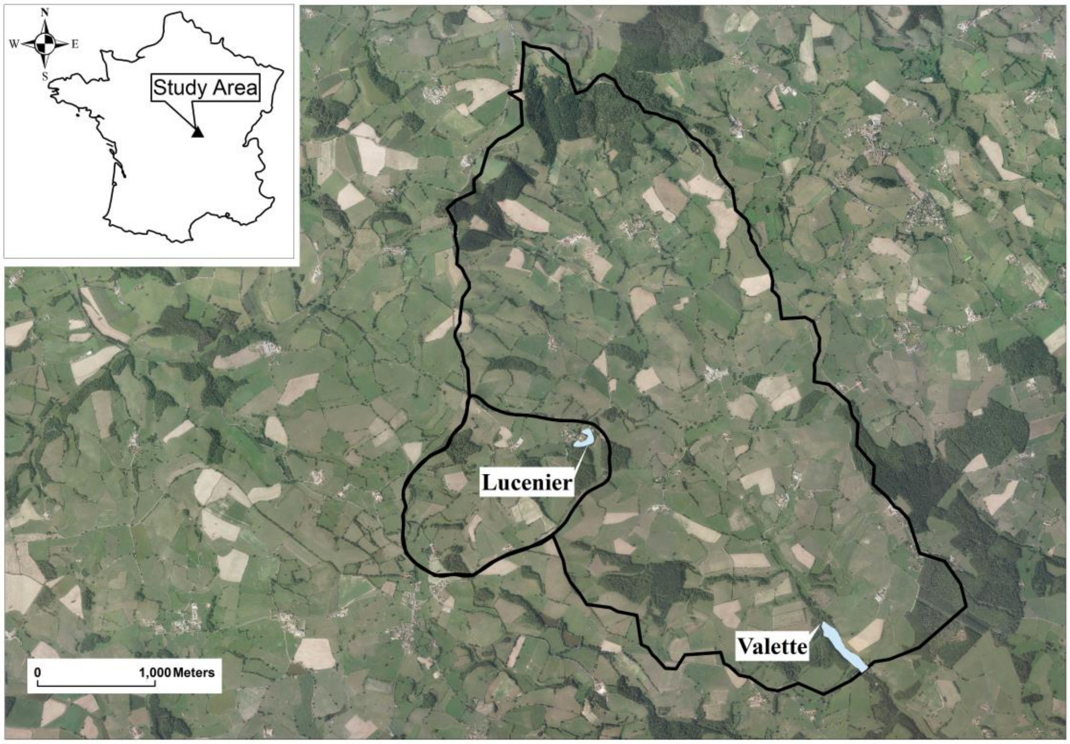


Figure 4.1. Aerial photo of the region showing study location and land cover across the study area (ponds areas are highlighted in blue).

4.2 STUDY AREA

An understanding of changes in historical land cover and land use is fundamental to recognizing the major environmental factors (i.e. agricultural practices, deforestation, construction, etc.) that are driving variations in pond sediment lithology and geochemistry over time. The modern east-central France and Burgundy landscape is largely rural. The modern landscape in the La Chapelle-au-mans study area is dominated by pasture (76%), primarily for livestock production. Much of the remaining modern landscape is crops (12% primarily wheat and corn) and forest (12%) (Corine Landcover Database, 2006). Geologically, the area is on the northern edge of the Massif Central, and is underlain by Precambrian to Paleozoic age igneous rocks. Average annual rainfall is 850 mm, generally occurring as rain in the late fall and early winter. Average annual temperature is around 11^{o} C, with a range of -7^{o} C to 23^{o} C (Meteo, France). The ponds at Lucenier and Valette are shallow (<3 m), well-mixed, open basin reservoirs with one inflow and one outflow stream. For a complete description of each pond refer to Chapters 2 (Lucenier) and 3 (Valette).

4.3 METHODS

4.3.1 Core Collection, Sampling, and Analyses

In July 2006, cores were collected from Lucenier and Valette pond using a sediment-water interface corer and modified square-rod piston coring system. The core collection and sampling methods are discussed in detail in Chapter 2, Section 2.4.1. Sediment ages and accumulation rates were determined by radiocarbon accelerator mass spectrometry (AMS) of both macroscopic and microscopic charcoal and terrestrial organic matter (wood, seeds). A description of the age model analysis for Lucenier is included in Chapter 2, Section 2.4.2, and for Valette in Chapter 3, Section 3.4.2. Elemental composition of the sediment cores was analyzed using scanning X-ray fluorescence (XRF) (See Chapter 3, Section 3.4. for a detailed discussion of XRF methods).

4.3.2 Stable Isotopes and Elemental Concentration of Bulk Organic Matter

A GV Instruments Isoprime continuous flow isotope ratio mass spectrometer (University of Pittsburgh Regional Stable Isotope Laboratory for Earth and Environmental Science Research) was used to determine $\delta^{13}C$, and $\delta^{15}N$. Stable isotopic results are reported in conventional delta (δ) notation relative to international standard V-PDB (Vienna PeeDee Belemnite) for carbon and atmospheric nitrogen for nitrogen. Results are corrected with repeated measurements of NIST Standard Reference Materials (Atropine, USGS-40, and USGS-41). Laboratory precision for $\delta^{13}C$ is ± 0.20 ‰ and ± 0.30 ‰ for $\delta^{15}N$ (1σ). Replicate sample measurements yielded an internal sample reproducibility of ± 0.07 ‰ for $\delta^{13}C$ and ± 0.51 ‰ for $\delta^{15}N$. Total carbon (TC) and nitrogen (TN) in the sediments were measured with a Eurovector high temperature elemental analyzer with autosampler. Organic carbon (OC) was estimated by subtraction of IC from TC. Total phosphorus (TP) was determined using an autoanalyzer, following digestion with persulfate (Schelske et al., 1986).

4.4 RESULTS

4.4.1 Elemental Organic Carbon and Total Nitrogen from Bulk Organic Matter

4.4.1.1 Lucenier Pond

The results for organic carbon and C:N values for Lucenier are reported in Chapter 2, Section 2.5.2. The total nitrogen (TN) content varied from 0.3% - 1.7%. Total nitrogen remained relatively constant for most of the core until after ca. AD 1900, when values increased to 1.7% in AD 1975, and then decreased to 1.3% at present.

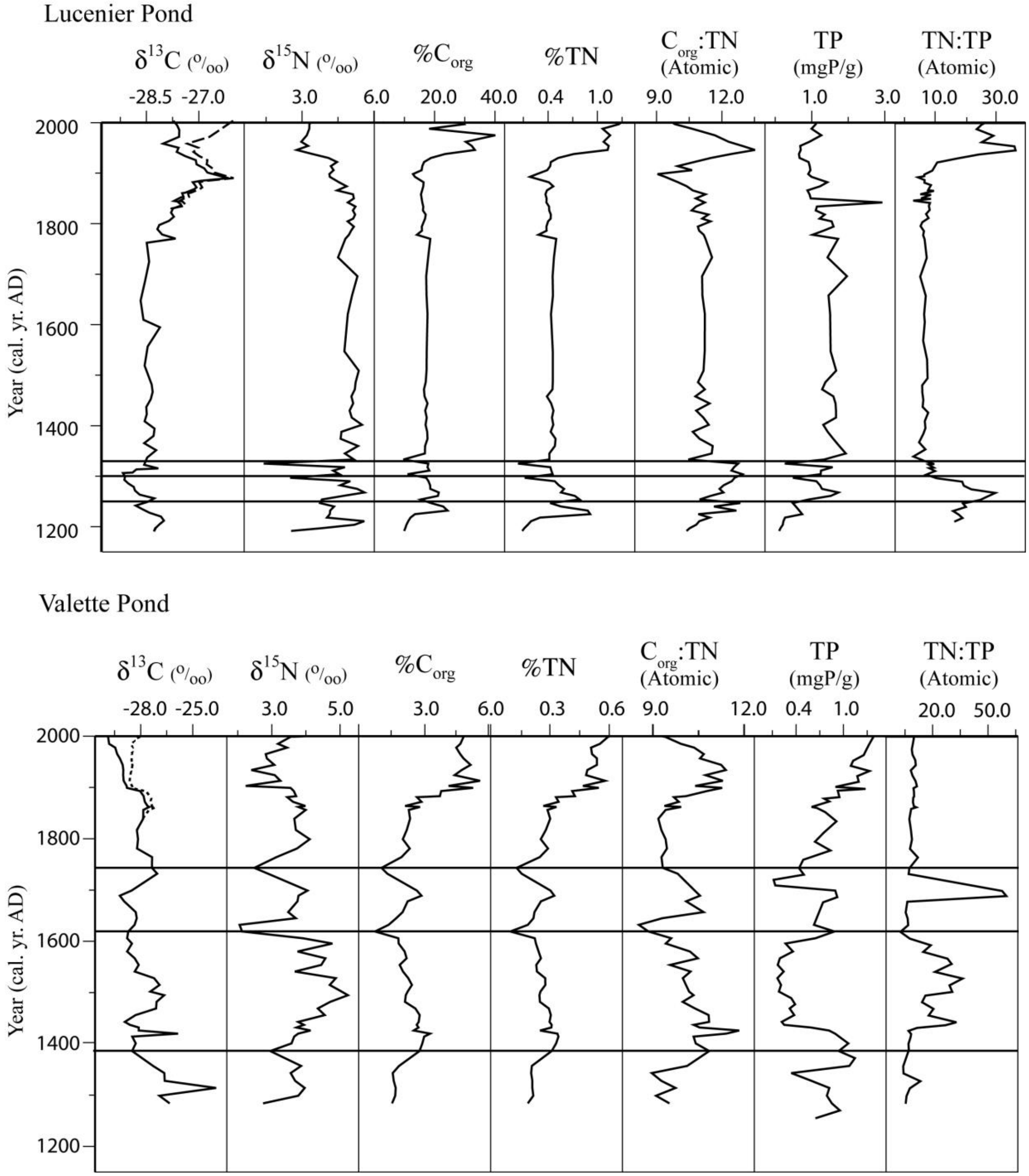


Figure 4.2. Changes in elemental and stable isotope data for both ponds over time. The Suess corrected values (see text) are shown as a dashed line on the δ13C plot. The solid black horizontal lines are approximate locations of gravels in the cores.

4.4.1.2 Valette Pond

Organic carbon content (Fig. 4.2) ranged from 0.7% – 5.6%, and TN values vary from 0.1% - 0.6%. At the base of the Valette record from AD 1280 – AD 1355, the OC and TN are low (average values of 1.7% C and 0.2% N). There is a distinct low around AD 1620 (0.75% OC and 0.1% TN), corresponding to a gravel layer in the core. Organic carbon and TN percentages increased and peaked around AD 1690 (2.9% OC and 0.32% TN), and then decreased once again in a sandy and gravelly interval deposited around AD 1740 (1.0% OC and 0.13% TN). Values steadily increased towards the top of the core with maximums occurring (5.6% OC and 0.6% TN) around AD 1913.

C/N values (Fig. 4.2) ranged from 9 – 12 with an average of 10. Starting in AD 1285 values vary around 10, and then increased to 12 around AD 1425. From there they decreased to the lowest value in the core of 9 in AD 1630. Subsequently, they fluctuated from 9 – 11 until AD 1900. There are several peaks to 11.3 from AD 1900 to AD 1935. Values declined at the top of the core to around 9.

4.4.2 Total Phosphorus

4.4.2.1 Lucenier Pond

The Total Phosphorous ranges from 0.1 mgP/g to 2.9 mgP/g with a mean of 1.1 mgP/g, indicating high concentrations in pond sediment (Fig. 4.2). In general, the phosphorous values do not vary widely. There is one peak at 2.9 mgP/g around AD 1840 that is defined by a single data point. Nitrogen to phosphorus molar ratio data has a range of 2.9 to 36.1 with a mean of 11.6 (Fig. 4.2). Values of N/P peaked (29.8) just after pond formation around AD 1270, and then declined rapidly to 7.1 around AD 1300, and fluctuate around 7 until AD 1930. Values increased rapidly and peaked at 36.1 around AD 1955, and then declined rapidly to 25.3 in AD 1960, and increased to 28 at the top of the core (AD 2005).

4.4.2.2 Valette Pond

Similar to Lucenier, the total phosphorous concentration at Valette is high, and ranges from 0.1 mgP/g to 1.3 mgP/g with a mean of 0.7 mgP/g (Fig. 4.3). There are two distinct peaks (1 mgP/g) starting around AD 1285 that are separated by a low point at AD 1330 (0.3 mgP/g). Then from AD 1430 to AD 1595 values remain low (0.3 mgP/g), and then increased rapidly around AD 1620 to 1mgP/g. Values remain high until AD 1700 when they decreased to their lowest values of 0.1 mgP/g. After AD 1700, values increased steadily to their maximum value of 1.4 mgP/g in AD 2006. Nitrogen phosphorus ratio data varies from 2.5 to 60.0 with a mean of 13.7 (Fig. 4.2). Values are low (˜10) until AD 1420 where they increased to ˜26.9 and remain high until around AD 1615. Except for one major peak around AD 1690 to AD 1700 where values reach their maximum of 60, the rest of the record remains low (˜11) until AD 2006.

4.4.3 Stable Isotopes of Bulk Organic Matter

4.4.3.1 Lucenier Pond

Stable carbon isotope values ranged from -29.3 ‰ to -25.8 ‰ (Fig. 4.2). From AD 1240 to AD 1770 $\delta^{13}C$ values fluctuate from -28.2 ‰ to -29.3 ‰ with a mean value of -28.7 ‰. The lowest values of $\delta^{13}C$ are in AD 1280 and AD 1310, and are associated with gravel layers. After AD 1770 the values steadily increased to -25.8 ‰ in AD 1900, and then declined to -27.3 ‰ in AD 1960. Values then increased again to -25.8 ‰ at the top of the core (AD 2005).

Nitrogen isotope values range from 1.4 ‰ to 5.6 ‰ (Fig. 4.2). $\delta^{15}N$ values fluctuate the most from AD 1240 to AD 1330, with the lowest values (2.5 ‰ in AD 1295 and 1.4 ‰ AD 1325) occurring during this time period. From AD 1330 to AD 1875 values fluctuate between 4.5 ‰ to 5.5 ‰ with an average of 5.0 ‰. After AD 1875 to AD 2006 values declined steadily with the lowest value of 2.8 ‰ in AD 1946.

4.4.3.2 Valette Pond

Stable carbon isotope values ranged from -29.2 ‰ to -23.7 ‰ (Fig. 4.2). The highest $\delta^{13}C$ value of -23.7 ‰ occurred around AD 1315. Values decline from there to -28.9 ‰ in AD 1440. Values increased to -26.6 ‰ in AD 1495 and decreased to -29.2 ‰ in AD 1690. From there values increased to -27.0 ‰ in AD 1730 and then declined to -28.2 ‰ in AD 1800 and increased to -27.3 ‰ in AD 1860. Values then decreased to -28.6 ‰ in AD 1910 and maintained this value until AD 1985. After that time period values increased steadily to -27.8 ‰ at the top of the core (AD 2005).

Nitrogen isotope values range from 2.0 ‰ to 5.2 ‰ (Fig. 4.2), with the highest $\delta^{15}N$ value in AD 1495. The lowest value of 2.1 is coincident with a gravel interval, and occurs from AD 1620 to 1630.

4.4.3.3 Data Visualization and Regression Analyses of Isotope, Elemental, and Environmental Variable Data

Regression analyses were completed with the gravel intervals removed to explore the relationships among isotopic composition, elemental concentration, and environmental variable data for both ponds. Most of the analyses resulted in low r^2 values (<0.2) suggesting weak relationships among most of the variables (Figs. 4.3, 4.4, 4.5, and 4.6). However, there were a few variables that had moderate to strong correlations. There was a strong positive correlation ($r^2 > 0.9$; $p < 0.01$) between OC (%) and TN (%) for both ponds (Figs. 4.3 and 4.4). At Lucenier there was a strong positive correlation between OC (%) and N/P (atomic), and a strong negative correlation for both OC (%) and TN (%) regressed against $\delta^{15}N$ ($r^2 = 0.6$; $p < 0.01$) (Fig. 4.3). At Valette there were moderate positive correlations between OC (%) and C/N ($r^2 = 0.3$; $p < 0.01$), and OC (%) and TP (%) ($r^2 = 0.5$; $p < 0.01$) (Fig. 4.4). Additionally, a comparison of carbon and nitrogen isotope values at Lucenier revealed increased $\delta^{15}N$ and $\delta^{13}C$ values over time (Fig. 4.4). A similar comparison of carbon and nitrogen isotope values for Valette did not show any significant trends or correlations.

Lucenier Pond

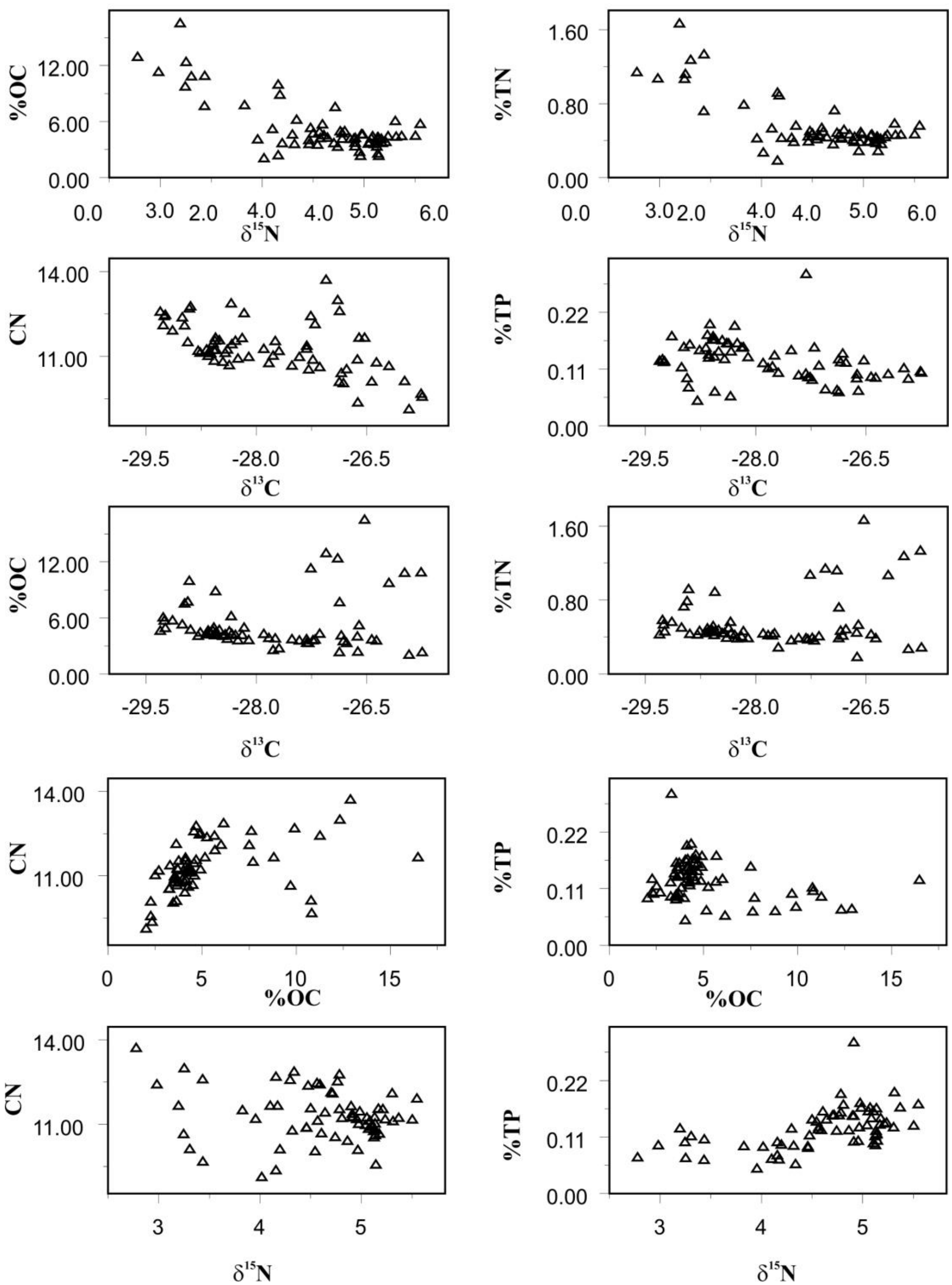


Figure 4.3. Scatter plots of elemental and isotopic data for Lucenier Pond.

Valette Pond

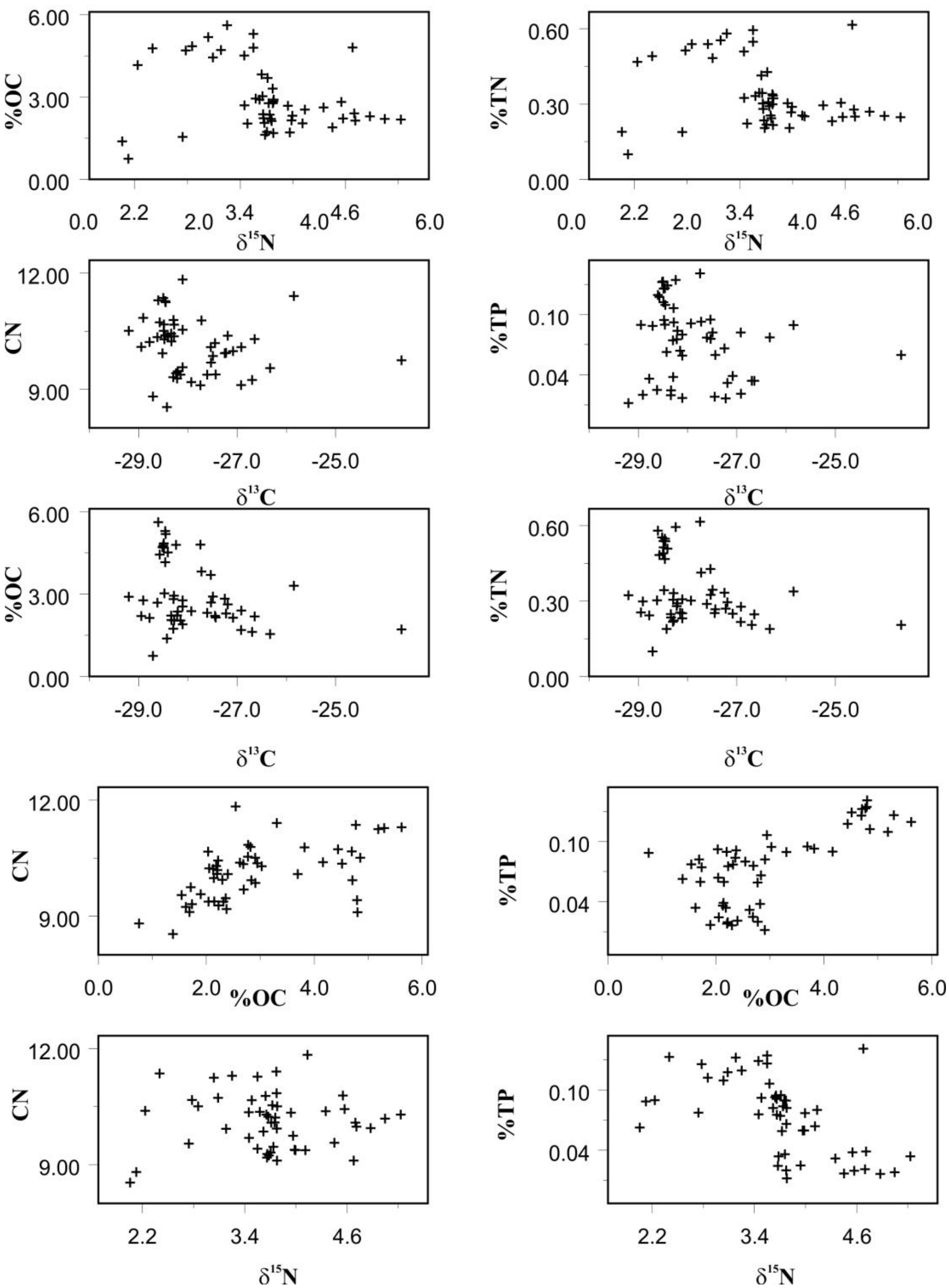
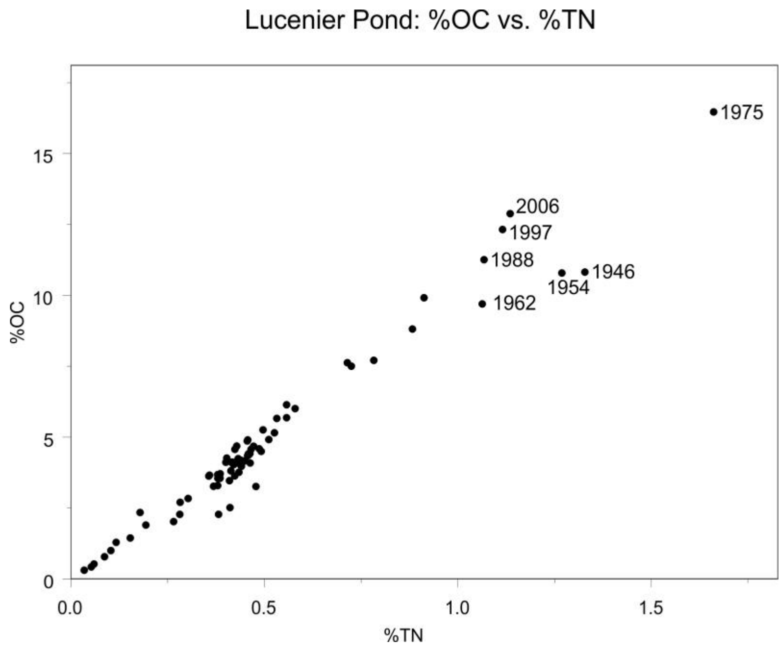


Figure 4.4. Scatter plots of elemental and isotopic data for Valette Pond.



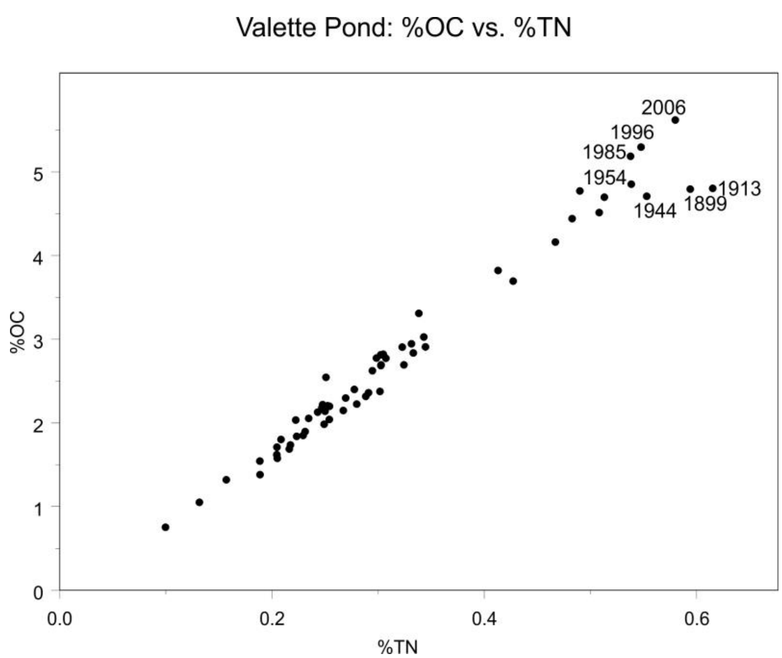


Figure 4.5. Scatter plots of organic carbon (%) versus total nitrogen (%) for Lucenier Pond and Valette. Lucenier has an $r^2 = 0.95$ and the y-intercept is 0.02, and Valette has an $r^2 = 0.97$ and an intercept of 0.2. The low y-intercept values for both ponds suggest that there is not a significant amount of inorganic nitrogen preserved in the bulk organic matter, and the data does not need to be corrected for inorganic nitrogen. The points on the bifurcation at the end of both plots are labeled with years to show that points after AD 1980 fall off of the regression line, and likely indicates a greater reliance on synthetic fertilizer in the watershed.

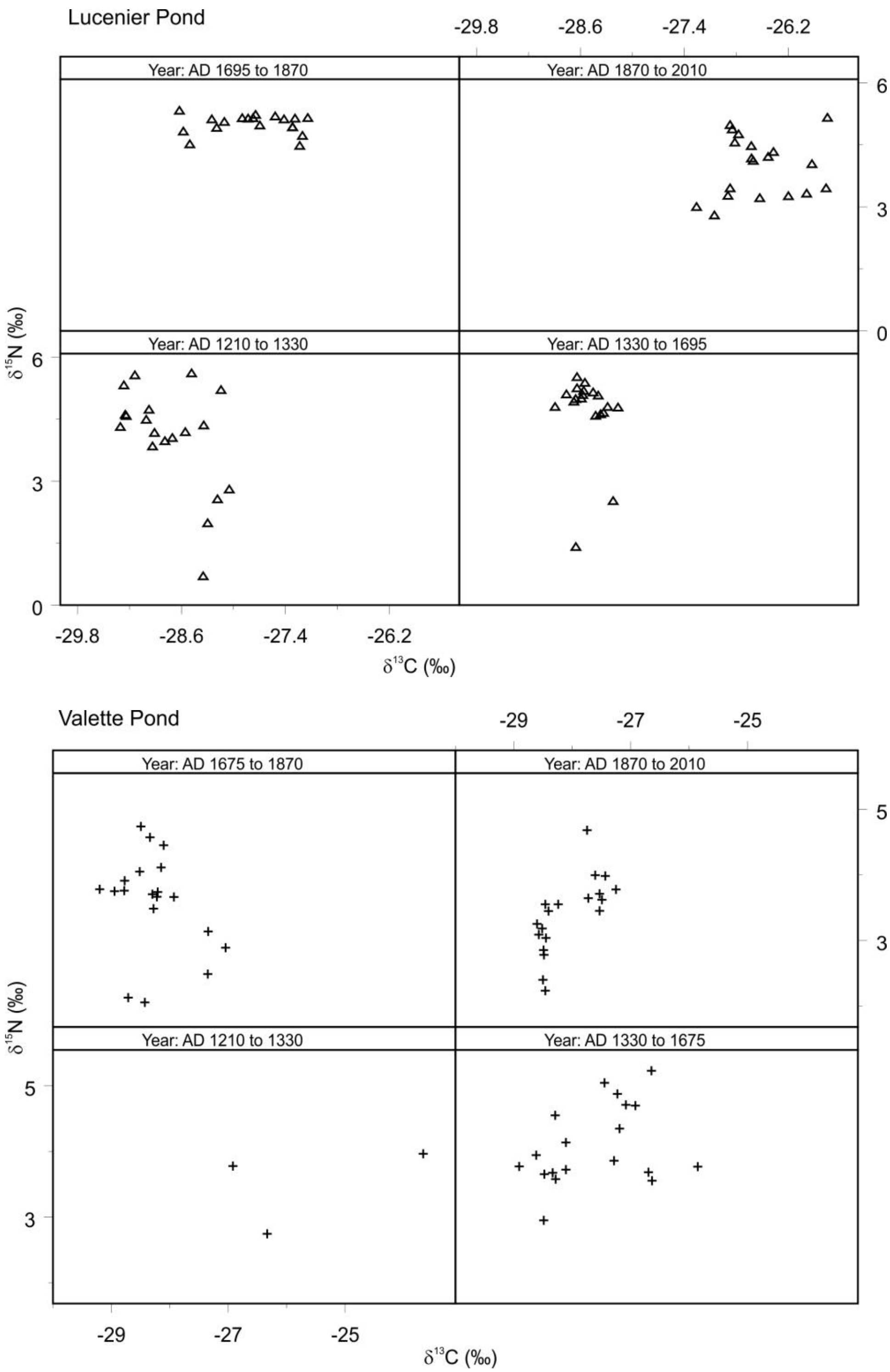


Figure 4.6. Values of $\delta^{13}C$ and $\delta^{15}N$ plotted for Lucenier and Valette showing the evolution of source material at each pond over time.

4.5 DISCUSSION

4.5.1 Historical Landscape from 1836 - 1934

Over the past 800 years, the historical landscape shifted from predominately farm fields supporting row-cropping agriculture to pastures supporting increasing livestock densities. Historical documents for the study region compiled by Jones, et al. (2012) indicate that the landscape in AD 1836 was 73% cropland with 20% woods and 6% pasture (Fig. 4.7). Between AD 1836 and AD 1934 there is an increase in mechanization and livestock production for market. Cattle for sale increased by 19%, horses (for pulling farm equipment) by 1850%, and goats increased by 86% (for cheese production) (Fig. 4.8). During this same time period, the area in crops decreased by 30%, while pastureland increased 281% and woods increased by 19% (Fig. 4.7). In AD 1836 crops were 30% rye, 15% potatoes, 15% fallow, and 3% or less of: wheat, barley, and oats. In AD 1934, a majority of the crops were wheat (32%), 17% potatoes, 12% oats, 9% hay, 9% Jerusalem artichoke, 8% clover dry hay, and less than 5% of: rye, barley, buckwheat, beets, and fodder crops (Jones et al., 2012). Additionally, the human population of the area shrinks from 1,050 (32 person km^{-2}) in AD 1836 to 670 (20 person km^{-2}) in AD 1934 (Jones et, al., 2012). Starting in ~AD 1950 state agricultural policy encouraged farmers to increase their herd sizes (Van Deventer, 2001). As a result of this policy, herd sizes in the study area increased 415% from AD 1950 – 1998.

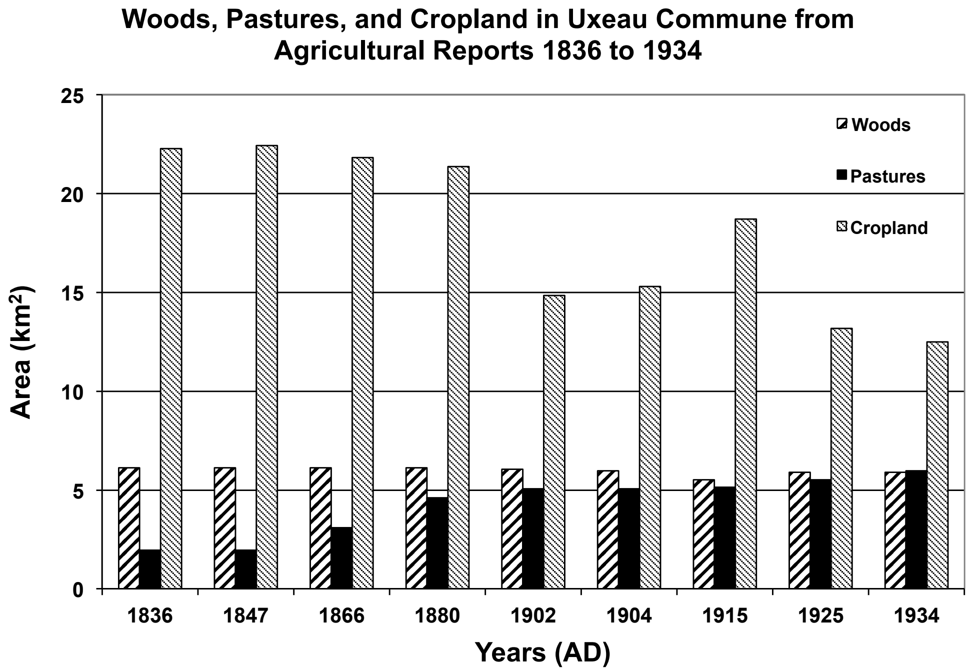


Figure 4.7. Bar graph showing changes in land cover for a nearby commune in an adjacent watershed to La Chapelle-au-Mans, from AD 1836 to 1934 (Jones, et al., 2012).

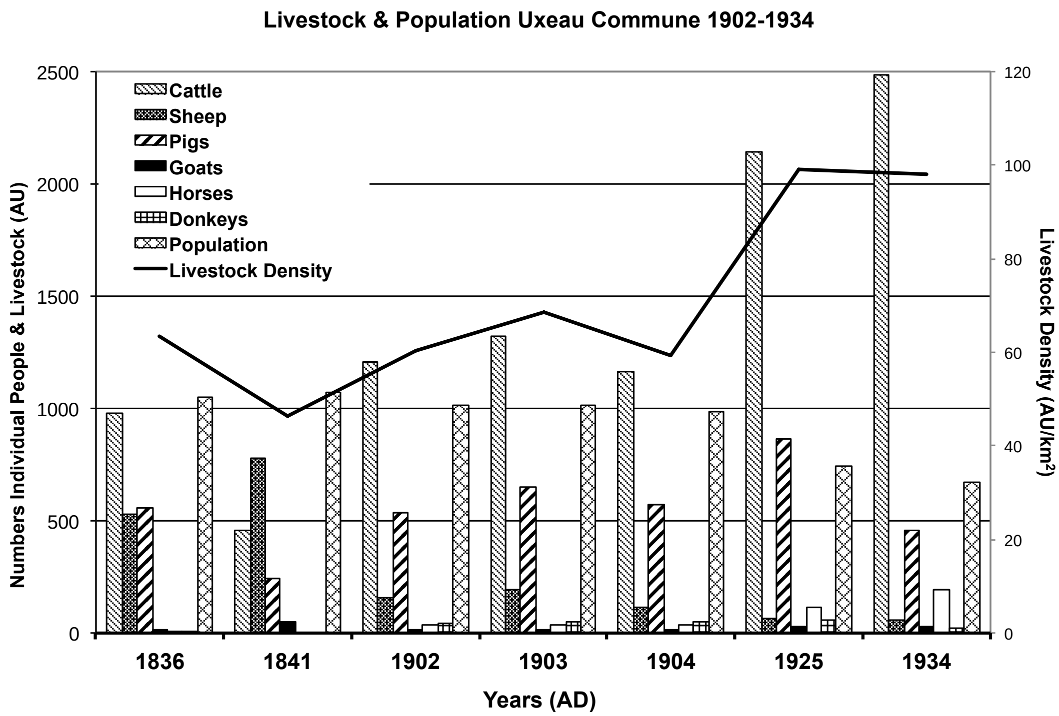


Figure 4.8. Bar graph showing changes in the number of livestock and people for a nearby commune from AD 1836 to 1934 (Jones et, al., 2012). The solid black line represents the change in livestock density since AD 1836.

4.5.2 Organic Matter Sources and Two End Member Mixing Model

A two-end member-mixing model was developed to explore the major source of nutrients to each pond system over time. Atomic C/N ratios are determined from both percent organic carbon (%OC) and percent total nitrogen (%TN) divided by atomic mass, and is used to distinguish between algal and plant derived organic material. Algae typically have low C/N ratios ranging from 4 – 12, because of their high protein content and absence of cellulose. In comparison, terrestrial plants are primarily cellulose (carbon-rich) resulting in ratios >15 (Meyers, 1994; Kendall, et al., 2001; Meyers and Teranes, 2001). Therefore, changes in C/N ratios can be used to infer the source of organic matter to the pond. For example, an increase in C/N ratios indicates a terrestrial contribution, while a decrease suggests increased algal input from primary productivity. The sediment for both ponds has a range of C/N values from ~9 – 14 that indicates most of the organic matter is from aquatic sources (Fig. 4.2).

Previous studies have shown that if inorganic nitrogen is present in sediment it can alter the C/N ratios and confound the interpretation of organic matter sources (Talbot, 2002). Inorganic nitrogen in sediments is commonly comprised mostly of ammonium (NH_4^+) that can attach readily to certain types of clays (Schubert and Calvert, 2001). A linear fit between %OC and %TN for both lakes resulted in low intercepts (Lucenier: 0.02 and Valette: 0.2) suggesting there is not a significant amount of inorganic nitrogen present in the pond sediments (Hedges, 1986; Talbot, 2002) (Fig. 4.5). Thus, a reliable estimate of algal contribution can be calculated with a mixing model. Additionally, since inorganic nitrogen seems limited in the pond sediment, total nitrogen is used instead of organic nitrogen in subsequent analyses. Furthermore, it is interesting to note that both ponds show a bifurcation in points for high %OC and %TN (Fig. 4.5). This bifurcation occurs after AD 1950 for both ponds, and points that occur after AD 1985 appear to fall off a best-fit line. This is likely related to a shift in the type of fertilizer used in modern times.

A two-end member-mixing model using C/N values was utilized to determine the contribution of algal material versus terrestrial material to bulk sedimentary organic matter. The following equation was used to determine the percent algae:

$$R_M = aR_A + bR_B \qquad \text{(Equation 4.1)}$$

$$a = \frac{R_B - R_M}{R_B - R_A} \qquad \text{(Equation 4.2)}$$

Where R_M is the measured value resulting from the mixture of the two end members (R_a and R_b), and a and b are the weighted contributions of each of the end members. In this case, we assume R_a is equal to the median C/N value of 6 for algae, and R_b is equal to the median C/N value of 18 for terrestrial plant material (Kendall, et al., 2001).

Results from the mixing model suggest that on average, algae contributes up to 56% of the organic material at Lucenier and 66% at Valette. Algal contributions to organic matter pools fluctuated between 36% and 79% over the 800-year record (Fig. 4.9). The most recent interval of eutrophication (>50% algal material) begins around AD 1950 and continues until AD 2006 (the top of the core) in both ponds. In addition, multiple episodes of increased algal production throughout the past 800 years are recorded.

Interestingly, the mixing model suggests that the period of highest proportion of algal contributions to organic matter at Valette occurred around AD 1630. Algae comprised nearly 80% of the bulk organic material, very similar to contemporary contributions of 74%. In contrast, the highest eutrophication event recorded at Lucenier did not occur until AD 1900, with algae contributing 74% of the organic matter during this period. Contemporary algal contributions at both ponds are similar, and less than their historical maximum contributions. Valette seems to have experienced more eutrophic events earlier than Lucenier.

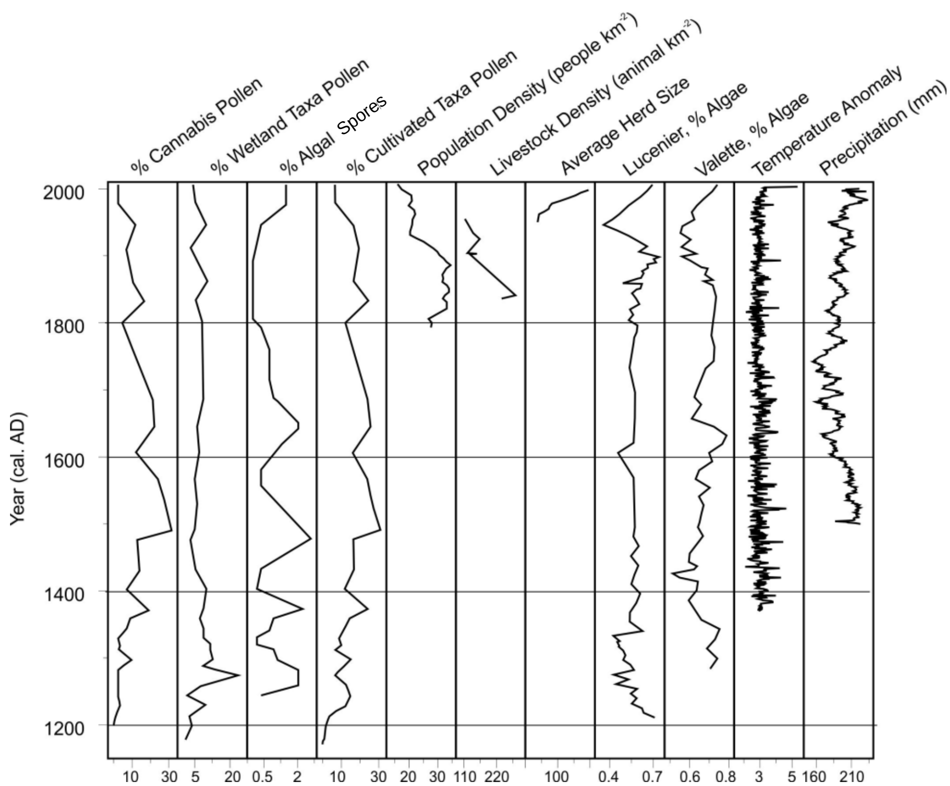


Figure 4.9. A comparison of selected proxies for the Lucenier and Valette watershed over the last ~ 800-years. From left to right: Pollen concentration data (%) in cultivated pollen taxa and algal spores (Chapter 2); Human and livestock population density and changes in farm animal herd size (Jones, et al., 2012; Van Deventer, 2001); Inferred algal contributions (%) to bulk organic matter over time is shown for both ponds, and was determined by a two-end member mixing model (this study); Temperature reconstruction based on grape harvest dates in Burgundy, France (Chuine, et al., 2004); Precipitation data for the Burgundy area; Global nitrogen fertilizer use (Davidson, 2009).

4.5.3 Sediment Organic Matter Sources

Stable carbon isotope data indicate that organic material deposited in pond sediment is a mixture of allochthonous terrestrial and autochthonous lacustrine algal matter. Both ponds occupy distinct ranges in C/N values. The stable isotopic composition of carbon can also be used to identify the source of organic matter to the pond. Carbon is incorporated into plant material during photosynthesis and is dependent upon the isotopic composition of the carbon source and the photosynthetic pathway utilized by the plant (Kendall, 2001). The most common plants found in the study area watershed are C_3 plants (woody plants and shrubs) that have $\delta^{13}C$ values ranging from -32 to -22 ‰ (Meyers, 1994, Kendall, et al., 2001; Meyers and Teranes, 2001). Another important source of organic matter to the pond is lacustrine algae, which have $\delta^{13}C$ values from – 42 to -24 ‰ (Meyers, 1994, Kendall, et al., 2001; Meyers and Teranes, 2001). Since there is considerable overlap in the $\delta^{13}C$ values of C_3 plants and lacustrine algae, C/N ratios are often used in conjunction with the $\delta^{13}C$ values to distinguish algae from terrestrial source material.

Shifts in $\delta^{13}C$ values can be used to infer periods of increased productivity in the ponds (Meyers 1994; Schelske and Hodell 1995; Hodell and Schelske 1998). Photosynthesis is likely the main process driving changes in DIC concentrations in these watersheds because the watershed is predominantly granite (no calcareous rocks mapped or observed) and thus would not contribute a significant amount of HCO_3^- to the ponds (Diefendorf et al., 2008). During photosynthesis, algae preferentially assimilate the lighter isotope (^{12}C) leaving the DIC enriched in ^{13}C. At times of increased lake productivity, algae will utilize all of the ^{12}C, and then start to assimilate ^{13}C from the enriched DIC as well, resulting in less negative $\delta^{13}C$ values. Therefore, changes in the trophic status of the pond can be inferred form shifts in $\delta^{13}C$ values (Meyers 1994; Schelske and Hodell 1995; Hodell and Schelske 1998).

However, caution must be taken in the use of $\delta^{13}C$ as a productivity indicator. High rates of fossil fuel combustion over the last ~200 years has resulted in atmospheric CO_2 that is depleted with respect to $\delta^{13}C$, also known as the Suess effect. Since CO_2 in the pond is in equilibrium with CO_2 in the atmosphere, this results in a shift of $\delta^{13}C$ of autochthonous organic matter to more negative values (Schelske and Hodell, 1995; Verburg, 2007). The following equation developed by Schelske and Hodell (1995) was used to correct for the Suess effect:

$$\delta^{13}C_{mod} = 4577.8 - 7.343 * Y + 3.9213 * 10^{-3} * Y^2 - 6.9812 * 10^{-7} * Y^3 \qquad \text{(Equation 4.3)}$$

$$\delta^{13}C_{corr} = \delta^{13}C_{orgC} - \delta^{13}C_{mod} \qquad \text{(Equation 4.4)}$$

The terms for the equations are defined as follows: $\delta^{13}C_{mod}$ = atmospherically modeled value; Y = year since AD 1840; $\delta^{13}C_{orgC}$ = the measured $\delta^{13}C$ value for each interval; $\delta^{13}C_{corr}$ = the corrected value. The difference in the $\delta^{13}C$ between this calculated value and the 1840's value were used to adjust measured $\delta^{13}C$ for each dated section at both ponds (Fig. 4.2).

The $\delta^{13}C$ values at both ponds are influenced by a mixture of terrestrial and lacustrine algae. A plot of $\delta^{13}C$ values against C/N ratios for both ponds (Fig. 4.10) shows that while some increments plot within the lacustrine range, most fall between terrestrial and lacustrine ranges, suggesting a mixture of source material is preserved in the pond sediment.

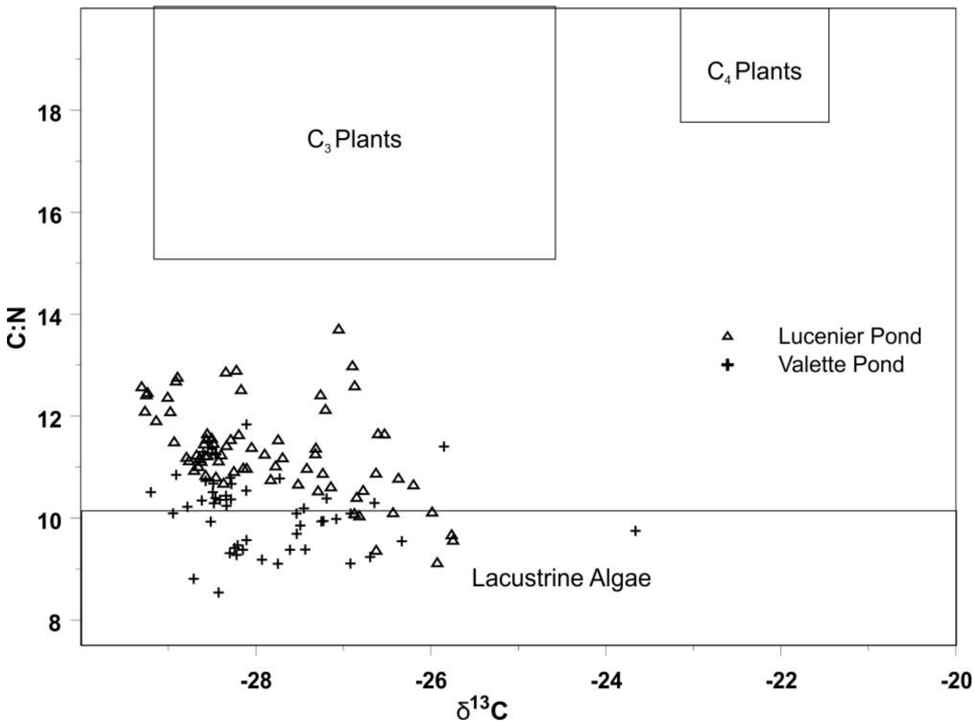


Figure 4.10. Values for C/N and δ^{13}C (values after AD 1840 were corrected for the Suess Effect, see text) of bulk organic material from pond sediment for Lucenier and Valette. Values for both ponds are shown in comparison to typical ranges for lacustrine, C_3, and C_4 plants (modified from Meyers, 1994). Pond data plot within and scattered just above the lacustrine algae towards C_3 plants, indicating a mixture of algal and terrestrial source material.

Additionally, in general, the values for Lucenier pond appear to be shifted more towards the terrestrial range. This indicates that allochthonous organic material from the watershed may be an important source of organic matter to the pond sediment. Although terrestrial material influences the variation in δ^{13}C values at Lucenier (-29.3 to –26.4 ‰), the data indicate that algae, and not terrestrial sources, contributed more organic matter to the pond sediment over time as a majority of the data points plot within or just above the lacustrine algae zone (Fig. 4.10). This suggests that carbon isotopes are a good proxy for productivity at this site. Low C/N elemental ratios and increased OC and TN data correspond with less negative δ^{13}C values that occur as a result of assimilation of the lighter carbon isotope during periods of increased productivity. This supports the idea that changes in $\delta^{13}C$ values are mostly controlled by changes in the contribution of algae to organic matter in the Lucenier pond sediment (Fig. 4.2).

In contrast, the $\delta^{13}C$ values at Valette are not a reliable proxy for productivity. The $\delta^{13}C$ values at Valette pond correspond well with changes in elemental C/N ratios, OC, and TN at the beginning of the ponds history until ~AD 1500. From ~AD 1500 until the most recent pond sediments, the $\delta^{13}C$ values are more negative during periods of increased algal productivity, as indicated by low C/N elemental ratios and increased OC, TN, and TP data. The shift to more negative $\delta^{13}C$ values during eutrophication are not expected, and are likely due to a greater contribution of terrestrial plants, which tend to have more negative $\delta^{13}C$ values, to pond sediment organic matter. This idea is also supported by the positive correlation between increased OC (%) values and larger elemental C/N ratio values ($r^2 = 0.3$; $p < 0.01$) at Valette (Fig. 4.4).

The analysis of $\delta^{13}C$ data shows that despite contributions to pond sediment by terrestrial sources, the main source of organic matter for both ponds is lacustrine algae. While, $\delta^{13}C$ values are a good proxy for changes in productivity at Lucenier pond, Valette pond seems to be more influenced by terrestrial organic matter sources than Lucenier. The following examination of $\delta^{15}N$ values will help to further elucidate changes in trophic status and source material to the ponds over time.

Changes in $\delta^{15}N$ values can be used as an additional proxy for productivity, organic material sources, and DIN sources to organic matter. In general, the signature for $\delta^{15}N$ in the pond sediment is controlled by the source of organic matter to the pond, and the source of nitrogen assimilated by organisms producing the organic matter (Talbot, 2002; Gu, 2009). The most common sources of DIN to the pond are ammonia (NH_4^+) and nitrate (NO_3^-) that enter the pond through inputs such as: rain ($\delta^{15}N$ ~ - 11 to + 3.5‰), surface water (~ -15 to + 14‰), and groundwater (Kendall, 2001; Kendall et al., 2007; Elliott et al., 2007). In addition to DIN sources to organic matter there are also organic nitrogen inputs that are dominated by the following: land plants ($\delta^{15}N$ + 2 to + 10), soil organic matter ($\delta^{15}N$ ~ + 5), and aquatic macrophytes ($\delta^{15}N$ – 15 to + 20) (Cravotta, 1997; Kendall et al., 2001; Woodward, et al., 2012). Biological processes occurring within the pond could also impact the $\delta^{15}N$ values of sediment through discrimination against the heavier isotope. Discrimination results in relative isotopic enrichment in the phytoplankton that consume the nitrogen in the water column (Talbot, 2002). For example, during times of primary productivity, ammonia, nitrate and nitrite are assimilated as sources of nitrogen. During this process the lighter isotope (^{14}N) is preferentially selected over the heavier isotope (^{15}N) for incorporation into organic matter.

Another process, nitrogen fixation, is typically accomplished in the pond system by blue-green algae that convert unreactive atmospheric nitrogen (i.e. N_2) to other forms of nitrogen. Mineralization or ammonification also occurs, which produces ammonium from soil organic matter in anoxic sediments. Nitrification produces nitrate or nitrite from the oxidation of ammonia under oxic conditions. Finally, denitrification can occur under anoxic conditions to produce nitrogen (N_2 or N_2O) gas from bacterial reduction of nitrate. This process commonly takes place within anoxic layers in the sediment (Talbot, 2002).

Additionally, anthropogenic activities and DIN sources such as sewage ($\delta^{15}N$ ~ +10 to +20 ‰) and fertilizer (- 5 to + 5‰) can also be sources of nitrogen that would impact the final $\delta^{15}N$ signature of organic matter (Cravotta, 1997; Kendall et al., 2007). Algae generally has higher $\delta^{15}N$ values than terrestrial plants because it is utilizing dissolved NO_3^- in pond water with higher $\delta^{15}N$ values than nitrogen assimilated by terrestrial plants (Kendall et al., 2007). Terrestrial plants typically have $\delta^{15}N$ values that range from +3 to +7 ‰, and algae have values from +2 to

+14 ‰ (Kendall, 2001; Talbot, 2002). If productivity occurs under nitrogen limited conditions, then nitrogen-fixing cyanobacteria will dominate and the resulting $\delta^{15}N$ (of total N) values will be – 3 to + 1 ‰ (Fogel and Cifuentes, 1993; Choudhary, et al., 2009).

Lucenier and Valette ponds have $\delta^{15}N$ values that range from +2 to +6 ‰, and fall within the ranges of both terrestrial and aquatic sources. Although the range for cyanobacteria is outside the observed values in the study area ponds, there is a shift towards lower $\delta^{15}N$ values, in the most recent years, that might suggest cyanobacteria is present, or there were increased contributions of N fertilizer to the ponds, or increased atmospheric N deposition (Fig. 4.2). Carbon and nitrogen ratio data plotted versus $\delta^{15}N$ values for both ponds shows that a majority of the data points plot within or just outside of the lacustrine algae range (Fig. 4.11). Furthermore, there were no apparent shifts in $\delta^{15}N$ isotope values that occurred when the percentage of macrophyte pollen increased.

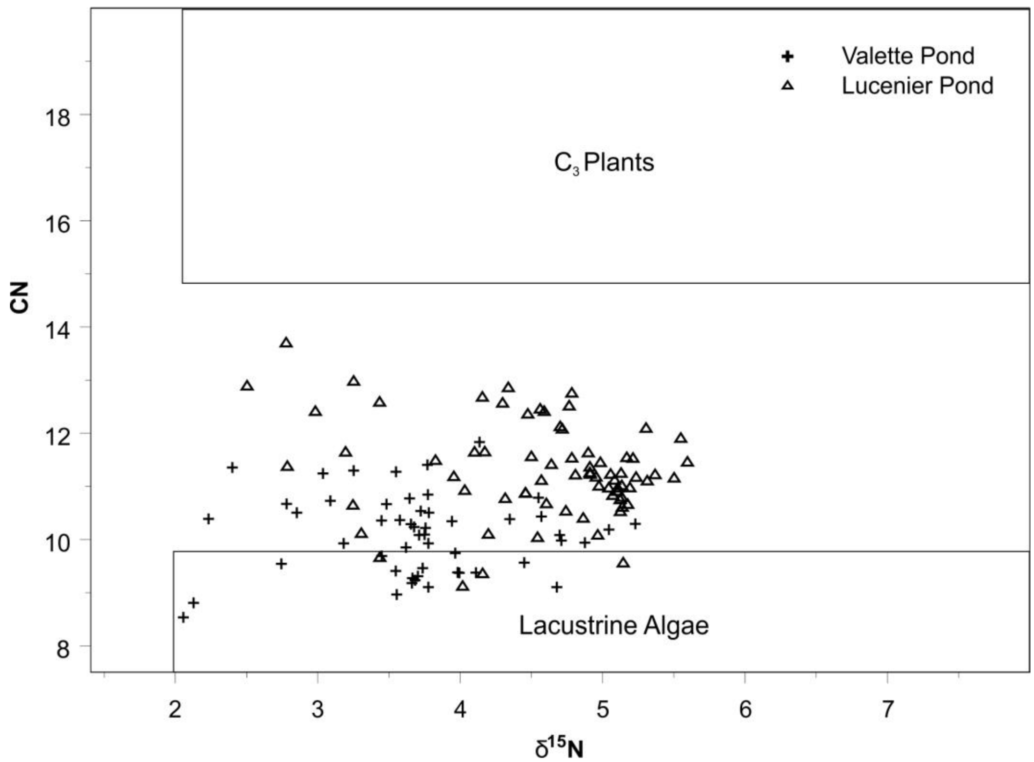


Figure 4.11. Values of CN and □[15]N for Lucenier (red triangle) and Valette (black circles) as compared to commonly observed values for algae, C_3, and macrophyte organic material. Organic material from both ponds plot within or scattered above the lacustrine algae range toward the terrestrial plant range.

4.5.4 Impact of hemp processing on lake productivity over time

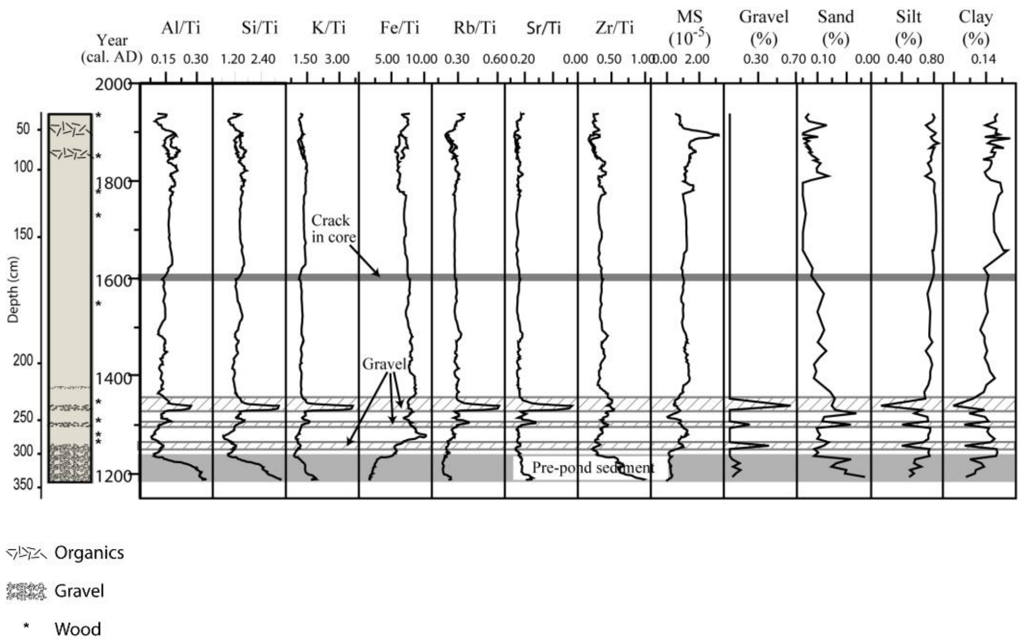
Enhanced lake productivity can result from climatic factors such as increased temperatures that stimulate algal growth or changes in precipitation regimes that can increase nutrient delivery from the watershed. Human impacts, such as fertilizer use and hemp retting, (soaking hemp fibers in the pond to soften them) can also result in eutrophication. During water retting, anaerobic pectinolytic bacteria are responsible for decomposing the pectin that attaches the hemp fibers to the stem (Akin, et al., 2002). The hemp stem and fibers are predominantly lignin and cellulose that produce butyric acids and pectins as by-products of water retting (Mathre, 1997). Previous studies have documented that the anaerobic bacterial fermentation that occurs pollutes

water bodies (i.e. high biochemical oxygen demand) and leads to acidification and eutrophication (Cox, et. al, 2001; Akin et al., 2002; Riera et. al, 2006; Laine et al., 2010). For most of the record, the ponds rarely show concurrent episodes of eutrophication, except early in their history (~AD 1300) and after AD 1950. Hydrologically the ponds are similar in that they are both open basin reservoirs with one inflow and outflow, adjacent land cover is similar, and the geology is the same. Further, they are only separated by 3 km in horizontal distance and ~ 50 m in elevation, and therefore should experience similar precipitation and temperature regimes. Thus, the inconsistency in eutrophication events between the ponds suggests that local, human activities influenced organic matter pools more strongly than regional factors, such as climate. For example, the percent *Cannabis* and algae spores, when compared with the mixing model, suggest that hemp retting drove historical eutrophication in Lucenier pond. Prior to the Little Ice Age (LIA), which began in ~ AD 1400, there is an interval where *Cannabis* and algae spores peak together (~AD 1370) at Lucenier. In contrast, during this interval, the percent algal contribution at Valette decreases from ~75% to ~50%. Additionally, throughout most of the LIA there are appear to be no significant peaks in percent algal contribution at Lucenier, whereas at Valette there are at least three noticeable peaks that occur around AD 1480, AD 1555, AD 1630.
In ~AD 1950 a decrease in precipitation and an increase in temperature likely resulted in lower pond water levels that may have impacted preservation of algal spores at Lucenier. In ~ AD 1950 there is a peak in *Cannabis* coincident with a sharp decrease in inferred percent algae and low percentage of algal spores. Percent pollen of wet meadows and pond shoreline taxa increased at this time suggesting that the pond water level may have been lower, encouraging the growth of wetland taxa and emergent pond plants such as *Phragmites* (reeds) and *Cyperaceae* (sedges). A decrease in water level would likely be detrimental to algal growth, and result in

lower percentages of algal contribution as indicated by the mixing model and pollen percentages at Lucenier. A similar decrease in algal productivity is indicated at Valette, and a comparison with climate data shows decreased precipitation and a slight increase in temperature during this time period (Fig. 4.9).

In addition to a change in climate, the pollen data shows *Cannabis* continued to decline after AD 1950 and the record shows it is no longer being processed in the pond. This corresponds well with historical documentation that indicate the development of cheaper cotton and synthetic textile industries, and the illegal designation of hemp, resulted in a decline of hemp cultivation (Lavreaux, 2013). If people were no longer processing hemp in the pond, they may have allowed the pond water levels to decrease. Thus the changes in water level may be more related to human management of the pond. Even though hemp was not being processed in the ponds, both ponds experience significant increases in algal productivity (Fig. 4.9). Thus the cause of eutrophication seems to shift from a history of retting to the advent of widespread use of fertilizer (Fig. 4.9). Synthetic nitrogen fertilizer use increased globally after the Second World War further supporting the idea that there was a shift in nutrient source in the watershed (Davidson, 2009) (Fig. 4.6).

Lucenier Pond



Valette Pond

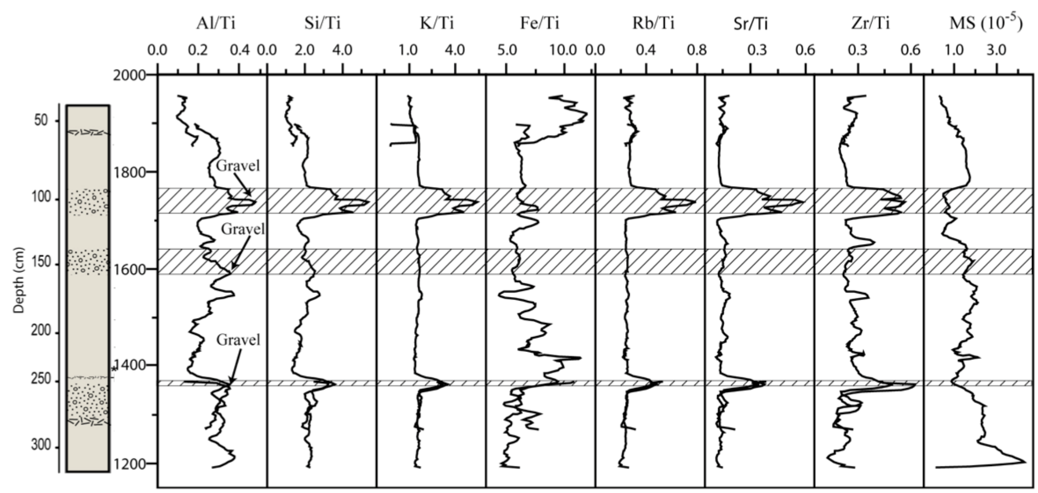


Figure 4.12. XRF, MS, and grain size data at Lucenier pond showing relative changes in elemental concentration and lithology throughout the core. The shaded gray area before 1240 AD denotes pre-pond sediment, and the shaded gray area around 1600 AD marks a crack in the core causing a distinct dip in data. The record stops in the 1900's AD because the upper 35 cm of the core was extruded in the field, and could not be scanned. A generalized description of the core lithology is also shown. Organic horizons are noted as well as gravel layers, and woody material (upper panel). XRF data at Valette Pond showing relative changes in elemental concentration throughout the core. The record stops in the 1900's AD because the upper 35 cm of the core was extruded in the field, and could not be scanned. A generalized description of the core lithology is also shown. Organic horizons are noted as well as gravel layers, and woody material (lower panel

4.5.5 Influence of Agriculture on nutrient inputs

Both ponds were negatively impacted by increased nitrogen and phosphorous loadings after ~AD 1900 (Fig. 4.2). Excess nutrients likely stemmed from an increase in nitrogen and phosphorous inputs from intensely fertilized farm fields (Gunderson, et al., 2006). In addition to an increase in nutrient export from chemical fertilizer use, there was also an increase in atmospheric N deposition at this time. Previous studies analyzed $\delta^{15}N\text{-}NO_3^-$ values in Greenland ice cores that indicated biomass burning and fossil fuel emissions were the major contributors to N loading in the atmosphere after AD 1850 (Felix and Elliott, 2013). This increased amount of atmospheric N available for deposition into the pond could be another significant input of N following the Industrial Revolution. There are significant increases in TN and OC at both ponds coincident with increased nutrient inputs (Fig. 4.2). Additionally, TP concentrations remained relatively stable at Lucenier, while values increased rapidly at Valette after AD 1850 (Fig. 4.2). These trends phosphorous concentrations indicate that while both ponds were impacted by increased fertilizer use, fertilizer composition in areas draining to each pond were different. Watersheds with a high percentage of row-crop agricultural practices tend to have high N/P elemental ratios as a result of excess nitrogen from nitrogenous fertilizer use (Arbuckle and Downing, 2001). In contrast, watersheds with a high percentage of livestock production tend to have low N/P ratios due to phosphorous enrichment from manure (Downing and McCauley, 1992). The N/P elemental ratios are high at Lucenier (mean = 22), and low at Valette (mean = 11) during this time period (Fig. 4.2). Additionally, decreased $\delta^{15}N$ values, after AD 1900, at Lucenier (- 2 ‰ shift) also suggest that farmers were utilizing chemical fertilizer (Fig. 4.2). Historical documents confirm chemical fertilizer was being used in the region after AD 1900 (Moulin, 1991).

Similar to Lucenier, $\delta^{15}N$ values declined initially at Valette in AD 1900 (Fig. 4.2). This suggests inorganic fertilizer may have impacted the pond system initially, but after ~AD 1920 the $\delta^{15}N$ values increased (~ 2 ‰ shift) to present (Fig. 4.2). This indicates that the main source of nitrogen at Valette changed, and was more dominated by manure with higher $\delta^{15}N$ values ($\delta^{15}N$ ~+10 to +20 ‰). Furthermore, there was a major change in land use during this time as livestock density increased and farms were consolidated and more mechanized (Fig. 4.9). A regression analysis of changes in herd size with $\delta^{15}N$ values from AD 1950 – 2006 resulted in a positive correlation ($r^2 = 0.6$; $p < 0.01$). Excess nutrients from agricultural practices typically enter the hydrologic system from runoff of manured or fertilized cropland, livestock grazed pastures or poor management of waste storage structures (Humenik, et al., 1992). Since Valette is lower in the watershed and potentially incorporating nutrient inputs from most of the catchment, one might conclude that livestock agricultural practices have more of an impact than row-cropping practices on hydrological systems in the catchment as a whole.

Analysis of changing N/P values over time indicates nitrogen is the limiting nutrient for both ponds during a majority of the past 800 years. Productivity in lakes is typically limited by the availability of nitrogen or phosphorus. It has been generally accepted that most lakes in temperate zones are phosphorous limited, and therefore changes in phosphorus concentrations are the main driver for lake productivity (Wetzel, 2001; Lehmann et al., 2004). Lake systems with N/P ratios of 10 are typically considered nitrogen limited, while N/P values greater than 15 are generally phosphorus limited (Shaw et al., 1993). High TP concentrations (Lucenier: 0.1 to 2.9 mgP/g; Valette: 0.1 to 3 mgP/g) and low N/P ratios (< ~10) indicate nitrogen is the limiting nutrient for primary productivity during most of the 800 year history of these pond systems (Das et al., 2008) (Fig. 4.2). Additionally, there is a strong positive correlation of OC and TN (r^2 >

0.9; $p<0.01$) at both ponds, while there is very little correlation of OC with TP at either site (Fig. 4.2).

There are distinct time periods over the past 800 years in which the N/P ratios were greater than 15, and the ponds would have been considered phosphorus limited. At Valette these episodes occurred in ~AD 1430 to 1600 and ~AD 1680 to 1700. During this time period there are also increases in C/N ratios, as well as small peaks in XRF Zr/Ti and MS data (Fig. 4.12), that suggests shifts in N/P ratios are related to the input of terrestrial organic matter to the pond from the surrounding watershed. The higher N/P ratios of soils (~33) and forested watersheds (~71) could shift the N/P ratios for the pond sediment to higher values (Loehr, 1974; Downing and McCauley, 1992). At Lucenier a shift to higher N/P values occurs from ~AD 1230 to 1325 and after ~AD 1900. Pollen data at Lucenier shows a number of peaks in tree pollen taxa during the ~AD 1230 – 1325 time period, which would support the idea that runoff from forested areas adjacent to the pond could increase the N/P values of the pond sediment during that time period. The more recent shift to high N/P ratios at Lucenier is likely related to the input of excess nitrogen from chemical fertilizer use after ~AD 1900.

4.6 CONCLUSIONS

Examination of elemental concentration (C, N, P) and stable isotopic data ($\delta^{13}C$ and $\delta^{15}N$) indicated that the water quality at both Lucenier and Valette have been negatively impacted by changing land use practices within their catchment over time. Analysis of elemental C and N values combined with stable $\delta^{13}C$ and $\delta^{15}N$ isotope data indicated that the main source of organic material to the ponds is from algae, and that both ponds experienced numerous episodes of eutrophication throughout their 800-year history. The inconsistent timing of eutrophication events between the ponds suggests that increased productivity was more related to changes in local activities such as row cropping, hemp retting, livestock production and fertilizer use, as opposed to changes in climate.

The main driver for eutrophication changed over time as human activities in the catchment evolved. For a majority of the record, hemp retting was the main source of excess nutrients causing eutrophication. However, after AD 1950 there was a decrease in the amount of hemp processed in the catchment, and a significant increase in chemical fertilizer use. This was recorded in sediments collected from each pond, and nutrient inputs remained the main cause of eutrophication at Lucenier until the end of the record. However, at Valette, high N/P ratios, TN and TP values, coupled with more positive $\delta^{15}N$ data indicated livestock manure was the main source of excess nutrients, as opposed to chemical fertilizer at this time. Since Valette is at the base of the watershed, this also suggests livestock agricultural practices have more of an impact than row-cropping practices on nutrient cycling in hydrological systems in the catchment as a whole, after AD 1950.

Changes in land use and land cover have shifted the relative importance of nitrogen and phosphorus as the limiting nutrient at each pond over time. The analysis of N/P ratios revealed that for most of the last 800 years, productivity at both ponds has been primarily limited by the amount of available nitrogen rather than phosphorous. Moreover, after ~AD 1900, the inputs of excess nitrogen from chemical fertilizers applied in areas draining to Lucenier shifted from being nitrogen to phosphorous limited. In contrast, the export of phosphorus from increased manure at Valette has kept that system nitrogen limited. These results suggest that despite being in the same catchment, local activities have resulted in important differences in pond sediment geochemistry and nutrient cycling. Currently, both ponds are being negatively impacted by land use practices in the watershed that have resulted in hypereutrophic conditions. The findings from this study emphasize the importance of understanding the changes in land use/land cover, and how that in turn influences the nutrient dynamics at each pond over a long time period. Understanding the changes in trophic status, and the main drivers for enhanced productivity are particularly important in order to understand the main driving factors for water quality impairment. Instead of assuming phosphorus limitation for the catchment as a whole, the knowledge that each lake is limited by different nutrients may impact the best methods for pond restoration and excess nutrient management at each site in the future.

5.0 SUMMARY AND CONCLUSIONS

An integrated analysis of the interaction of human and environmental systems within the La Chapelle-au-Mans watershed over the past 800 years revealed that there were periods of relative landscape stability interrupted by episodes of increased erosion and nutrient flux to receiving waters. These episodes of increased material flux degraded both the landscape and the pond systems over time. Stable isotope measurements ($\delta^{15}N$ and $\delta^{13}C$) from bulk organic sediment, as well as detailed sedimentological (grain size analysis, sediment yield, and scanning X-ray fluorescence) and biological (palynology) analyses were used to reconstruct the response of small mill and farm ponds to historical changes in land cover/use within the catchment. Ultimately, these periods of increased sediment and nutrient delivery to the pond systems resulted from human activities (agriculture, construction, etc.).

This sediment record, when viewed in the context of additional documentary data such as: historical maps, aerial photos, tax records, agricultural reports, census, parish, and civil records of farm families, records the history of land-cover and land-use change for the region via several proxy responses in the core. Linking apparent periods of landscape instability recorded in the core to historical human activities is an important step towards calibrating changes in sediment sources to and trophic states within the pond system, potentially leading to more precise inferences about nutrient cycling and sediment erosion from sediment records.

Lucenier pond was apparently more impacted by human activity (i.e., land use change) relative to regional climate change. The relative importance of human and climate drivers is supported by available temperature and precipitation data for the study region, and shows minimal direct association among the records. Moreover, changes in the sediment record are coincident with historical human activities, thus the pond systems are sensitive to human activities. For example, both ponds experienced episodes of eutrophication apparently from hemp processing, indicated by increases in algal percentages in both pollen and sediment data. Similarly, the sediment record indicated that land use practices such as increased livestock production and early agricultural mechanization, disrupted landscape systems more than centuries of row cropping, as sediments increased in volume, grain size, magnetic susceptibility, C:N ratios, and pollen accumulation rates at Lucenier pond during time periods of increased livestock productivity.

Nevertheless, these changes in material flux to the ponds following intensification of livestock production were somewhat ameliorated by French and European Union water management and land conservation policies leading to relatively lower modern sediment yields (~7 tons km^{-2} yr^{-1}) after AD 1945. For comparison, sediment yields for stable deciduous woodland landscapes in lowland England and New Hampshire have been reported between 2 to 10 tons km^{-2} yr^{-1} (Likens et al., 1977; Morgan, 1977; Foster et al., 1985). The sediment in Lucenier captures the positive impacts of modern conservation policies on landscape stability.

Historical sediment dynamics in the watershed was explored through mixing model analysis based on scanning XRF ratio data. Comparison of the sediment records at Lucenier pond (upland site) and Valette pond (lowland site) highlight synchronous periods of stability and instability in the landscape, indicated by changes in sediment sources and sediment volumes associated with human activities such as agricultural transitions, deforestation, and construction.

In general, sedimentation yields were higher from the smaller Lucenier catchment where fewer sinks are available to trap sediment (e.g., stream banks and floodplains).

Furthermore, this analysis suggests that the scanning XRF ratio technique can provide useful insight into sediment chemistries and thus changes in land-use in the contributing watershed. Careful attention to particle size and surface effects on XRF results revealed the core sediment size (fine grained) and composition (moderate concentrations of organic matter, silica and iron) allows relatively straightforward interpretation of the core sediment.

Finally, stable isotope ($\delta^{13}C$ and $\delta^{15}N$) and elemental (C, N, and P) analysis of bulk organic sediment revealed numerous episodes of eutrophication have occurred at both pond sites over the past 800 years. Valette, receiving fluxes from the larger catchment, did experience more frequent and prolonged episodes of eutrophication compared to Lucenier. Eutrophication events were primarily driven by human factors such as: hemp processing and fertilizer use in the watershed. Early periods of inferred eutrophication (indicated by increased pollen algal percentages and decreased C:N values) occurred during periods of increased hemp pollen percentages, suggesting hemp was being processed in the ponds, and further, negatively impacted the pond systems. However, after AD 1950 the driving mechanism for eutrophication at both ponds shifted to excess nitrogen from chemical fertilizer. This shift was recorded as increased carbon, nitrogen, and phosphorus concentrations and decreased $\delta^{15}N$. Furthermore, at points during agricultural transitions nitrogen rather than phosphorus seemed to limit pond productivity.

This analysis illustrates how local land-use histories create sensitive proxy records in sediments and provide an opportunity to reconstruct the coupling among human activities, natural environmental changes, and long-term watershed dynamics. In this case, humans have driven most of the changes recorded in the pond sediment. In particular, changes in agricultural practices, such as increased livestock production, resulted in increased erosion from the landscape to the ponds. Further, activities such as hemp processing and chemical fertilization both resulted in episodes of eutrophication. Ultimately, this work provides a framework for predicting future impacts of agricultural policies on the Burgundian landscape, and utilizes a multiproxy approach to landscape history that may be applied to other regions. For example, if governments continue to implement policies that encourage increased farm sizes and herd density, these data suggest potential impacts to landscape and pond systems, such as increased sediment yield and increased eutrophication. Furthermore, this study documents landscape history within a paleoenvironmental context, and in a geographic area (southern Burgundy, France) where studies on environmental archives (i.e. reservoir sediments, tree rings, etc.) are scarce. Therefore, these data are particularly important to formulating sustainable land-management practices and policies to create a more resilient Burgundy in the face of future climate change.

APPENDIX A

Table A- 1. Original AMS data for both pond sites.

UCIAMS #	Sample name	Other ID	$\delta^{13}C$ (‰)	±	fraction Modern	±	$D^{14}C$ (‰)	±	^{14}C age (BP)	±
32635	505-Fr. VAL123VII06-3-278-279				0.9081	0.0014	-91.9	1.4	775	15
32637	507-Fr. LCNRCH221VII06-2-180-181				0.9570	0.0016	-43.0	1.6	355	15
32638	508-Fr. LCNRCH-221VII06-D3-266-267				0.9202	0.0014	-79.8	1.4	670	15
58712	VAL-1-23-VII-06-73-74				0.9834	0.0025	-16.6	2.5	135	25
58713	VAL-1-23-VII-06-D1-104				0.9818	0.0019	-18.2	1.9	145	20
58714	VAL-1-23-VII-06-D3-230-231				0.9431	0.0018	-56.9	1.8	470	20
58715	VAL-1-23-VII-06-D3-254-255				0.9360	0.0018	-64.0	1.8	530	20
58716	VAL-1-23-VII-06-D3-259				0.9326	0.0018	-67.4	1.8	560	20
58717	VAL-1-23-VII-06-D4-316				0.9047	0.0017	-95.3	1.7	805	20
58718	LCNRCH-2-21-VII-06-D1-140-142				0.9772	0.0019	-22.8	1.9	185	20
58719	LCNRCH-2-21-VII-06-D2-233-235				0.9424	0.0022	-57.6	2.2	475	20
58720	LCNRCH-2-21-VII-06-D2-237-238				0.9281	0.0021	-71.9	2.1	600	20
58751	LCNRCH-2-21-VII-06-67-68 .19mgC				0.9759	0.0025	-24.1	2.5	195	25

Table A- 2. Elemental and stable isotope data for Lucenier pond.

Depth (cm)	Year (AD)	Corr. d13C	Corr. d15N	%C	%N	C/N	TP (mgP/g)	TP%	N/P	Suess Corr d13C
0	2006	-27.76	3.44	10.82	1.33	9.66	1.05	0.10	28.09	-25.76
5	1997	-27.65	3.31	10.79	1.27	10.11	1.11	0.11	25.29	-25.99
10	1988	-27.58	3.25	9.70	1.06	10.64	0.99	0.10	23.68	-26.20
15	1975	-27.58	3.20	16.47	1.66	11.64	1.26	0.13	29.15	-26.53
20	1962	-28.07	2.98	11.26	1.07	12.40	0.93	0.09	25.32	-27.26
25	1954	-27.60	3.25	12.32	1.12	12.97	0.68	0.07	36.10	-26.90
30	1946	-27.66	2.78	12.88	1.14	13.69	0.70	0.07	36.01	-27.05
35	1938	-27.40	3.43	7.62	0.71	12.58	0.65	0.06	24.43	-26.87
40	1930	-27.07	4.10	5.15	0.53	11.64	0.67	0.07	17.42	-26.60
45	1922	-27.05	4.46	3.97	0.44	10.87	0.91	0.09	10.70	-26.63
50	1914	-26.81	4.20	3.64	0.42	10.09	0.94	0.09	9.93	-26.43
55	1906	-26.72	4.32	3.54	0.38	10.77	0.92	0.09	9.13	-26.37
60	1898	-26.25	4.02	2.02	0.27	9.11	0.90	0.09	6.49	
62	1895	-26.06	5.14	2.28	0.28	9.55	1.02	0.10	6.08	
65	1890	-26.93	4.16	2.34	0.18	9.35	0.99	0.10	3.98	
67	1887	-27.17	4.97	2.28	0.38	10.08	1.28	0.13	6.59	
70	1882	-27.10	4.54	3.47	0.41	10.03	1.39	0.14	6.52	
73	1877	-27.05	4.74	3.26	0.48	10.53	1.21	0.12	8.70	
75	1874	-27.12	4.86	4.09	0.46	10.39	1.22	0.12	8.36	
79	1867	-27.40	5.14	4.26	0.40	10.60	1.16	0.12	7.70	
80	1866	-27.49	4.46	3.55	0.39	10.86	0.88	0.09	9.66	
84	1859	-27.45	4.70	3.63	0.36	12.12	1.51	0.15	5.22	
85	1858	-27.53	5.13	3.27	0.37	10.52	0.94	0.09	8.69	
89	1851	-27.74	5.18	3.66	0.36	10.65	1.46	0.15	5.43	
90	1850	-27.64	5.11	3.54	0.38	10.96	0.97	0.10	8.70	
94	1844	-27.53	4.91	3.29	0.38	11.36	2.94	0.29	2.86	
95	1842	-27.53	4.91	3.68	0.38	11.25	1.00	0.10	8.37	
99	1836	-27.77	5.13	2.51	0.41	11.01	1.14	0.11	7.97	
104	1828	-27.83	5.12	3.81	0.41	10.74	1.11	0.11	8.24	
109	1820	-27.74	5.21	3.76	0.43	11.52	1.35	0.14	7.09	
114	1812	-27.90	5.13	4.24	0.43	11.24	1.21	0.12	7.90	
119	1804	-28.19	4.90	4.12	0.40	11.62	1.51	0.15	5.87	
124	1796	-28.25	5.10	3.55	0.38	10.90	1.59	0.16	5.27	
130	1786	-28.11	5.04	3.59	0.38	10.96	1.32	0.13	6.39	
135	1778	-27.69	4.95	2.70	0.28	11.17	1.02	0.10	6.13	
140	1770	-28.58	4.81	4.92	0.51	11.21	1.72	0.17	6.57	
145	1733	-28.50	4.50	4.68	0.47	11.55	1.43	0.14	7.29	
150	1696	-28.62	5.31	4.34	0.46	11.10	1.96	0.20	5.14	
155	1658	-28.76	5.08	4.39	0.46	11.11	1.46	0.15	6.98	
160	1621	-28.68	4.91	4.20	0.44	11.22	1.50	0.15	6.41	

162	1606	-28.17	4.77	4.90	0.46	12.51	1.52	0.15	6.67	
167	1569	-28.55	5.37	4.41	0.46	11.21	1.67	0.17	6.08	
172	1532	-28.64	5.23	4.39	0.46	11.16	1.37	0.14	7.38	
177	1495	-28.42	4.57	4.18	0.44	11.11	1.28	0.13	7.57	
182	1481	-28.39	5.06	3.71	0.39	11.22	1.59	0.16	5.36	
187	1467	-28.45	5.13	4.04	0.44	10.79	1.65	0.16	5.86	
192	1452	-28.59	4.98	4.57	0.47	11.44	1.66	0.17	6.18	
197	1438	-28.57	5.07	4.16	0.45	10.82	1.66	0.17	5.96	
202	1424	-28.64	5.50	4.42	0.46	11.15	1.32	0.13	7.78	
207	1410	-28.33	4.64	4.22	0.43	11.40	1.43	0.14	6.66	
212	1396	-28.37	4.61	4.50	0.49	10.67	1.59	0.16	6.84	
217	1382	-28.66	4.97	4.59	0.49	11.00	1.75	0.18	6.14	
222	1368	-28.29	4.78	4.12	0.42	11.52	1.93	0.19	4.77	
227	1354	-28.56	5.17	4.11	0.42	11.54	1.33	0.13	6.88	
232	1340	-28.65	1.39	0.31	0.03	10.47	0.26	0.03	2.90	
235	1333	-28.22	2.50	1.29	0.12	12.88	0.48	0.05	5.37	
236	1331	-28.89	4.78	4.69	0.43	12.75	1.57	0.16	6.04	
240	1325	-29.01	4.47	5.26	0.50	12.36	1.12	0.11	9.76	
241	1324	-29.31	4.30	4.57	0.42	12.56	1.25	0.13	7.48	
245	1318	-29.25	4.59	5.66	0.53	12.40	1.23	0.12	9.59	
246	1317	-29.24	4.56	4.87	0.46	12.45	1.24	0.12	8.12	
250	1311	-29.27	5.30	6.00	0.58	12.08	1.28	0.13	10.01	
255	1304	-29.14	5.55	5.68	0.56	11.90	1.73	0.17	7.13	
260	1297	-28.98	4.72	7.51	0.72	12.07	1.52	0.15	10.55	
265	1290	-28.93	3.83	7.71	0.78	11.48	0.91	0.09	18.93	
270	1282	-28.79	3.96	4.03	0.42	11.18	0.48	0.05	19.49	
275	1275	-28.34	4.34	6.14	0.56	12.85	0.56	0.06	21.91	
280	1268	-28.56	4.17	8.81	0.88	11.64	0.65	0.07	29.81	
285	1261	-28.91	4.16	9.92	0.91	12.67	0.74	0.07	27.37	
290	1254	-28.71	4.03	2.83	0.30	10.92	0.27	0.03	24.82	
295	1247	-28.48	5.60	1.90	0.19	11.45	0.22	0.02	19.19	
300	1240	-28.14	5.19	1.44	0.15	10.97	0.17	0.02	20.14	
305	1232	-28.05	2.79	1.00	0.10	11.37	0.14	0.01	15.94	
310	1225	-28.18	2.55	0.78	0.09	10.52	0.11	0.01	17.77	
315	1218	-28.30	1.97	0.53	0.06	10.38	0.07	0.01	19.02	
320	1211	-28.35	0.69	0.43	0.05	9.48	0.07	0.01	16.34	

Table A- 3. Elemental and stable isotope data for Valette Pond.

Depth (cm)	Year (AD)	Corr.d15N	Corr.d13C	%N	%C	C/N	TP (mgP/g)	TP%	TN/TP	Suess Corr d13C
0	2006	4.68	-29.74	0.62	4.80	9.10	1.41	0.14	9.65	-27.75
5	1996	3.55	-29.87	0.59	4.80	9.41	1.34	0.13	9.78	-28.24
10	1985	3.18	-29.81	0.55	4.71	9.93	1.32	0.13	9.25	-28.51
15	1975	3.45	-29.46	0.51	4.51	10.36	1.29	0.13	8.72	-28.41
20	1965	2.78	-29.35	0.51	4.70	10.67	1.26	0.13	9.03	-28.49
25	1954	2.85	-29.19	0.54	4.85	10.51	1.12	0.11	10.61	-28.49
30	1944	3.04	-29.04	0.54	5.19	11.25	1.09	0.11	10.87	-28.45
35	1934	2.40	-29.00	0.49	4.77	11.36	1.33	0.13	8.15	-28.50
40	1924	3.09	-29.00	0.48	4.44	10.73	1.18	0.12	9.08	-28.57
45	1913	3.25	-28.98	0.58	5.62	11.30	1.19	0.12	10.74	-28.60
50	1903	2.23	-28.80	0.47	4.16	10.39	0.90	0.09	11.50	-28.46
52	1899	3.55	-28.79	0.55	5.30	11.28	1.26	0.13	9.60	-28.46
55	1893	3.64	-28.04	0.41	3.82	10.78	0.93	0.09	9.84	-27.73
60	1883	3.71	-27.82	0.43	3.70	10.09	0.95	0.09	9.96	-27.53
61	1881	3.45	-27.82	0.32	2.69	9.69	0.76	0.08	9.48	-27.53
65	1872	3.62	-27.76	0.34	2.91	9.85	0.82	0.08	9.28	-27.49
69	1864	3.98	-27.69	0.27	2.15	9.38	0.60	0.06	9.89	-27.44
70	1862	3.78	-27.50	0.33	2.84	9.93	0.66	0.07	11.13	-27.25
73	1856	3.99	-27.85	0.29	2.32	9.37	0.77	0.08	8.29	-27.61
77	1839	3.66	-27.93	0.30	2.38	9.18	0.91	0.09	7.32	
82	1817	3.66	-28.22	0.28	2.23	9.28	0.75	0.08	8.22	
86	1799	4.11	-28.15	0.25	2.04	9.38	0.64	0.06	8.80	
90	1781	3.74	-28.21	0.29	2.36	9.46	0.84	0.08	7.69	
94	1764	3.14	-27.34	0.25	1.98	9.28	0.49	0.05	11.25	
99	1743	2.49	-27.35	0.13	1.05	9.33	0.44	0.04	6.63	

103	1732	2.89	-27.05	0.16	1.32	9.82	0.50	0.05	6.95	
116	1699	4.05	-28.52	0.30	2.69	10.37	0.12	0.01	57.68	
120	1689	3.78	-29.20	0.32	2.91	10.51	0.12	0.01	60.00	
124	1678	3.75	-28.95	0.25	2.20	10.09	0.90	0.09	6.28	
132	1657	3.48	-28.28	0.22	2.03	10.67	0.92	0.09	5.34	
137	1645	3.70	-28.30	0.22	1.74	9.31	0.74	0.07	6.48	
142	1632	2.06	-28.43	0.19	1.38	8.54	0.63	0.06	6.67	
147	1619	2.13	-28.71	0.10	0.75	8.81	0.89	0.09	2.49	
152	1606	3.91	-28.77	0.22	1.84	9.60	0.65	0.06	7.64	
157	1593	4.74	-28.50	0.23	1.85	9.42	0.27	0.03	19.01	
162	1580	3.76	-28.78	0.24	2.13	10.22	0.36	0.04	14.91	
167	1567	4.57	-28.34	0.25	2.22	10.44	0.20	0.02	28.09	
172	1554	4.45	-28.11	0.23	1.90	9.56	0.17	0.02	30.26	
177	1541	3.68	-28.33	0.23	2.05	10.24	0.24	0.02	21.25	
182	1528	4.88	-27.23	0.27	2.30	9.94	0.16	0.02	36.22	
187	1515	4.70	-26.92	0.28	2.40	10.08	0.21	0.02	29.15	
192	1502	5.04	-27.45	0.25	2.21	10.19	0.18	0.02	30.69	
195	1495	5.23	-26.64	0.25	2.18	10.29	0.34	0.03	16.07	
200	1482	4.71	-27.08	0.25	2.14	9.98	0.39	0.04	14.24	
205	1469	4.35	-27.19	0.29	2.62	10.38	0.32	0.03	20.43	
210	1456	4.55	-28.29	0.30	2.82	10.79	0.38	0.04	17.82	
215	1443	3.77	-28.91	0.30	2.78	10.84	0.20	0.02	32.89	
220	1437	3.94	-28.62	0.30	2.69	10.34	0.25	0.02	26.87	
225	1432	3.72	-28.11	0.31	2.77	10.54	0.59	0.06	11.52	
230	1426	4.14	-28.11	0.25	2.55	11.84	0.80	0.08	6.93	
235	1420	3.77	-25.85	0.34	3.31	11.40	0.89	0.09	8.37	
240	1414	3.65	-28.48	0.34	3.03	10.29	0.94	0.09	8.03	
245	1401	3.58	-28.28	0.33	2.95	10.37	1.06	0.11	6.90	
250	1386	2.95	-28.49	0.30	2.81	10.85	0.94	0.09	7.10	
260	1357	3.86	-27.28	0.21	1.80	10.08	1.15	0.11	4.02	
265	1343	3.55	-26.63	0.21	1.58	8.96	1.07	0.11	4.22	
270	1328	3.68	-26.69	0.20	1.62	9.24	0.34	0.03	13.31	
275	1314	3.97	-23.66	0.20	1.71	9.75	0.60	0.06	7.60	
280	1299	3.78	-26.92	0.22	1.69	9.10	0.82	0.08	5.83	
285	1284	2.74	-26.33	0.19	1.54	9.54	0.77	0.08	5.40	

Table A- 4. X-ray fluorescence data for Lucenier pond.

Depth (cm)	Year (AD)	Al/Ti	Si/Ti	K/Ti	Fe/Ti	Rb/Ti	Sr/Ti	Zr/Ti
35	1938	0.11	1.11	1.17	7.80	0.36	0.20	0.31
36	1936	0.15	1.45	1.27	6.49	0.31	0.18	0.24
37	1934	0.15	1.37	1.27	6.86	0.32	0.18	0.25
38	1933	0.15	1.36	1.27	6.74	0.32	0.17	0.24
39	1931	0.15	1.26	1.23	6.92	0.33	0.18	0.24
40	1930	0.13	1.14	1.19	7.21	0.34	0.18	0.25
41	1928	0.12	1.02	1.14	7.39	0.34	0.17	0.25
42	1926	0.11	0.94	1.12	7.52	0.33	0.17	0.25
43	1925	0.10	0.92	1.12	7.54	0.32	0.16	0.25
44	1923	0.10	0.91	1.14	7.53	0.31	0.15	0.24
45	1922	0.10	0.90	1.16	7.41	0.29	0.14	0.23
46	1920	0.11	0.97	1.18	7.40	0.29	0.14	0.22
47	1918	0.11	0.98	1.17	7.52	0.29	0.15	0.23
48	1917	0.11	0.99	1.16	7.56	0.29	0.15	0.24
49	1915	0.12	1.02	1.16	7.52	0.28	0.15	0.24
50	1914	0.12	1.09	1.18	7.44	0.28	0.15	0.25
51	1912	0.13	1.12	1.20	7.28	0.28	0.15	0.25
52	1911	0.13	1.15	1.21	7.17	0.27	0.15	0.25
53	1909	0.13	1.17	1.21	7.08	0.27	0.15	0.28
54	1907	0.13	1.21	1.23	6.93	0.27	0.15	0.30
55	1906	0.14	1.24	1.24	6.81	0.26	0.15	0.31
56	1904	0.15	1.24	1.22	6.76	0.26	0.16	0.32
57	1903	0.16	1.34	1.25	6.58	0.25	0.15	0.30
58	1901	0.18	1.42	1.27	6.42	0.23	0.14	0.26
59	1899	0.19	1.44	1.26	6.43	0.22	0.13	0.23
60	1898	0.19	1.49	1.27	6.42	0.21	0.13	0.23
61	1896	0.20	1.50	1.28	6.39	0.21	0.13	0.24
62	1895	0.18	1.42	1.26	6.46	0.21	0.14	0.28
63	1893	0.18	1.40	1.26	6.56	0.21	0.15	0.32
64	1891	0.18	1.41	1.27	6.63	0.22	0.15	0.32
65	1890	0.16	1.30	1.22	6.84	0.23	0.16	0.30
66	1888	0.15	1.25	1.19	6.97	0.23	0.16	0.28
67	1887	0.15	1.25	1.17	7.05	0.24	0.16	0.24
68	1885	0.15	1.20	1.12	7.16	0.24	0.15	0.20
69	1883	0.14	1.16	1.08	7.25	0.25	0.15	0.19
70	1882	0.14	1.18	1.07	7.22	0.25	0.15	0.19
71	1880	0.15	1.20	1.08	7.24	0.25	0.14	0.20
72	1879	0.15	1.21	1.10	7.23	0.25	0.14	0.20
73	1877	0.14	1.22	1.11	7.22	0.26	0.14	0.21

74	1875	0.14	1.22	1.13	7.28	0.27	0.15	0.22
75	1874	0.14	1.22	1.14	7.35	0.28	0.15	0.23
76	1872	0.14	1.20	1.14	7.43	0.28	0.15	0.24
77	1871	0.14	1.23	1.16	7.42	0.29	0.16	0.24
78	1869	0.14	1.20	1.16	7.43	0.29	0.16	0.26
79	1867	0.14	1.22	1.16	7.28	0.29	0.16	0.26
80	1866	0.15	1.26	1.19	7.01	0.28	0.15	0.25
81	1864	0.16	1.29	1.20	6.79	0.27	0.15	0.25
82	1863	0.16	1.27	1.20	6.71	0.27	0.15	0.25
83	1861	0.16	1.32	1.22	6.57	0.26	0.15	0.24
84	1859	0.16	1.30	1.23	6.60	0.25	0.15	0.24
85	1858	0.16	1.29	1.23	6.73	0.26	0.15	0.24
86	1856	0.15	1.25	1.23	6.80	0.27	0.15	0.25
87	1855	0.16	1.29	1.25	6.83	0.27	0.15	0.26
88	1853	0.16	1.30	1.27	6.93	0.27	0.15	0.27
89	1851	0.16	1.32	1.29	6.89	0.28	0.15	0.28
90	1850	0.16	1.31	1.30	6.90	0.28	0.15	0.29
91	1848	0.17	1.37	1.32	6.81	0.28	0.15	0.29
92	1847	0.17	1.39	1.33	6.77	0.28	0.15	0.30
93	1845	0.18	1.44	1.32	6.55	0.27	0.15	0.28
94	1844	0.19	1.50	1.32	6.38	0.25	0.14	0.28
62	1895	0.20	1.55	1.32	6.20	0.23	0.13	0.25
63	1893	0.20	1.55	1.29	6.13	0.22	0.13	0.22
64	1891	0.20	1.52	1.25	6.05	0.20	0.13	0.19
65	1890	0.19	1.46	1.23	6.09	0.21	0.13	0.18
66	1888	0.18	1.41	1.21	6.17	0.21	0.13	0.17
68	1885	0.17	1.40	1.20	6.20	0.22	0.13	0.16
69	1883	0.18	1.42	1.20	6.22	0.22	0.13	0.16
70	1882	0.18	1.44	1.21	6.19	0.22	0.13	0.17
71	1880	0.18	1.46	1.23	6.21	0.23	0.14	0.18
72	1879	0.18	1.48	1.25	6.21	0.23	0.13	0.18
73	1877	0.18	1.47	1.25	6.23	0.24	0.14	0.19
75	1874	0.17	1.45	1.27	6.19	0.25	0.14	0.20
76	1872	0.17	1.45	1.29	6.13	0.25	0.14	0.22
77	1871	0.17	1.43	1.29	6.06	0.26	0.14	0.22
78	1869	0.18	1.44	1.28	5.96	0.26	0.14	0.22
79	1867	0.19	1.50	1.31	5.81	0.25	0.14	0.22
80	1866	0.20	1.55	1.32	5.71	0.25	0.14	0.22
81	1864	0.21	1.60	1.33	5.63	0.24	0.14	0.22
82	1863	0.22	1.68	1.36	5.53	0.24	0.13	0.22
83	1861	0.22	1.71	1.37	5.54	0.24	0.14	0.23
84	1859	0.21	1.68	1.36	5.60	0.24	0.14	0.23

85	1858	0.20	1.63	1.34	5.87	0.25	0.14	0.24
86	1856	0.20	1.63	1.35	5.96	0.26	0.15	0.25
87	1855	0.20	1.59	1.35	6.01	0.26	0.15	0.26
88	1853	0.19	1.57	1.36	6.00	0.26	0.15	0.25
89	1851	0.20	1.59	1.37	6.02	0.27	0.15	0.26
90	1850	0.20	1.61	1.39	5.82	0.26	0.15	0.26
91	1848	0.19	1.56	1.39	5.85	0.27	0.15	0.27
92	1847	0.18	1.53	1.40	5.86	0.27	0.15	0.30
93	1845	0.18	1.49	1.41	5.90	0.28	0.15	0.32
94	1844	0.17	1.43	1.41	5.91	0.28	0.16	0.34
95	1842	0.16	1.40	1.43	5.94	0.29	0.16	0.36
96	1840	0.16	1.37	1.42	5.98	0.29	0.16	0.38
97	1839	0.16	1.37	1.43	6.04	0.30	0.17	0.40
98	1837	0.16	1.42	1.45	6.02	0.30	0.17	0.40
99	1836	0.18	1.48	1.48	5.97	0.30	0.17	0.41
101	1832	0.19	1.54	1.48	5.92	0.29	0.17	0.39
102	1831	0.19	1.59	1.48	5.96	0.29	0.16	0.37
103	1829	0.20	1.61	1.48	5.97	0.28	0.16	0.34
104	1828	0.20	1.63	1.46	5.96	0.28	0.16	0.34
105	1826	0.20	1.62	1.44	6.03	0.28	0.16	0.33
106	1824	0.20	1.63	1.46	6.06	0.28	0.16	0.35
107	1823	0.20	1.65	1.48	5.96	0.28	0.15	0.36
108	1821	0.21	1.67	1.49	5.87	0.28	0.16	0.36
109	1820	0.20	1.64	1.49	5.97	0.29	0.16	0.38
110	1818	0.19	1.60	1.49	6.08	0.30	0.17	0.40
111	1816	0.18	1.54	1.47	6.19	0.30	0.18	0.40
112	1815	0.17	1.48	1.45	6.29	0.31	0.18	0.41
113	1813	0.17	1.47	1.45	6.33	0.31	0.19	0.41
114	1812	0.17	1.45	1.45	6.26	0.31	0.18	0.39
115	1810	0.17	1.47	1.44	6.28	0.30	0.17	0.36
116	1808	0.18	1.51	1.44	6.30	0.30	0.16	0.34
117	1807	0.18	1.51	1.44	6.26	0.30	0.15	0.31
118	1805	0.18	1.50	1.42	6.24	0.30	0.15	0.30
119	1804	0.18	1.54	1.43	6.21	0.30	0.15	0.30
120	1802	0.19	1.58	1.44	6.08	0.29	0.15	0.31
121	1800	0.19	1.55	1.42	6.04	0.29	0.15	0.32
122	1799	0.19	1.57	1.42	6.04	0.29	0.15	0.32
123	1797	0.19	1.60	1.43	6.12	0.29	0.15	0.33
124	1796	0.19	1.60	1.42	6.19	0.29	0.16	0.33
125	1794	0.19	1.58	1.41	6.13	0.29	0.15	0.33
126	1792	0.19	1.60	1.42	5.98	0.28	0.15	0.31
127	1791	0.19	1.60	1.44	5.98	0.28	0.15	0.31

128	1789	0.19	1.56	1.43	5.93	0.28	0.15	0.32
129	1788	0.19	1.52	1.43	5.95	0.28	0.15	0.33
130	1786	0.18	1.50	1.42	5.97	0.28	0.15	0.35
131	1784	0.17	1.48	1.42	5.93	0.28	0.16	0.37
132	1783	0.17	1.47	1.42	6.12	0.28	0.16	0.38
133	1781	0.17	1.50	1.43	6.20	0.28	0.16	0.38
134	1780	0.17	1.54	1.43	6.20	0.28	0.16	0.38
135	1778	0.18	1.56	1.44	6.27	0.28	0.16	0.39
136	1777	0.18	1.56	1.44	6.68	0.27	0.16	0.40
137	1775	0.18	1.53	1.42	6.80	0.27	0.16	0.41
138	1773	0.18	1.53	1.41	6.88	0.27	0.16	0.40
139	1772	0.18	1.54	1.39	7.02	0.26	0.16	0.37
140	1770	0.17	1.50	1.36	7.21	0.27	0.16	0.35
141	1763	0.17	1.46	1.35	7.17	0.27	0.16	0.33
142	1755	0.17	1.49	1.35	7.06	0.28	0.15	0.31
143	1748	0.17	1.46	1.33	7.03	0.28	0.15	0.31
144	1740	0.17	1.42	1.33	6.96	0.28	0.15	0.31
145	1733	0.17	1.44	1.34	6.90	0.28	0.14	0.31
146	1725	0.17	1.43	1.34	6.92	0.27	0.14	0.31
147	1718	0.16	1.41	1.34	6.94	0.27	0.15	0.32
148	1710	0.16	1.42	1.35	7.02	0.27	0.15	0.33
149	1703	0.16	1.42	1.35	6.99	0.27	0.15	0.33
150	1696	0.17	1.43	1.36	6.99	0.27	0.15	0.34
151	1688	0.17	1.45	1.37	6.97	0.28	0.15	0.33
152	1681	0.16	1.44	1.37	6.95	0.27	0.15	0.34
153	1673	0.17	1.47	1.37	6.94	0.27	0.14	0.32
154	1666	0.17	1.49	1.39	7.03	0.27	0.14	0.32
155	1658	0.17	1.50	1.40	7.09	0.27	0.14	0.31
156	1651	0.18	1.53	1.40	7.11	0.27	0.14	0.31
157	1643	0.18	1.59	1.42	7.34	0.27	0.15	0.30
158	1636	0.18	1.61	1.43	7.44	0.27	0.15	0.32
159	1629	0.18	1.62	1.42	7.43	0.27	0.15	0.32
160	1621	0.16	1.53	1.26	7.43	0.28	0.16	0.34
161	1614	0.16	1.54	1.23	7.41	0.28	0.16	0.35
162	1606	0.15	1.43	1.16	7.49	0.27	0.16	0.35
163	1599	0.13	1.32	1.12	7.65	0.28	0.16	0.36
163	1599	0.13	1.24	1.09	7.83	0.29	0.17	0.37
164	1591	0.14	1.27	1.21	7.79	0.29	0.16	0.36
165	1584	0.14	1.22	1.21	7.78	0.29	0.16	0.35
166	1576	0.14	1.27	1.24	7.70	0.29	0.16	0.35
167	1569	0.15	1.29	1.24	7.61	0.29	0.16	0.35
168	1562	0.14	1.31	1.24	7.50	0.28	0.15	0.34

169	1554	0.14	1.33	1.24	7.56	0.28	0.15	0.34
170	1547	0.14	1.41	1.26	7.54	0.28	0.15	0.34
171	1539	0.15	1.45	1.27	7.30	0.28	0.15	0.33
172	1532	0.15	1.49	1.27	7.18	0.27	0.15	0.33
173	1524	0.15	1.54	1.28	7.21	0.28	0.15	0.33
174	1517	0.15	1.51	1.28	7.42	0.28	0.15	0.33
175	1509	0.13	1.43	1.27	7.51	0.29	0.16	0.35
176	1502	0.12	1.37	1.24	7.59	0.30	0.17	0.36
177	1495	0.12	1.35	1.24	7.61	0.30	0.17	0.36
178	1492	0.11	1.27	1.24	7.86	0.31	0.17	0.38
179	1489	0.11	1.23	1.25	7.86	0.32	0.18	0.41
180	1486	0.11	1.20	1.23	8.02	0.32	0.18	0.42
181	1483	0.12	1.22	1.27	8.07	0.32	0.18	0.43
182	1481	0.13	1.20	1.29	8.21	0.32	0.18	0.43
183	1478	0.14	1.25	1.31	7.98	0.31	0.18	0.42
184	1475	0.15	1.29	1.32	7.93	0.30	0.17	0.41
185	1472	0.15	1.30	1.33	7.78	0.29	0.16	0.38
186	1469	0.15	1.30	1.31	7.84	0.29	0.16	0.37
187	1467	0.15	1.30	1.30	7.89	0.29	0.15	0.35
188	1464	0.14	1.27	1.26	8.08	0.29	0.16	0.35
189	1461	0.14	1.26	1.23	8.13	0.29	0.16	0.35
190	1458	0.14	1.28	1.21	8.13	0.29	0.16	0.36
191	1455	0.14	1.27	1.21	8.14	0.29	0.16	0.37
192	1452	0.14	1.28	1.22	8.09	0.28	0.16	0.38
193	1450	0.15	1.33	1.24	7.85	0.28	0.15	0.39
194	1447	0.15	1.33	1.25	7.86	0.28	0.15	0.38
195	1444	0.14	1.28	1.25	7.89	0.28	0.16	0.39
196	1441	0.13	1.23	1.25	7.82	0.28	0.16	0.40
197	1438	0.13	1.19	1.23	7.91	0.28	0.16	0.40
198	1436	0.12	1.14	1.22	8.10	0.28	0.16	0.39
199	1433	0.13	1.15	1.21	7.91	0.27	0.15	0.37
200	1430	0.13	1.18	1.20	7.76	0.27	0.15	0.36
201	1427	0.13	1.16	1.18	7.82	0.28	0.15	0.34
202	1424	0.13	1.14	1.16	7.78	0.29	0.15	0.34
203	1421	0.13	1.12	1.16	7.66	0.29	0.15	0.33
204	1419	0.12	1.09	1.16	7.66	0.29	0.16	0.34
205	1416	0.12	1.08	1.17	7.70	0.30	0.16	0.34
206	1413	0.12	1.11	1.19	7.74	0.29	0.15	0.32
207	1410	0.13	1.18	1.22	7.79	0.28	0.15	0.31
208	1407	0.13	1.20	1.23	7.89	0.27	0.15	0.32
209	1405	0.13	1.20	1.23	8.11	0.27	0.15	0.32
210	1402	0.13	1.17	1.24	8.37	0.28	0.15	0.31

211	1399	0.13	1.16	1.23	8.55	0.28	0.15	0.32
212	1396	0.12	1.12	1.23	8.47	0.30	0.16	0.33
213	1393	0.13	1.13	1.22	8.57	0.30	0.15	0.32
214	1390	0.13	1.15	1.22	8.56	0.30	0.16	0.31
215	1388	0.13	1.15	1.21	8.56	0.30	0.15	0.30
216	1385	0.13	1.17	1.22	8.57	0.29	0.15	0.30
217	1382	0.13	1.18	1.21	8.68	0.29	0.15	0.29
218	1379	0.13	1.17	1.21	8.62	0.29	0.15	0.32
219	1376	0.13	1.20	1.22	8.46	0.29	0.15	0.33
220	1374	0.13	1.21	1.24	8.53	0.29	0.16	0.36
221	1371	0.12	1.22	1.22	8.55	0.29	0.16	0.38
222	1368	0.12	1.22	1.21	8.67	0.30	0.16	0.41
223	1365	0.11	1.21	1.22	8.66	0.29	0.16	0.42
224	1362	0.12	1.23	1.22	8.69	0.29	0.16	0.43
225	1360	0.13	1.32	1.25	8.41	0.29	0.16	0.43
226	1357	0.14	1.36	1.29	8.06	0.29	0.17	0.44
227	1354	0.15	1.39	1.32	7.80	0.29	0.17	0.47
228	1351	0.16	1.46	1.37	7.63	0.30	0.18	0.51
229	1348	0.16	1.51	1.44	7.49	0.32	0.22	0.51
230	1345	0.16	1.57	1.52	7.45	0.35	0.25	0.50
231	1343	0.18	1.81	1.90	7.61	0.41	0.30	0.48
232	1340	0.26	2.87	3.28	7.54	0.57	0.48	0.44
233	1337	0.27	3.18	3.63	7.59	0.61	0.53	0.48
234	1334	0.26	3.13	3.57	7.58	0.59	0.50	0.51
235	1333	0.25	3.03	3.50	7.96	0.57	0.47	0.52
236	1331	0.23	2.80	3.12	8.07	0.50	0.42	0.53
237	1330	0.16	1.77	1.74	8.10	0.32	0.23	0.53
238	1328	0.14	1.42	1.35	8.07	0.27	0.17	0.45
239	1327	0.14	1.45	1.37	8.27	0.28	0.17	0.42
240	1325	0.14	1.46	1.39	7.96	0.29	0.18	0.42
241	1324	0.14	1.44	1.41	7.82	0.30	0.20	0.44
242	1323	0.13	1.39	1.43	7.89	0.31	0.20	0.45
243	1321	0.13	1.36	1.42	7.75	0.31	0.20	0.45
244	1320	0.13	1.30	1.38	7.66	0.30	0.19	0.44
245	1318	0.13	1.30	1.36	7.48	0.30	0.18	0.43
246	1317	0.13	1.26	1.32	7.16	0.29	0.17	0.40
247	1315	0.13	1.25	1.26	6.92	0.27	0.15	0.38
248	1314	0.13	1.29	1.27	7.03	0.28	0.18	0.38
249	1313	0.14	1.40	1.30	7.00	0.29	0.18	0.38
249	1313	0.15	1.49	1.33	6.99	0.28	0.18	0.37
250	1311	0.15	1.52	1.34	7.36	0.29	0.18	0.35
251	1310	0.16	1.58	1.49	7.66	0.34	0.23	0.37

252	1308	0.17	1.61	1.61	7.64	0.36	0.25	0.36
253	1307	0.16	1.58	1.61	7.75	0.38	0.27	0.36
254	1305	0.15	1.48	1.58	7.92	0.38	0.28	0.38
255	1304	0.14	1.45	1.56	7.73	0.38	0.28	0.40
256	1303	0.14	1.37	1.41	7.79	0.34	0.24	0.39
257	1301	0.13	1.31	1.29	7.93	0.31	0.20	0.43
258	1300	0.12	1.24	1.24	7.88	0.29	0.17	0.44
259	1298	0.11	1.20	1.23	8.10	0.30	0.18	0.44
260	1297	0.11	1.17	1.22	8.40	0.29	0.17	0.42
261	1295	0.12	1.19	1.23	8.26	0.28	0.16	0.39
262	1294	0.12	1.18	1.21	8.43	0.27	0.15	0.36
263	1293	0.11	1.17	1.19	8.67	0.26	0.15	0.34
264	1291	0.11	1.16	1.17	8.65	0.25	0.14	0.34
265	1290	0.10	1.17	1.18	8.54	0.25	0.14	0.34
266	1288	0.10	1.11	1.15	8.77	0.26	0.15	0.36
267	1287	0.10	1.06	1.14	8.69	0.26	0.15	0.36
268	1285	0.09	1.01	1.12	8.75	0.26	0.16	0.37
269	1284	0.10	0.96	1.11	8.98	0.26	0.16	0.37
270	1282	0.10	0.91	1.09	9.32	0.27	0.16	0.35
271	1281	0.09	0.87	1.08	9.74	0.27	0.15	0.33
272	1280	0.09	0.79	1.05	10.20	0.27	0.16	0.33
273	1278	0.09	0.74	1.03	10.27	0.28	0.16	0.32
274	1277	0.08	0.68	1.00	10.22	0.28	0.16	0.30
275	1275	0.08	0.66	0.98	9.93	0.27	0.16	0.31
276	1274	0.08	0.67	0.96	9.26	0.27	0.16	0.30
277	1272	0.08	0.72	0.97	8.58	0.25	0.15	0.29
278	1271	0.09	0.79	1.00	8.03	0.24	0.15	0.28
279	1270	0.10	0.87	1.02	7.52	0.23	0.15	0.26
280	1268	0.11	0.95	1.05	7.11	0.23	0.15	0.26
281	1267	0.11	1.01	1.07	6.85	0.22	0.15	0.25
282	1265	0.12	1.02	1.07	6.72	0.22	0.15	0.26
283	1264	0.11	1.02	1.06	6.68	0.22	0.15	0.29
284	1262	0.12	1.05	1.10	6.45	0.23	0.17	0.31
285	1261	0.13	1.13	1.13	6.16	0.23	0.17	0.32
286	1260	0.13	1.18	1.17	5.90	0.23	0.17	0.33
287	1258	0.14	1.25	1.20	5.59	0.22	0.17	0.32
288	1257	0.14	1.26	1.19	5.49	0.22	0.17	0.28
289	1255	0.14	1.24	1.15	5.48	0.21	0.15	0.25
290	1254	0.13	1.13	1.11	5.47	0.21	0.14	0.23
291	1252	0.12	1.12	1.09	5.52	0.21	0.14	0.21
292	1251	0.12	1.08	1.05	5.63	0.21	0.14	0.21
293	1250	0.13	1.11	1.05	5.60	0.21	0.14	0.22

294	1248	0.12	1.12	1.03	5.70	0.22	0.14	0.24
295	1247	0.12	1.10	0.99	5.80	0.22	0.15	0.27
296	1245	0.12	1.07	0.96	5.70	0.22	0.16	0.29
297	1244	0.11	1.04	0.96	5.55	0.22	0.16	0.29
298	1242	0.10	0.96	0.93	5.43	0.22	0.16	0.30
299	1241	0.09	0.90	0.90	5.32	0.22	0.16	0.30
300	1240	0.09	0.91	0.90	5.30	0.22	0.16	0.28
301	1238	0.09	0.89	0.89	5.24	0.21	0.16	0.29
302	1237	0.09	0.92	0.89	4.99	0.21	0.16	0.36
303	1235	0.10	1.04	0.94	4.56	0.20	0.16	0.40
304	1234	0.12	1.16	1.00	3.95	0.20	0.17	0.46
305	1232	0.13	1.25	1.06	3.41	0.20	0.17	0.54
306	1231	0.14	1.33	1.12	3.01	0.20	0.18	0.59
307	1230	0.15	1.42	1.17	2.85	0.19	0.18	0.59
308	1228	0.16	1.51	1.20	2.76	0.19	0.18	0.60
309	1227	0.18	1.62	1.24	2.73	0.19	0.18	0.60
310	1225	0.19	1.75	1.27	2.67	0.18	0.18	0.58
311	1224	0.22	1.94	1.32	2.63	0.18	0.17	0.58
312	1222	0.24	2.06	1.35	2.52	0.18	0.17	0.60
313	1221	0.25	2.14	1.37	2.45	0.18	0.18	0.64
314	1220	0.25	2.27	1.39	2.44	0.18	0.18	0.65
315	1218	0.27	2.36	1.41	2.42	0.19	0.18	0.68
316	1217	0.27	2.39	1.41	2.38	0.19	0.18	0.67
317	1215	0.28	2.43	1.41	2.31	0.19	0.18	0.66
318	1214	0.29	2.49	1.41	2.27	0.19	0.18	0.63
319	1212	0.29	2.45	1.41	2.24	0.19	0.18	0.61
320	1211	0.30	2.45	1.41	2.18	0.19	0.18	0.60
321	1210	0.30	2.46	1.40	2.17	0.18	0.18	0.60
322	1208	0.30	2.50	1.40	2.15	0.18	0.18	0.60
323	1207	0.31	2.54	1.41	2.13	0.19	0.18	0.62
324	1205	0.31	2.59	1.42	2.08	0.19	0.18	0.63
325	1204	0.32	2.62	1.43	2.08	0.19	0.18	0.62
326	1202	0.32	2.66	1.46	2.03	0.19	0.19	0.64
327	1201	0.32	2.67	1.50	1.99	0.19	0.19	0.68
328	1199	0.32	2.72	1.55	1.94	0.19	0.19	0.70
329	1198	0.31	2.76	1.66	1.86	0.21	0.22	0.74
330	1197	0.31	2.85	1.74	1.77	0.22	0.23	0.79
331	1195	0.31	2.95	1.81	1.72	0.23	0.24	0.83
332	1194	0.32	3.01	1.84	1.68	0.23	0.24	0.84
333	1192	0.32	3.07	1.89	1.65	0.24	0.26	0.87
334	1191	0.33	3.14	1.83	1.70	0.23	0.23	0.92
335	1189	0.35	3.23	1.91	1.63	0.25	0.25	0.98

336	1188	0.32	3.20	1.68	1.85	0.23	0.21	0.96

Table A- 5. X-ray fluorescence data for Valette pond.

Depth (cm)	Year (AD)	Al/Ti	Si/Ti	K/Ti	Fe/Ti	Rb/Ti	Sr/Ti	Zr/Ti
25	1954	0.10	1.10	0.87	9.99	0.31	0.19	0.34
26	1952	0.14	1.30	1.17	8.73	0.22	0.13	0.24
27	1950	0.14	1.29	1.18	9.61	0.24	0.15	0.24
28	1948	0.13	1.15	1.11	10.23	0.26	0.15	0.24
29	1946	0.12	1.07	1.11	9.99	0.26	0.14	0.24
30	1944	0.13	1.21	1.11	10.47	0.26	0.14	0.26
31	1942	0.11	1.05	1.08	10.00	0.25	0.15	0.24
32	1940	0.14	0.99	0.97	12.84	0.33	0.19	0.28
33	1938	0.10	1.01	0.98	12.44	0.27	0.19	0.27
34	1936	0.12	1.24	1.13	9.46	0.23	0.14	0.22
35	1934	0.13	1.11	1.13	10.20	0.23	0.13	0.21
36	1932	0.15	1.45	1.26	10.03	0.22	0.12	0.19
37	1930	0.16	1.13	1.13	10.42	0.24	0.13	0.21
38	1928	0.11	1.05	1.11	10.44	0.24	0.14	0.22
39	1926	0.11	1.10	1.17	10.83	0.27	0.16	0.26
40	1924	0.12	1.02	1.09	11.50	0.29	0.16	0.29
41	1922	0.14	1.00	1.11	12.17	0.29	0.16	0.29
42	1920	0.10	0.97	1.09	12.33	0.28	0.16	0.29
43	1918	0.10	0.99	1.13	12.18	0.26	0.15	0.29
44	1915	0.09	0.97	1.09	12.19	0.27	0.15	0.30
45	1913	0.09	1.03	1.19	11.49	0.25	0.13	0.26
46	1911	0.09	0.94	1.22	11.17	0.29	0.14	0.30
47	1909	0.10	0.95	1.14	11.80	0.28	0.14	0.29
48	1907	0.11	1.03	1.17	12.01	0.26	0.13	0.30
49	1905	0.12	1.18	1.31	10.73	0.26	0.12	0.25
50	1903	0.14	1.18	1.30	11.38	0.27	0.14	0.25
51	1901	0.11	1.01	1.16	12.88	0.29	0.16	0.26
52	1899	0.13	1.11	1.24	11.45	0.30	0.16	0.31
53	1897	0.14	1.21	1.38	9.60	0.28	0.14	0.26
54	1895	0.16	1.47	1.44	9.14	0.28	0.14	0.24
55	1893	0.16	1.46	1.41	10.51	0.32	0.16	0.29
56	1891	0.14	1.19	1.36	10.07	0.30	0.16	0.26
57	1889	0.15	1.24	1.40	9.36	0.29	0.16	0.24

58	1887	0.14	1.31	1.42	9.44	0.29	0.13	0.23
59	1885	0.12	0.92	1.25	10.63	0.36	0.17	0.26
60	1883	0.15	1.22	1.41	10.23	0.33	0.16	0.24
61	1881	0.15	1.25	1.40	9.60	0.31	0.15	0.27
62	1878	0.14	1.30	1.39	9.56	0.33	0.16	0.27
63	1876	0.15	1.30	1.44	11.03	0.27	0.13	0.21
64	1874	0.19	1.45	1.47	9.53	0.28	0.14	0.21
65	1872	0.20	1.61	1.53	8.28	0.27	0.13	0.22
66	1870	0.20	1.58	1.48	9.44	0.31	0.15	0.21
67	1868	0.19	1.54	1.45	7.96	0.26	0.11	0.22
68	1866	0.21	1.64	1.60	8.19	0.29	0.13	0.22
69	1864	0.17	1.40	1.45	7.63	0.29	0.13	0.22
70	1862	0.18	1.49	1.53	7.75	0.29	0.13	0.21
71	1860	0.18	1.38	1.47	7.59	0.28	0.13	0.23
72	1858	0.17	1.34	1.42	7.32	0.27	0.12	0.21
73	1856	0.17	1.60	1.05	6.84	0.22	0.10	0.19
74	1852	0.16	0.77	-5.73	0.85	0.11	0.11	0.22
52	1899	0.16	1.48	1.25	8.27	0.31	0.14	0.34
53	1897	0.21	1.69	1.45	6.88	0.29	0.15	0.27
54	1895	0.20	1.70	1.46	6.91	0.28	0.15	0.27
55	1893	0.20	1.74	1.51	6.78	0.28	0.15	0.24
56	1891	0.20	1.73	1.51	6.77	0.29	0.15	0.23
57	1889	0.21	1.71	1.55	7.28	0.31	0.16	0.21
58	1887	0.14	1.02	0.88	7.34	0.40	0.21	0.31
59	1885	0.22	1.89	1.49	6.47	0.32	0.17	0.26
61	1881	0.29	2.14	1.64	6.16	0.28	0.15	0.24
62	1878	0.25	1.94	1.64	6.23	0.28	0.14	0.21
63	1876	0.28	2.04	1.67	6.68	0.28	0.14	0.23
64	1874	0.22	1.93	1.58	7.87	0.31	0.16	0.25
65	1872	0.26	2.07	1.65	7.08	0.30	0.15	0.22
66	1870	0.30	2.27	1.74	6.39	0.28	0.14	0.22
67	1868	0.27	2.15	1.67	6.93	0.27	0.13	0.22
68	1866	0.28	2.14	1.69	6.95	0.29	0.14	0.22
69	1864	0.30	2.17	1.67	5.96	0.27	0.13	0.20
70	1862	0.31	2.17	1.69	5.59	0.27	0.14	0.19
71	1860	0.29	2.07	1.69	5.62	0.26	0.13	0.20
72	1858	0.29	2.07	1.70	5.73	0.26	0.13	0.21
73	1856	0.32	2.23	1.70	5.81	0.27	0.13	0.19
74	1852	0.28	2.06	1.71	6.16	0.28	0.14	0.19
75	1848	0.32	2.26	1.69	5.71	0.26	0.13	0.19
76	1843	0.31	2.16	1.69	5.93	0.27	0.13	0.20
77	1839	0.31	2.14	1.69	6.01	0.26	0.13	0.19

78	1834	0.29	2.09	1.70	6.47	0.28	0.13	0.20
79	1830	0.31	2.14	1.69	6.14	0.27	0.13	0.20
80	1825	0.28	2.09	1.66	6.36	0.26	0.13	0.22
81	1821	0.25	1.87	1.62	6.85	0.28	0.13	0.21
82	1817	0.25	1.85	1.60	6.15	0.26	0.13	0.23
83	1812	0.23	1.79	1.63	6.21	0.26	0.13	0.22
84	1808	0.27	1.92	1.66	6.27	0.26	0.13	0.23
85	1803	0.29	2.00	1.62	6.15	0.25	0.13	0.23
86	1799	0.22	2.04	1.62	6.45	0.26	0.13	0.22
87	1794	0.24	1.97	1.61	6.12	0.27	0.14	0.24
88	1790	0.26	1.86	1.64	6.37	0.27	0.14	0.23
89	1786	0.28	2.03	1.68	6.10	0.27	0.14	0.23
90	1781	0.29	2.11	1.73	6.40	0.26	0.13	0.23
91	1777	0.28	2.09	1.73	6.57	0.28	0.14	0.24
92	1772	0.30	2.16	1.75	6.58	0.28	0.14	0.23
93	1768	0.27	2.05	1.74	6.65	0.28	0.15	0.25
94	1764	0.26	2.03	1.71	6.79	0.30	0.17	0.24
95	1759	0.35	3.18	3.14	6.45	0.49	0.37	0.39
96	1755	0.56	7.34	7.48	4.86	1.00	0.79	1.09
97	1750	0.29	2.50	2.17	5.54	0.35	0.22	0.39
98	1746	0.28	2.48	2.30	6.02	0.37	0.27	0.37
99	1743	0.33	3.13	3.19	6.57	0.54	0.38	0.45
100	1740	0.29	2.70	2.57	6.97	0.43	0.30	0.42
101	1738	0.72	7.22	6.87	5.64	0.88	0.64	0.47
102	1735	0.63	8.90	8.97	5.56	1.31	1.11	0.66
103	1732	0.43	4.85	5.36	7.62	0.78	0.47	0.82
104	1730	0.30	2.59	2.31	5.76	0.34	0.21	0.41
105	1727	0.23	2.05	1.93	10.06	0.29	0.19	0.36
106	1725	0.24	2.60	2.93	8.75	0.41	0.30	0.46
107	1722	0.53	7.73	7.50	6.61	0.93	0.70	0.49
108	1720	0.40	4.34	4.70	7.56	0.67	0.54	0.52
109	1717	0.33	3.06	3.11	6.10	0.46	0.32	0.58
110	1714	0.30	2.97	2.98	6.12	0.44	0.33	0.55
111	1712	0.41	4.61	4.47	5.46	0.66	0.46	0.57
112	1709	0.25	2.29	2.09	5.40	0.34	0.20	0.41
113	1707	0.23	1.81	1.60	7.08	0.24	0.13	0.23
114	1704	0.21	1.77	1.55	7.27	0.24	0.12	0.23
115	1701	0.20	2.07	1.62	7.71	0.24	0.12	0.24
116	1699	0.19	1.77	1.64	8.29	0.25	0.13	0.25
117	1696	0.20	1.61	1.47	7.76	0.23	0.11	0.20
118	1694	0.20	1.53	1.49	7.92	0.24	0.12	0.24
119	1691	0.19	1.65	1.52	7.43	0.24	0.12	0.22

120	1689	0.20	1.69	1.52	7.25	0.25	0.13	0.24
121	1686	0.19	1.55	1.52	6.90	0.23	0.13	0.25
122	1683	0.19	1.55	1.49	6.51	0.25	0.15	0.26
123	1681	0.22	1.82	1.56	5.74	0.23	0.13	0.26
124	1678	0.19	1.64	1.52	5.68	0.24	0.13	0.26
125	1676	0.21	1.72	1.53	5.46	0.24	0.14	0.27
126	1673	0.22	1.91	1.58	5.60	0.23	0.14	0.25
127	1670	0.23	1.90	1.56	5.44	0.23	0.14	0.25
128	1668	0.21	1.87	1.57	5.83	0.24	0.14	0.26
129	1665	0.29	2.18	1.65	5.31	0.25	0.15	0.31
130	1663	0.30	2.31	1.65	4.93	0.24	0.16	0.30
131	1660	0.29	2.35	1.68	5.20	0.25	0.17	0.31
132	1657	0.23	2.11	1.63	5.53	0.24	0.17	0.36
133	1655	0.29	2.06	1.67	5.78	0.23	0.17	0.53
134	1652	0.26	2.15	1.66	5.52	0.23	0.16	0.39
135	1650	0.15	2.08	1.66	5.90	0.25	0.17	0.36
136	1647	0.19	1.91	1.54	6.11	0.24	0.17	0.27
137	1645	0.23	1.97	1.56	6.14	0.24	0.15	0.25
138	1642	0.23	1.88	1.52	5.92	0.24	0.16	0.23
139	1639	0.29	2.02	1.58	5.81	0.24	0.15	0.25
140	1637	0.32	2.13	1.65	5.85	0.25	0.16	0.24
141	1634	0.24	2.18	1.61	5.76	0.23	0.16	0.23
142	1632	0.24	2.07	1.62	5.93	0.25	0.17	0.25
143	1629	0.21	1.75	1.59	6.00	0.26	0.17	0.25
144	1626	0.23	1.90	1.66	6.42	0.25	0.17	0.26
145	1624	0.24	1.92	1.75	6.18	0.26	0.18	0.25
146	1621	0.21	1.72	1.62	6.18	0.25	0.16	0.29
147	1619	0.24	1.91	1.64	6.23	0.25	0.14	0.28
148	1616	0.26	2.12	1.66	6.07	0.25	0.16	0.25
149	1614	0.31	2.40	1.71	5.78	0.25	0.16	0.24
150	1611	0.30	2.18	1.66	6.25	0.25	0.15	0.24
151	1608	0.32	2.42	1.75	6.44	0.26	0.15	0.21
152	1606	0.28	2.13	1.68	5.91	0.25	0.15	0.22
153	1603	0.31	2.38	1.74	5.59	0.25	0.15	0.22
154	1601	0.32	2.44	1.76	5.67	0.25	0.14	0.23
155	1598	0.32	2.46	1.75	5.30	0.24	0.15	0.24
156	1595	0.37	2.59	1.75	5.45	0.25	0.13	0.23
157	1593	0.37	2.54	1.73	5.54	0.25	0.13	0.21
158	1590	0.35	2.45	1.73	5.74	0.22	0.11	0.21
159	1588	0.35	2.53	1.74	5.64	0.24	0.14	0.21
160	1585	0.35	2.44	1.70	5.72	0.23	0.12	0.21
161	1583	0.30	2.29	1.68	5.81	0.24	0.14	0.23

162	1580	0.29	2.24	1.68	6.02	0.24	0.14	0.23
163	1577	0.30	2.20	1.68	5.72	0.25	0.15	0.25
164	1575	0.29	2.18	1.67	5.47	0.25	0.14	0.24
165	1572	0.25	1.95	1.65	5.97	0.27	0.15	0.25
166	1570	0.27	1.99	1.64	5.92	0.26	0.15	0.25
167	1567	0.29	2.15	1.69	7.89	0.23	0.13	0.23
168	1564	0.28	2.25	1.69	6.57	0.25	0.15	0.24
169	1562	0.23	2.16	1.67	8.82	0.23	0.13	0.20
170	1559	0.25	2.06	1.66	7.85	0.26	0.16	0.23
171	1557	0.31	2.37	1.70	5.49	0.25	0.15	0.23
172	1554	0.35	2.51	1.75	5.18	0.26	0.15	0.22
173	1551	0.38	2.60	1.77	5.04	0.25	0.16	0.25
174	1549	0.39	2.71	1.80	5.42	0.25	0.16	0.24
175	1546	0.40	3.18	1.98	2.84	0.25	0.21	0.46
176	1544	0.36	2.86	2.07	3.64	0.30	0.22	0.54
177	1541	0.32	2.55	1.78	4.92	0.26	0.17	0.27
178	1539	0.27	2.18	1.66	5.67	0.24	0.17	0.26
179	1536	0.25	2.10	1.68	7.55	0.24	0.18	0.26
180	1533	0.26	2.24	1.67	7.08	0.24	0.17	0.25
181	1531	0.25	2.14	1.64	7.20	0.24	0.16	0.24
182	1528	0.23	2.05	1.64	7.18	0.26	0.17	0.25
183	1526	0.25	2.08	1.67	7.93	0.25	0.15	0.26
184	1523	0.26	2.04	1.65	7.95	0.26	0.16	0.28
185	1520	0.27	2.13	1.70	7.55	0.25	0.16	0.25
186	1518	0.23	2.06	1.62	7.13	0.26	0.15	0.28
187	1515	0.28	2.27	1.69	6.43	0.24	0.14	0.27
188	1513	0.25	2.12	1.71	7.37	0.24	0.15	0.30
189	1510	0.24	2.10	1.68	6.44	0.24	0.15	0.27
190	1508	0.26	2.15	1.63	5.74	0.23	0.15	0.30
191	1505	0.27	2.14	1.61	5.74	0.24	0.16	0.28
192	1502	0.28	2.26	1.65	5.95	0.23	0.14	0.29
193	1500	0.20	1.70	1.54	6.63	0.23	0.13	0.31
194	1497	0.16	1.75	1.55	7.10	0.22	0.14	0.31
195	1495	0.19	1.67	1.40	5.88	0.23	0.14	0.26
196	1492	0.16	1.80	1.52	7.61	0.25	0.16	0.24
197	1489	0.18	1.85	1.67	9.38	0.27	0.16	0.28
198	1487	0.18	1.85	1.60	8.91	0.24	0.15	0.25
199	1484	0.19	1.76	1.59	8.69	0.24	0.15	0.27
200	1482	0.19	1.76	1.58	8.50	0.24	0.14	0.28
201	1479	0.21	1.70	1.57	8.70	0.26	0.16	0.29
202	1477	0.15	1.41	1.51	7.62	0.27	0.15	0.29
203	1474	0.13	1.21	1.38	7.99	0.24	0.14	0.34

204	1471	0.17	1.51	1.44	7.84	0.25	0.14	0.36
205	1469	0.16	1.53	1.53	8.38	0.26	0.16	0.32
206	1466	0.17	1.71	1.52	10.17	0.25	0.16	0.28
207	1464	0.21	1.79	1.50	8.04	0.23	0.16	0.28
208	1461	0.23	1.98	1.56	7.45	0.23	0.17	0.28
209	1458	0.24	1.82	1.49	7.11	0.26	0.18	0.30
210	1456	0.21	1.73	1.47	6.05	0.25	0.20	0.28
211	1453	0.23	1.79	1.45	7.46	0.25	0.15	0.26
212	1451	0.22	1.81	1.44	8.01	0.23	0.13	0.23
213	1448	0.23	1.89	1.51	5.76	0.24	0.15	0.25
214	1446	0.21	1.73	1.46	6.89	0.23	0.15	0.24
215	1443	0.19	1.65	1.46	7.20	0.25	0.14	0.24
216	1442	0.20	1.68	1.47	7.14	0.23	0.14	0.26
217	1441	0.21	1.78	1.51	7.20	0.23	0.13	0.24
218	1440	0.21	1.75	1.47	6.73	0.24	0.13	0.23
219	1438	0.24	1.91	1.52	6.64	0.28	0.14	0.21
220	1437	0.18	1.65	1.41	6.16	0.24	0.15	0.26
221	1436	0.18	1.58	1.36	5.99	0.23	0.14	0.31
222	1435	0.20	1.70	1.40	6.29	0.23	0.13	0.24
223	1434	0.22	1.81	1.44	6.29	0.22	0.13	0.25
224	1433	0.20	1.68	1.41	5.43	0.22	0.13	0.24
225	1432	0.17	1.63	1.42	6.83	0.23	0.13	0.25
226	1430	0.21	1.77	1.48	8.70	0.23	0.13	0.27
227	1429	0.19	1.69	1.46	7.41	0.23	0.13	0.28
228	1428	0.19	1.61	1.44	7.98	0.21	0.12	0.28
229	1427	0.18	1.54	1.40	8.15	0.23	0.12	0.30
230	1426	0.17	1.51	1.46	7.32	0.23	0.13	0.30
231	1425	0.15	1.52	1.48	7.33	0.24	0.14	0.36
232	1424	0.19	1.58	1.53	7.26	0.23	0.15	0.41
233	1422	0.20	1.78	1.57	7.34	0.24	0.14	0.28
234	1421	0.18	1.43	1.37	8.39	0.22	0.11	0.28
235	1420	0.18	1.56	1.43	9.18	0.22	0.12	0.31
236	1419	0.17	1.48	1.40	9.57	0.21	0.12	0.24
237	1418	0.17	1.52	1.35	13.79	0.20	0.10	0.25
238	1417	0.17	1.54	1.39	12.59	0.22	0.11	0.24
239	1415	0.18	1.64	1.43	12.28	0.23	0.12	0.29
240	1414	0.14	1.27	1.35	9.39	0.26	0.14	0.29
241	1413	0.14	1.18	1.34	8.71	0.24	0.12	0.26
242	1412	0.17	1.39	1.41	9.23	0.24	0.13	0.23
243	1411	0.20	1.56	1.50	9.42	0.24	0.13	0.24
244	1410	0.18	1.53	1.50	10.23	0.26	0.14	0.29
245	1401	0.17	1.51	1.43	9.85	0.27	0.14	0.29

246	1398	0.15	1.34	1.44	10.35	0.24	0.13	0.28
247	1395	0.14	1.26	1.44	10.10	0.25	0.14	0.29
248	1392	0.12	1.10	1.38	9.61	0.25	0.14	0.30
249	1389	0.16	1.37	1.42	8.56	0.23	0.14	0.29
250	1386	0.17	1.52	1.48	8.69	0.24	0.13	0.32
251	1383	0.19	1.61	1.52	8.49	0.24	0.14	0.32
252	1380	0.17	1.40	1.38	7.94	0.24	0.14	0.29
253	1377	0.17	1.58	1.51	8.14	0.27	0.15	0.30
254	1375	0.28	2.76	2.99	8.66	0.49	0.31	0.35
255	1372	0.30	3.15	3.23	9.69	0.46	0.37	0.47
256	1369	0.37	3.78	3.46	10.15	0.47	0.33	0.47
257	1366	0.34	3.51	3.04	9.85	0.43	0.34	0.38
258	1363	0.27	2.57	2.56	9.35	0.34	0.25	0.40
259	1360	0.37	3.80	3.98	7.86	0.53	0.48	0.48
260	1357	0.42	4.26	4.49	5.74	0.62	0.49	1.38
261	1354	0.31	2.76	2.29	5.76	0.34	0.23	0.45
262	1351	0.24	2.20	1.83	6.13	0.26	0.16	0.32
263	1348	0.23	1.82	1.64	7.72	0.24	0.15	0.28
264	1345	0.31	2.23	1.77	5.94	0.26	0.16	0.29
265	1343	0.29	2.24	1.72	6.18	0.25	0.14	0.24
266	1340	0.26	1.92	1.61	6.66	0.24	0.12	0.19
267	1337	0.24	1.75	1.55	6.20	0.24	0.12	0.19
268	1334	0.28	1.99	1.58	5.86	0.23	0.11	0.16
269	1331	0.31	2.18	1.64	6.24	0.24	0.12	0.21
270	1328	0.35	2.28	1.67	6.51	0.25	0.14	0.19
271	1325	0.31	2.31	1.72	5.83	0.25	0.16	0.24
272	1322	0.28	2.19	1.67	6.84	0.24	0.14	0.24
273	1319	0.28	2.27	1.71	6.19	0.24	0.15	0.24
274	1316	0.27	2.15	1.64	6.43	0.24	0.14	0.26
275	1314	0.33	2.59	1.80	5.09	0.25	0.18	0.31
276	1311	0.30	2.53	1.99	4.77	0.27	0.18	0.52
277	1308	0.25	1.88	1.55	7.15	0.23	0.12	0.20
278	1305	0.28	2.06	1.61	7.68	0.23	0.13	0.21
279	1302	0.28	1.96	1.61	9.56	0.22	0.13	0.18
280	1299	0.27	1.95	1.59	8.49	0.21	0.11	0.15
281	1296	0.27	1.95	1.53	6.97	0.23	0.12	0.16
282	1293	0.33	2.65	1.78	5.25	0.25	0.15	0.26
283	1290	0.27	2.20	1.58	6.12	0.22	0.12	0.17
284	1287	0.26	1.88	1.53	7.22	0.23	0.12	0.17
285	1284	0.26	1.93	1.58	6.93	0.22	0.12	0.18
286	1282	0.24	1.81	1.47	10.06	0.19	0.11	0.14
287	1279	0.27	1.97	1.51	6.17	0.21	0.11	0.16

288	1276	0.26	1.83	1.37	5.36	0.19	0.12	0.14
289	1273	0.28	1.93	1.37	5.31	0.20	0.14	0.17
290	1270	0.24	1.75	1.44	7.11	0.23	0.14	0.18
230	1426	0.13	2.46	2.83	10.98	0.53	0.39	0.43
231	1425	0.29	3.19	2.96	10.54	0.43	0.31	0.44
232	1424	0.39	3.95	4.05	8.48	0.54	0.44	0.65
233	1422	0.34	2.57	1.92	5.65	0.27	0.17	0.33
234	1421	0.27	2.14	1.71	5.78	0.28	0.18	0.29
235	1420	0.38	2.69	1.83	5.85	0.25	0.16	0.26
236	1419	0.35	2.37	1.70	5.09	0.25	0.14	0.19
237	1418	0.33	2.35	1.65	5.40	0.24	0.12	0.16
238	1417	0.32	2.14	1.65	6.07	0.25	0.13	0.22
239	1415	0.35	2.44	1.76	5.64	0.26	0.16	0.22
240	1414	0.37	2.92	1.90	4.68	0.25	0.17	0.26
242	1412	0.28	2.44	1.81	7.98	0.24	0.14	0.26
243	1411	0.28	2.35	1.77	6.49	0.25	0.15	0.26
244	1410	0.28	2.25	1.67	5.29	0.22	0.15	0.25
245	1401	0.35	2.74	1.77	4.67	0.25	0.18	0.28
246	1398	0.42	3.48	2.12	3.10	0.28	0.21	0.49
247	1395	0.31	2.30	1.75	4.77	0.26	0.15	0.33
248	1392	0.28	2.08	1.62	6.17	0.23	0.14	0.21
250	1386	0.33	2.37	1.74	5.58	0.25	0.14	0.20
251	1383	0.30	2.24	1.65	5.47	0.22	0.12	0.19
252	1380	0.30	2.15	1.65	6.47	0.23	0.12	0.16
253	1377	0.28	1.99	1.59	6.21	0.25	0.13	0.18
254	1375	0.28	2.10	1.61	6.38	0.25	0.14	0.20
255	1372	0.30	2.28	1.66	6.26	0.23	0.13	0.18
256	1369	0.30	2.18	1.61	6.27	0.23	0.12	0.17
258	1363	0.33	2.45	1.68	4.93	0.24	0.13	0.18
259	1360	0.32	2.46	1.69	4.10	0.25	0.15	0.23
260	1357	0.31	2.19	1.58	4.97	0.21	0.12	0.17
261	1354	0.33	2.24	1.56	4.91	0.22	0.14	0.16
262	1351	0.33	2.27	1.55	5.21	0.21	0.13	0.16
263	1348	0.33	2.27	1.58	5.87	0.22	0.14	0.16
264	1345	0.34	2.30	1.62	5.48	0.23	0.14	0.16
266	1340	0.31	2.15	1.56	5.24	0.24	0.13	0.19
267	1337	0.30	2.10	1.59	5.54	0.24	0.13	0.19
268	1334	0.34	2.41	1.66	4.94	0.23	0.14	0.22
269	1331	0.30	2.22	1.67	4.78	0.25	0.14	0.23
270	1328	0.30	2.21	1.64	4.82	0.24	0.14	0.23
271	1325	0.28	2.09	1.64	5.58	0.24	0.15	0.26
272	1322	0.32	2.24	1.65	5.24	0.24	0.15	0.24

274	1316	0.33	2.40	1.59	4.26	0.24	0.19	0.21
275	1314	0.30	2.22	1.62	5.32	0.23	0.12	0.20
276	1311	0.28	2.23	1.63	5.36	0.24	0.13	0.22
277	1308	0.22	1.85	1.56	6.16	0.23	0.13	0.25
278	1305	0.20	1.71	1.54	7.39	0.24	0.14	0.29
279	1302	0.27	2.01	1.68	6.32	0.25	0.15	0.30
280	1299	0.30	2.21	1.68	4.95	0.23	0.13	0.21
281	1296	0.33	2.48	1.76	4.77	0.24	0.14	0.21
283	1290	0.29	2.21	1.66	4.95	0.23	0.14	0.22
284	1287	0.29	2.21	1.70	5.16	0.25	0.14	0.23
285	1284	0.30	2.15	1.65	5.79	0.23	0.14	0.27
286	1282	0.29	2.15	1.59	5.17	0.23	0.13	0.19
287	1279	0.40	2.43	1.59	4.93	0.22	0.12	0.16
288	1276	0.35	2.45	1.72	4.56	0.24	0.16	0.25
289	1273	0.32	2.27	1.61	4.88	0.22	0.13	0.21
291	1267	0.36	2.31	1.52	4.83	0.21	0.12	0.12
292	1264	0.37	2.26	1.50	5.06	0.20	0.12	0.10
293	1261	0.36	2.42	1.55	4.76	0.20	0.13	0.16
294	1258	0.41	2.43	1.61	5.40	0.24	0.11	0.12
295	1255	0.39	2.39	1.57	5.07	0.21	0.12	0.16
296	1253	0.36	2.14	1.44	6.03	0.20	0.11	0.09
297	1250	0.34	2.26	1.44	4.64	0.18	0.12	0.15
299	1244	0.34	2.22	1.42	4.52	0.18	0.12	0.19
300	1241	0.36	2.32	1.46	4.66	0.19	0.12	0.19
301	1238	0.33	2.17	1.41	4.50	0.19	0.13	0.19
302	1235	0.31	2.13	1.45	4.67	0.19	0.12	0.20
303	1232	0.27	2.29	1.81	6.19	0.26	0.15	0.28

Table A- 6. Magnetic susceptibility data for Lucenier pond.

Depth (cm)	MS
35	0.50
36	0.60
37	0.63
38	0.80
39	0.85
40	0.75
41	0.78
42	0.75

43	0.83
44	0.83
45	0.88
46	0.80
47	0.73
48	0.83
49	0.63
50	0.85
51	1.03
52	0.98
53	1.05
54	0.85
55	0.98
56	1.68
57	2.03
58	2.10
59	2.18
60	2.80
61	3.45
62	3.75
63	3.66
64	4.34
65	3.38
66	2.24
67	1.73
68	1.75
69	1.60
70	1.55
71	1.53
72	1.38
73	1.39
74	1.40
75	1.36
76	1.23
77	1.39
78	1.41
79	1.52
80	1.28
81	1.50
82	1.79
83	1.84
84	2.00
85	1.84
86	1.58
87	1.19
88	1.21
89	1.41
90	1.50
91	1.41
92	1.39

93	1.48
94	1.44
95	1.48
96	1.48
97	1.45
98	1.33
99	1.48
100	1.30
101	1.28
102	1.20
103	1.28
104	1.33
105	1.28
106	0.98
107	0.80
108	1.15
109	1.25
110	1.10
111	1.28
112	1.35
113	1.25
114	1.05
115	0.95
116	1.00
117	1.05
118	1.20
119	1.18
120	1.15
121	1.18
122	1.15
123	1.13
124	1.03
125	1.20
126	1.20
127	0.90
128	0.70
129	1.58
130	1.65
131	1.43
132	1.55
133	1.78
134	1.73
135	1.63
136	1.50
137	1.50
138	1.60
139	1.60
140	1.83
141	1.13
142	1.05

143	1.08
144	0.85
145	0.83
146	1.08
147	1.15
148	1.15
149	1.05
150	1.10
151	1.13
152	1.15
153	1.18
154	1.30
155	1.20
156	1.15
157	1.15
158	1.18
159	1.23
160	1.28
161	1.16
162	0.98
163	1.18
164	1.29
165	1.00
166	0.99
167	1.08
168	0.75
169	0.91
170	0.69
171	0.73
172	1.08
173	1.10
174	1.15
175	0.85
176	0.80
177	0.95
178	1.05
179	1.05
180	0.93
181	0.80
182	1.00
183	1.20
184	1.25
185	1.25
186	1.25
187	1.25
188	0.85
189	1.20
190	1.20
191	1.28
192	1.15

193	1.25
194	1.15
195	1.08
196	1.15
197	1.18
198	1.05
199	1.10
200	1.10
201	0.75
202	1.20
203	1.15
204	1.30
205	1.25
206	1.40
207	1.35
208	1.35
209	1.05
210	0.73
211	1.20
212	1.30
213	1.50
214	1.38
215	1.35
216	1.30
217	1.30
218	1.25
219	1.40
220	1.33
221	1.40
222	1.40
223	1.30
224	1.33
225	1.25
226	1.28
227	1.40
228	1.40
229	1.55
230	1.53
231	1.40
232	1.20
233	1.23
234	1.10
235	1.10
236	1.15
237	0.98
238	0.70
239	0.93
240	1.00
241	1.05
242	1.05

243	0.93
244	0.80
245	0.78
246	0.85
247	0.70
248	0.55
249	0.51
250	1.41
251	0.67
252	0.28
253	0.42
254	0.87
255	0.76
256	0.76
257	0.72
258	0.67
259	0.93
260	1.06
261	1.17
262	1.09
263	0.98
264	0.92
265	0.91
266	0.88
267	0.87
268	0.79
269	0.65
270	0.56
271	0.75
272	0.79
273	0.69
274	0.61
275	0.82
276	0.71
277	0.81
278	0.95
279	1.28
280	0.95
281	0.59
282	0.72
283	0.73
284	0.38
285	0.23
286	0.07
287	0.07
288	0.14
289	0.12
290	0.11
291	0.18
292	0.18

293	0.21
294	0.20
295	0.14
296	0.11
297	0.10
298	0.09
299	0.13
300	0.19
301	0.19
302	0.18
303	0.17
304	0.16
305	0.20
306	0.19
307	0.25
308	0.21
309	0.25
310	0.24
311	0.21
312	0.23
313	0.29
314	0.30
315	0.40
316	0.31
317	0.26
318	0.16
319	0.09
320	0.01
321	-0.01
322	0.01

Table A- 7. Magnetic susceptibility data for Valette pond.

depth(cm)	Real(10^-5)
25	0.3
26	0.4
27	0.33
28	0.4
29	0.48
30	0.45
31	0.45
32	0.33

33	0.3
34	0.5
35	0.68
36	0.63
37	0.63
38	0.63
39	0.6
40	0.65
41	0.78
42	0.68
43	0.7
44	0.63
45	0.73
46	0.8
47	0.63
48	0.93
49	0.93
50	0.63
51	0.68
52	0.565
53	0.85625
54	1.05
55	0.98125
56	1.0625
57	1.075
58	0.9875
59	1.14
60	1.3775
61	1.44
62	1.3275
63	0.64
64	1.065
65	1.315
66	1.2625
67	1.4775
68	1.415
69	1.6275
70	1.4375
71	1.3
72	1.25875
73	1.4

74	1.5
75	1.525
76	1.6
77	1.5875
78	1.6
79	1.5
80	1.6
81	1.575
82	1.575
83	1.55
84	1.6
85	1.575
86	1.65
87	1.8
88	1.7625
89	1.775
90	1.7
91	1.7
92	1.625
93	1.4
94	1.1125
95	0.3
96	0.1
97	0.375
98	0.65
99	1.075
100	0.7625
101	0.325
102	0.175
103	0.775
104	1.375
105	0.95
106	0.55
107	0.325
108	0.6
109	0.8
110	0.9
111	0.25
112	0.95
113	0.9
114	1.05

115	1.25
116	1
117	0.8
118	0.65
119	0.6
120	0.575
121	0.675
122	0.675
123	0.525
124	0.5
125	0.45
126	0.525
127	0.525
128	0.2125
129	0.85
130	1.25
131	0.975
132	1.125
133	1.35
134	1.425
135	1.375
136	1.675
137	1.8
138	1.525
139	1.425
140	1.65
141	1.5
142	1.425
143	1.25
144	1.675
145	1.55
146	1.425
147	2.2
148	1.825
149	1.925
150	1.8
151	1.775
152	1.675
153	1.6
154	1.525
155	1.65

156	1.7
157	1.45
158	1.45
159	1.45
160	1.25
161	1.5
162	1.425
163	1.55
164	1.75
165	1.575
166	1.775
167	1.9
168	1.95
169	2.4
170	2.3
171	1.725
172	1.85
173	1.9
174	1.975
175	2.075
176	1.65
177	1.6
178	1.725
179	2.25
180	2.275
181	2.075
182	1.95
183	2.025
184	1.975
185	1.7
186	1.675
187	1.775
188	1.825
189	1.75
190	1.725
191	1.75
192	1.425
193	1.325
194	1.05
195	1.5075
196	1.735

197	1.8125
198	1.7825
199	1.8075
200	1.76
201	1.695
202	1.68
203	1.5475
204	1.5575
205	1.5725
206	1.7875
207	1.9625
208	1.89
209	1.91
210	1.76
211	1.1825
212	1.3425
213	1.37
214	1.3075
215	1.2525
216	1.285
217	1.27
218	1.2
219	1.175
220	1.19
221	1.1075
222	0.9825
223	0.8925
224	0.77
225	0.955
226	1.07
227	1.2825
228	1.3825
229	1.2675
230	0.685
231	0.6375
232	1.130625
233	1.55875
234	1.7775
235	1.9975
236	2.120625
237	2.35125

238	2.22125
239	1.96625
240	1.0175
241	1.1225
242	1.185
243	1.275
244	1.345
245	1.5325
246	1.6425
247	1.56
248	1.1825
249	1.0475
250	1.095
251	1.1425
252	1.16
253	1.1425
254	1.085
255	1.08
256	0.6175
257	0.66
258	0.94625
259	1.35
260	1.50875
261	1.48875
262	1.52375
263	1.595
264	1.664375
265	2.30625
266	2.05625
267	1.77375
268	1.50125
269	1.945
270	2.11625
271	2.235
272	2.155
273	2.414375
274	2.53625
275	2.495
276	2.1975
277	1.99
278	2.44625

279	2.57875
280	2.435
281	2.15375
282	2.21625
283	2.540625
284	2.38375
285	2.23125
286	2.0925
287	2.36125
288	2.38625
289	2.4275
290	2.3825
291	2.3175
292	2.41625
293	2.59875
294	2.5675
295	2.335
296	2.2425
297	2.24875
298	2.04125
299	2.015
300	1.96125
301	2.365
302	2.91375
303	3.355
304	3.1575
305	2.785
306	3.055
307	3.6325
308	3.4575
309	3.41
310	3.635
311	4.4675
312	4.35
313	4.3425
314	4.2075
315	4.0775
316	1.74
317	0.14

Table A- 8. SGS Minerals ICP-MS data for select intervals at Lucenier pond.

ANALYTE		WtKg	Ag	Al	As	Ba	Be
METHOD		WGH79	ICP40B	ICP40B	ICP40B	ICP40B	ICP40B
DETECTION		0.001	2	0.01	3	1	0.5
UNITS	depth	kg	ppm	%	ppm	ppm	ppm
LCNRCH-2-21-VII-06-Surf 40-41 cm	40	0.002	<2	8.28	23	538	9.8
DUP-LCNRCH-2-21-VII-06-Surf 40-41 cm	40	<0.001	<2	8.32	22	527	9.8
LCNRCH-2-21-VII-06-Surf 46-47 cm	46	0.004	<2	8.36	22	548	9.5
LCNRCH-2-21-VII-06-Surf 54-55 cm	54	0.004	<2	7.96	23	524	8.9
LCNRCH-2-21-VII-06-Surf 63-64 cm	63	0.003	<2	8.53	22	527	8.8
LCNRCH-2-21-VII-06-D1 81-82 cm	81	0.002	<2	8.11	20	521	8.7
LCNRCH-2-21-VII-06-D1 87-88 cm	87	0.001	<2	8.07	23	558	9.1
LCNRCH-2-21-VII-06-D1 94-95 cm	94	0.001	<2	8	22	618	9
LCNRCH-2-21-VII-06-D1 108-109 cm	108	0.001	<2	8.2	23	584	8.7

LCNRCH-2-21-VII-06-D1 113-114 cm	113	0.001	<2	7.55	24	577	7.9
LCNRCH-2-21-VII-06-D1 127-128 cm	127	0.002	<2	7.97	22	567	9
LCNRCH-2-21-VII-06-D1 134-135 cm	134	0.002	<2	7.6	21	575	8.6
LCNRCH-2-21-VII-06-D1 147-148 cm	147	0.001	<2	7.79	22	586	8.9
LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	<2	7.67	21	578	8.5
DUP-LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	<2	7.56	20	585	8.7
LCNRCH-2-21-VII-06-D2 181-182 cm	181	0.001	<2	7.34	23	597	8.8
LCNRCH-2-21-VII-06-D2 186-187 cm	186	0.001	<2	7.77	22	592	8.6
LCNRCH-2-21-VII-06-D2 202-203 cm	202	0.001	<2	7.43	23	532	8.8
LCNRCH-2-21-VII-06-D2 235-236 cm	235	0.003	<2	5.42	16	961	4.1
LCNRCH-2-21-VII-06-D2 239-240 cm	239	0.002	<2	7.06	20	587	7.4
LCNRCH-2-21-VII-06-D3 255-256 cm	255	0.005	<2	7.87	20	602	8.5
LCNRCH-2-21-VII-06-D3 269-270 cm	269	0.004	<2	7.59	20	533	8.3
LCNRCH-2-21-VII-06-D3 289-290 cm	289	0.004	<2	6.57	16	711	5.9
LCNRCH-2-21-VII-06-D3 295-296 cm	295	0.002	<2	8.15	21	516	8.7

LCNRCH-2-21-VII-06-D3 298-299 cm	298	0.002	<2	7.6	15	479	7.7
LCNRCH-2-21-VII-06-D3 327-328 cm	327	0.005	<2	6.36	15	697	5.6
LCNRCH-2-21-VII-06-D3 336-337 cm	336	0.015	<2	5.86	13	696	5
DUP-LCNRCH-2-21-VII-06-D3 336-337 cm	336	<0.001	<2	5.7	13	662	4.8
average				7.524642857	20.25	592.0714286	8.075

ANALYTE		WtKg	Bi	Ca	Cd	Co	Cr
METHOD		WGH79	ICP40B	ICP40B	ICP40B	ICP40B	ICP40B
DETECTION		0.001	5	0.01	1	1	1
UNITS	depth	kg	ppm	%	ppm	ppm	ppm
LCNRCH-2-21-VII-06-Surf 40-41 cm	40	0.002	<5	0.27	<1	15	52
DUP-LCNRCH-2-21-VII-06-Surf 40-41 cm	40	<0.001	<5	0.28	<1	15	46
LCNRCH-2-21-VII-06-Surf 46-47 cm	46	0.004	6	0.27	<1	15	47
LCNRCH-2-21-VII-06-Surf 54-55 cm	54	0.004	<5	0.25	<1	14	46
LCNRCH-2-21-VII-06-Surf 63-64 cm	63	0.003	<5	0.28	<1	11	49
LCNRCH-2-21-VII-06-D1 81-82 cm	81	0.002	<5	0.24	<1	13	56

LCNRCH-2-21-VII-06-D1 87-88 cm	87	0.001	<5	0.23	<1	14	67
LCNRCH-2-21-VII-06-D1 94-95 cm	94	0.001	<5	0.25	<1	15	49
LCNRCH-2-21-VII-06-D1 108-109 cm	108	0.001	<5	0.25	<1	14	41
LCNRCH-2-21-VII-06-D1 113-114 cm	113	0.001	<5	0.26	<1	15	45
LCNRCH-2-21-VII-06-D1 127-128 cm	127	0.002	<5	0.22	<1	14	47
LCNRCH-2-21-VII-06-D1 134-135 cm	134	0.002	<5	0.24	<1	13	40
LCNRCH-2-21-VII-06-D1 147-148 cm	147	0.001	<5	0.23	<1	15	56
LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	<5	0.2	<1	13	47
DUP-LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	<5	0.2	<1	13	43
LCNRCH-2-21-VII-06-D2 181-182 cm	181	0.001	<5	0.2	<1	13	46
LCNRCH-2-21-VII-06-D2 186-187 cm	186	0.001	<5	0.23	<1	14	47
LCNRCH-2-21-VII-06-D2 202-203 cm	202	0.001	<5	0.19	<1	14	50
LCNRCH-2-21-VII-06-D2 235-236 cm	235	0.003	<5	0.1	<1	6	17
LCNRCH-2-21-VII-06-D2 239-240 cm	239	0.002	<5	0.18	<1	13	49

LCNRCH-2-21-VII-06-D3 255-256 cm	255	0.005	<5	0.22	<1	13	51
LCNRCH-2-21-VII-06-D3 269-270 cm	269	0.004	<5	0.19	<1	15	53
LCNRCH-2-21-VII-06-D3 289-290 cm	289	0.004	<5	0.17	<1	6	38
LCNRCH-2-21-VII-06-D3 295-296 cm	295	0.002	<5	0.17	<1	8	54
LCNRCH-2-21-VII-06-D3 298-299 cm	298	0.002	<5	0.15	<1	6	58
LCNRCH-2-21-VII-06-D3 327-328 cm	327	0.005	<5	0.17	<1	3	31
LCNRCH-2-21-VII-06-D3 336-337 cm	336	0.015	<5	0.16	<1	2	20
DUP-LCNRCH-2-21-VII-06-D3 336-337 cm	336	<0.001	<5	0.16	<1	2	19
average			6	0.212857143	#DIV/0!	11.57142857	45.14285714
ANALYTE		WtKg	Cu	Fe	K	La	Li
METHOD		WGH79	ICP40B	ICP40B	ICP40B	ICP40B	ICP40B
DETECTION		0.001	0.5	0.01	0.01	0.5	1
UNITS	depth	kg	ppm	%	%	ppm	ppm
LCNRCH-2-21-VII-06-Surf 40-41 cm	40	0.002	13.9	3.25	2.32	89.2	141
DUP-LCNRCH-2-21-VII-06-Surf 40-41 cm	40	<0.001	14.3	3.23	2.29	93	138
LCNRCH-2-21-VII-06-Surf 46-47 cm	46	0.004	18.5	3.45	2.32	90	144

LCNRCH-2-21-VII-06-Surf 54-55 cm	54	0.004	14.8	3.34	2.39	84.1	127
LCNRCH-2-21-VII-06-Surf 63-64 cm	63	0.003	10.4	3.89	2.41	87.8	144
LCNRCH-2-21-VII-06-D1 81-82 cm	81	0.002	13.8	3.55	2.31	76.6	135
LCNRCH-2-21-VII-06-D1 87-88 cm	87	0.001	13.9	3.68	2.36	76.5	135
LCNRCH-2-21-VII-06-D1 94-95 cm	94	0.001	13.9	3.46	2.56	74.6	125
LCNRCH-2-21-VII-06-D1 108-109 cm	108	0.001	15.2	3.58	2.55	76.6	124
LCNRCH-2-21-VII-06-D1 113-114 cm	113	0.001	13.1	3.49	2.56	71.1	107
LCNRCH-2-21-VII-06-D1 127-128 cm	127	0.002	12.4	3.64	2.49	68.2	125
LCNRCH-2-21-VII-06-D1 134-135 cm	134	0.002	12.7	4.16	2.48	70.9	121
LCNRCH-2-21-VII-06-D1 147-148 cm	147	0.001	15.2	4.08	2.38	76	121
LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	13.8	3.79	2.42	66	117
DUP-LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	14.5	3.82	2.48	65.4	120
LCNRCH-2-21-VII-06-D2 181-182 cm	181	0.001	11.9	3.69	2.65	61	108
LCNRCH-2-21-VII-06-D2 186-187 cm	186	0.001	14.3	3.8	2.49	68.9	114

LCNRCH-2-21-VII-06-D2 202-203 cm	202	0.001	13.5	3.8	2.25	64.8	117
LCNRCH-2-21-VII-06-D2 235-236 cm	235	0.003	5	1.51	3.91	27.2	50
LCNRCH-2-21-VII-06-D2 239-240 cm	239	0.002	9.9	3.39	2.79	51.7	99
LCNRCH-2-21-VII-06-D3 255-256 cm	255	0.005	13.6	3.58	2.79	70.4	119
LCNRCH-2-21-VII-06-D3 269-270 cm	269	0.004	10.2	3.75	2.29	56.8	112
LCNRCH-2-21-VII-06-D3 289-290 cm	289	0.004	6.3	2.23	3.29	39	87
LCNRCH-2-21-VII-06-D3 295-296 cm	295	0.002	9.6	3.3	2.53	58.4	143
LCNRCH-2-21-VII-06-D3 298-299 cm	298	0.002	10.8	2.75	1.98	56.5	107
LCNRCH-2-21-VII-06-D3 327-328 cm	327	0.005	3.3	0.98	3.46	31.1	82
LCNRCH-2-21-VII-06-D3 336-337 cm	336	0.015	2.2	0.65	3.75	29	60
DUP-LCNRCH-2-21-VII-06-D3 336-337 cm	336	<0.001	2	0.64	3.51	31.6	58
average			11.53571429	3.16	2.643214286	64.72857143	113.5714286
ANALYTE		WtKg	Mg	Mn	Mo	Na	Ni
METHOD		WGH79	ICP40B	ICP40B	ICP40B	ICP40B	ICP40B
DETECTION		0.001	0.01	2	1	0.01	1
UNITS	depth	kg	%	ppm	ppm	%	ppm
LCNRCH-2-21-VII-06-Surf 40-41 cm	40	0.002	0.95	478	<1	0.82	28

DUP-LCNRCH-2-21-VII-06-Surf 40-41 cm	40	<0.001	0.94	471	<1	0.81	28
LCNRCH-2-21-VII-06-Surf 46-47 cm	46	0.004	0.96	524	<1	0.81	30
LCNRCH-2-21-VII-06-Surf 54-55 cm	54	0.004	0.9	523	<1	0.93	26
LCNRCH-2-21-VII-06-Surf 63-64 cm	63	0.003	1.08	507	<1	1.15	28
LCNRCH-2-21-VII-06-D1 81-82 cm	81	0.002	0.91	595	<1	0.89	27
LCNRCH-2-21-VII-06-D1 87-88 cm	87	0.001	0.9	593	<1	0.89	27
LCNRCH-2-21-VII-06-D1 94-95 cm	94	0.001	0.82	619	<1	1.01	25
LCNRCH-2-21-VII-06-D1 108-109 cm	108	0.001	0.83	637	<1	1	25
LCNRCH-2-21-VII-06-D1 113-114 cm	113	0.001	0.76	676	<1	0.99	23
LCNRCH-2-21-VII-06-D1 127-128 cm	127	0.002	0.82	685	<1	0.99	24
LCNRCH-2-21-VII-06-D1 134-135 cm	134	0.002	0.78	617	<1	1	23
LCNRCH-2-21-VII-06-D1 147-148 cm	147	0.001	0.79	790	<1	0.87	25
LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	0.76	516	<1	0.92	23

DUP-LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	0.76	527	<1	0.94	24
LCNRCH-2-21-VII-06-D2 181-182 cm	181	0.001	0.71	580	<1	1.09	22
LCNRCH-2-21-VII-06-D2 186-187 cm	186	0.001	0.76	722	<1	0.93	24
LCNRCH-2-21-VII-06-D2 202-203 cm	202	0.001	0.75	573	<1	0.86	24
LCNRCH-2-21-VII-06-D2 235-236 cm	235	0.003	0.3	186	<1	1.26	9
LCNRCH-2-21-VII-06-D2 239-240 cm	239	0.002	0.62	445	<1	1.14	19
LCNRCH-2-21-VII-06-D3 255-256 cm	255	0.005	0.79	537	<1	1.04	24
LCNRCH-2-21-VII-06-D3 269-270 cm	269	0.004	0.73	474	<1	0.89	22
LCNRCH-2-21-VII-06-D3 289-290 cm	289	0.004	0.56	220	<1	1.28	16
LCNRCH-2-21-VII-06-D3 295-296 cm	295	0.002	0.88	325	<1	1.11	23
LCNRCH-2-21-VII-06-D3 298-299 cm	298	0.002	0.6	281	<1	0.65	22
LCNRCH-2-21-VII-06-D3 327-328 cm	327	0.005	0.22	87	<1	1.39	8
LCNRCH-2-21-VII-06-D3 336-337 cm	336	0.015	0.13	56	<1	1.57	5
DUP-LCNRCH-2-21-VII-06-D3 336-337 cm	336	<0.001	0.13	62	<1	1.51	5
average			0.719285714	475.214285		1.0264	21.7

				7		28571	5
ANALYTE		WtKg	P	Pb	Sb	Sc	Sn
METHOD		WGH79	ICP40B	ICP40B	ICP40B	ICP40B	ICP40B
DETECTION		0.001	0.01	2	5	0.5	10
UNITS	depth	kg	%	ppm	ppm	ppm	ppm
LCNRCH-2-21-VII-06-Surf 40-41 cm	40	0.002	0.19	57	9	12.1	10
DUP-LCNRCH-2-21-VII-06-Surf 40-41 cm	40	<0.001	0.19	56	6	12.1	10
LCNRCH-2-21-VII-06-Surf 46-47 cm	46	0.004	0.22	55	9	12.1	10
LCNRCH-2-21-VII-06-Surf 54-55 cm	54	0.004	0.25	50	7	11.4	<10
LCNRCH-2-21-VII-06-Surf 63-64 cm	63	0.003	0.25	38	6	12.5	<10
LCNRCH-2-21-VII-06-D1 81-82 cm	81	0.002	0.22	46	<5	11.4	10
LCNRCH-2-21-VII-06-D1 87-88 cm	87	0.001	0.23	49	6	11.5	10
LCNRCH-2-21-VII-06-D1 94-95 cm	94	0.001	0.25	50	6	10.7	10
LCNRCH-2-21-VII-06-D1 108-109 cm	108	0.001	0.24	48	6	10.9	10
LCNRCH-2-21-VII-06-D1 113-114 cm	113	0.001	0.33	50	7	9.9	10
LCNRCH-2-21-VII-06-D1 127-128 cm	127	0.002	0.29	42	5	10.8	10
LCNRCH-2-21-VII-06-D1 134-135 cm	134	0.002	0.8	41	5	10.2	<10

LCNRCH-2-21-VII-06-D1 147-148 cm	147	0.001	0.44	45	8	10.7	10
LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	0.37	41	<5	10.2	<10
DUP-LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	0.38	42	6	10	<10
LCNRCH-2-21-VII-06-D2 181-182 cm	181	0.001	0.5	41	6	9.3	<10
LCNRCH-2-21-VII-06-D2 186-187 cm	186	0.001	0.41	43	<5	10.3	10
LCNRCH-2-21-VII-06-D2 202-203 cm	202	0.001	0.34	41	6	10.1	<10
LCNRCH-2-21-VII-06-D2 235-236 cm	235	0.003	0.14	39	<5	3.8	<10
LCNRCH-2-21-VII-06-D2 239-240 cm	239	0.002	0.36	41	6	8.4	<10
LCNRCH-2-21-VII-06-D3 255-256 cm	255	0.005	0.29	50	8	10.2	10
LCNRCH-2-21-VII-06-D3 269-270 cm	269	0.004	0.31	41	7	10	<10
LCNRCH-2-21-VII-06-D3 289-290 cm	289	0.004	0.11	36	6	7	<10
LCNRCH-2-21-VII-06-D3 295-296 cm	295	0.002	0.12	33	8	12	10
LCNRCH-2-21-VII-06-D3 298-299 cm	298	0.002	0.17	40	6	10.5	<10
LCNRCH-2-21-VII-06-D3 327-328 cm	327	0.005	0.05	39	<5	6.1	<10
LCNRCH-2-21-VII-06-D3 336-337 cm	336	0.015	0.03	37	<5	4.4	<10

DUP-LCNRCH-2-21-VII-06-D3 336-337 cm	336	<0.001	0.03	37	<5	4.4	<10
average			0.268214286	43.85714286	6.619047619	9.75	10

ANALYTE		WtKg	Sr	Ti	V	W	Y	Zn	Zr
METHOD		WGH79	ICP40B	ICP40B	ICP40B	ICP40B	ICP40B	ICP40B	ICP40B
DETECTION		0.001	0.5	0.01	2	10	0.5	0.5	0.5
UNITS	depth	kg	ppm	%	ppm	ppm	ppm	ppm	ppm
LCNRCH-2-21-VII-06-Surf 40-41 cm	40	0.002	109	0.61	95	20	26.3	139	66.5
DUP-LCNRCH-2-21-VII-06-Surf 40-41 cm	40	<0.001	111	0.61	92	20	27.4	136	62.8
LCNRCH-2-21-VII-06-Surf 46-47 cm	46	0.004	107	0.63	96	10	25.7	138	65.8
LCNRCH-2-21-VII-06-Surf 54-55 cm	54	0.004	113	0.59	95	20	26.2	119	83.1
LCNRCH-2-21-VII-06-Surf 63-64 cm	63	0.003	132	0.71	93	20	26.1	118	121
LCNRCH-2-21-VII-06-D1 81-82 cm	81	0.002	113	0.63	96	20	21.8	122	72.8
LCNRCH-2-21-VII-06-D1 87-88 cm	87	0.001	111	0.63	99	20	21.8	127	73.7
LCNRCH-2-21-VII-06-D1 94-95 cm	94	0.001	122	0.59	86	20	21.6	122	94.6
LCNRCH-2-21-VII-06-D1 108-109 cm	108	0.001	121	0.58	84	20	22.5	123	97.6
LCNRCH-2-21-VII-06-D1 113-114 cm	113	0.001	123	0.51	87	20	22.4	112	86.8
LCNRCH-2-21-VII-06-D1 127-128 cm	127	0.002	115	0.62	84	10	19.8	119	89.2

LCNRCH-2-21-VII-06-D1 134-135 cm	134	0.002	118	0.57	79	20	20.7	114	102
LCNRCH-2-21-VII-06-D1 147-148 cm	147	0.001	110	0.58	86	20	22.3	124	80.6
LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	110	0.55	80	20	19.3	116	85.9
DUP-LCNRCH-2-21-VII-06-D1 161-162 cm	161	<0.001	110	0.56	80	20	19.3	117	87.8
LCNRCH-2-21-VII-06-D2 181-182 cm	181	0.001	121	0.52	75	20	18	110	89.2
LCNRCH-2-21-VII-06-D2 186-187 cm	186	0.001	114	0.56	79	20	20.1	119	93
LCNRCH-2-21-VII-06-D2 202-203 cm	202	0.001	102	0.57	80	10	18.8	116	84
LCNRCH-2-21-VII-06-D2 235-236 cm	235	0.003	156	0.22	30	<10	8.6	44.5	79.3
LCNRCH-2-21-VII-06-D2 239-240 cm	239	0.002	124	0.51	64	10	15.3	96.9	97.8
LCNRCH-2-21-VII-06-D3 255-256 cm	255	0.005	123	0.59	80	10	20.2	118	87.5
LCNRCH-2-21-VII-06-D3 269-270 cm	269	0.004	107	0.58	79	20	16.5	110	94
LCNRCH-2-21-VII-06-D3 289-290 cm	289	0.004	158	0.48	54	<10	10.8	71.7	85
LCNRCH-2-21-VII-06-D3 295-296 cm	295	0.002	123	0.76	86	10	14.5	111	71.2
LCNRCH-2-21-VII-06-D3 298-299 cm	298	0.002	96.1	0.59	83	10	14.6	90.3	63

LCNRCH-2-21-VII-06-D3 327-328 cm	327	0.005	150	0.46	48	<10	10.2	35.8	142
LCNRCH-2-21-VII-06-D3 336-337 cm	336	0.015	164	0.37	33	<10	10	21.8	168
DUP-LCNRCH-2-21-VII-06-D3 336-337 cm	336	<0.001	159	0.36	34	<10	9.6	22.5	179
average			122.2178571	0.555	77.03571429	16.95652174	18.94285714	104.0535714	92.97142857

Table A- 9. Grain size data for Lucenier pond.

Depth (cm)	Year (AD)	%gravel	%sand	%silt	%clay
35	1938	0.00%	4.11%	78.06%	17.84%
40	1930	0.00%	1.99%	80.74%	17.28%
45	1922	0.00%	4.02%	78.40%	17.58%
50	1914	0.00%	16.34%	69.91%	13.75%
55	1906	0.00%	6.89%	75.09%	18.02%
60	1898	0.00%	0.21%	82.24%	17.54%
62	1895	0.00%	0.00%	80.98%	19.02%
65	1890	0.00%	10.41%	76.10%	13.49%
67	1887	0.00%	0.00%	77.04%	22.96%
70	1882	0.00%	4.30%	79.71%	15.99%
73	1877	0.00%	1.34%	84.03%	14.64%
75	1874	0.00%	2.99%	79.88%	17.13%
79	1867	0.00%	4.73%	75.12%	20.15%
80	1866	0.00%	2.93%	80.77%	16.30%
84	1859	0.00%	6.01%	78.06%	15.92%
85	1858	0.00%	4.35%	78.19%	17.46%
89	1851	0.00%	6.62%	76.61%	16.78%
90	1850	0.00%	7.62%	76.04%	16.34%
94	1844	0.00%	10.26%	76.85%	12.89%
95	1842	0.00%	7.57%	76.52%	15.91%
99	1836	0.00%	12.06%	72.38%	15.55%
105	1826	0.00%	9.45%	75.74%	14.81%
110	1818	0.00%	9.78%	76.73%	13.49%
115	1810	0.00%	16.53%	69.34%	14.14%
120	1802	0.00%	5.99%	78.27%	15.75%
124	1796	0.00%	0.00%	80.67%	19.33%

130	1786	0.00%	0.00%	80.49%	19.51%
135	1778	0.00%	0.00%	79.97%	20.03%
140	1770	0.00%	0.00%	81.36%	18.64%
145	1733	0.00%	1.11%	82.58%	16.31%
150	1696	0.00%	0.02%	82.95%	17.03%
155	1658	0.00%	0.00%	79.58%	20.42%
155	1658	0.00%	0.00%	78.02%	21.98%
160	1621	0.00%	6.64%	80.13%	13.23%
162	1606	0.00%	5.80%	79.34%	14.86%
167	1569	0.00%	14.35%	71.97%	13.68%
172	1532	0.00%	9.96%	75.40%	14.64%
177	1495	0.00%	13.67%	74.52%	11.81%
182	1481	0.00%	12.41%	74.17%	13.41%
187	1467	0.00%	10.18%	76.44%	13.37%
192	1452	0.00%	15.93%	69.66%	14.41%
197	1438	0.00%	11.25%	75.26%	13.48%
202	1424	0.00%	7.53%	77.78%	14.68%
207	1410	0.00%	9.22%	75.33%	15.45%
212	1396	0.00%	7.49%	75.24%	17.28%
217	1382	0.00%	13.02%	72.89%	14.09%
222	1368	0.00%	18.77%	68.06%	13.17%
227	1354	0.00%	21.88%	69.07%	9.05%
232	1340	64.50%	19.73%	13.98%	1.78%
236	1331	0.00%	22.17%	64.44%	13.39%
241	1324	0.00%	36.65%	55.61%	7.74%
246	1317	0.00%	14.53%	71.91%	13.56%
252	1308	0.00%	12.32%	72.78%	14.90%
257	1301	21.11%	32.85%	40.13%	5.91%
262	1294	0.00%	9.46%	75.43%	15.11%
267	1287	0.00%	10.31%	75.25%	14.44%
272	1280	0.00%	11.76%	72.96%	15.28%
277	1272	0.00%	9.80%	73.08%	17.12%
282	1265	0.00%	17.66%	66.68%	15.67%
287	1258	41.50%	14.23%	38.26%	6.01%
292	1251	0.00%	7.64%	74.44%	17.92%
297	1244	0.00%	10.45%	71.38%	18.17%
302	1237	0.00%	7.64%	74.65%	17.71%
307	1230	2.40%	32.99%	56.61%	8.00%
312	1222	10.20%	22.90%	55.11%	11.78%
317	1215	3.20%	19.57%	64.03%	13.20%
322	1208	9.90%	29.71%	50.21%	10.18%
327	1201	6.30%	28.74%	55.12%	9.84%
332	1194	2.80%	41.67%	49.06%	6.47%

Table A- 10. Sediment yield data for Lucenier pond.

Depth (cm)	Bulk Density (g/cc)	Sedimention Rate (cm/yr)	Sediment Accumulation Rate (km2/yr)	Sediment Yield (tons/km2yr)
0.00	0.05	0.55	292.05	2.36
5.00	0.12	0.55	664.95	5.38
10.00	0.20	0.55	1115.95	9.03
15.00	0.21	0.35	725.23	5.87
20.00	0.14	0.63	885.81	7.17
25.00	0.15	0.63	962.29	7.79
30.00	0.13	0.63	794.28	6.43
35.00	0.35	0.63	2196.03	17.78
40.00	0.41	0.63	2591.60	20.98
45.00	0.45	0.63	2790.33	22.59
50.00	0.59	0.63	3692.44	29.89
55.00	0.67	0.63	4193.33	33.95
60.00	0.81	0.63	5074.76	41.08
65.00	0.78	0.63	4913.02	39.77
70.00	0.51	0.63	3190.29	25.83
75.00	0.35	0.63	2184.75	17.69
80.00	0.49	0.63	3064.29	24.81
85.00	0.47	0.63	2957.71	23.94
90.00	0.52	0.63	3241.70	26.24
94.00	0.59	0.63	3681.16	29.80
99.00	0.49	0.63	3101.27	25.11
105.00	0.61	0.63	3811.55	30.86
110.00	0.55	0.63	3478.67	28.16
115.00	0.57	0.63	3583.36	29.01
120.00	0.58	0.63	3624.11	29.34
125.00	0.64	0.63	3987.08	32.28
130.00	0.72	0.63	4525.59	36.64
135.00	0.52	0.63	3271.79	26.49
140.00	0.57	0.63	3584.61	29.02
145.00	0.58	0.13	780.01	6.31
150.00	0.49	0.13	662.37	5.36
155.00	0.51	0.13	687.75	5.57
161.00	0.61	0.13	823.66	6.67
162.00	0.54	0.13	722.27	5.85
167.00	0.41	0.13	554.66	4.49

172.00	0.43	0.13	574.94	4.65
177.00	0.42	0.36	1474.02	11.93
182.00	0.44	0.36	1565.99	12.68
187.00	0.48	0.36	1690.63	13.69
192.00	0.45	0.36	1581.97	12.81
197.00	0.48	0.36	1705.55	13.81
202.00	0.48	0.36	1703.06	13.79
207.00	0.49	0.36	1751.71	14.18
212.00	0.56	0.36	1998.15	16.18
217.00	0.63	0.36	2249.91	18.21
222.00	0.62	0.36	2196.29	17.78
227.00	0.77	0.36	2726.81	22.07
232.00	1.18	0.70	8274.49	66.98
237.00	0.84	0.70	5898.57	47.75
242.00	0.66	0.70	4644.22	37.60
247.00	0.67	0.70	4704.32	38.08
252.00	0.57	0.70	3961.50	32.07
257.00	0.79	0.70	5487.68	44.42
262.00	0.63	0.70	4426.90	35.84
267.00	0.63	0.70	4396.85	35.59
272.00	0.56	0.70	3907.69	31.63
277.00	0.64	0.70	4475.12	36.23
282.00	0.67	0.70	4661.69	37.74
287.00	1.16	0.70	8108.18	65.64
292.00	0.83	0.70	5810.52	47.04
297.00	0.38	0.70	2677.10	21.67
302.00	0.52	0.70	3652.63	29.57
307.00	1.15	0.70	8006.15	64.81
312.00	1.31	0.70	9164.76	74.19
317.00	1.60	0.70	11178.70	90.49
322.00	1.72	0.70	12000.49	97.15
327.00	1.75	0.70	12215.72	98.89
332.00	1.69	0.70	11787.36	95.42

Table A- 11. Algal mixing model data for Lucenier pond.

Year (AD)	%Algal Contribution

2006	0.695258302
1997	0.657801361
1988	0.613494055
1975	0.530127134
1962	0.466338983
1954	0.418804958
1946	0.358883889
1938	0.451637434
1930	0.530058185
1922	0.59443768
1914	0.658916486
1906	0.602767535
1898	0.7405941
1895	0.703978709
1890	0.720578279
1887	0.660381198
1882	0.664088626
1877	0.622637839
1874	0.633953324
1867	0.616607041
1866	0.594811172
1859	0.490263654
1858	0.623333333
1851	0.612248698
1850	0.586450665
1844	0.553588372
1842	0.562603841
1836	0.582683242
1828	0.604849939
1820	0.539711195
1812	0.563314224
1804	0.531343737
1796	0.591571073
1786	0.586609096
1778	0.569143336
1770	0.565828299
1733	0.537347253
1696	0.575194665
1658	0.573985576
1621	0.564995432
1606	0.457779267

1569	0.565473168
1532	0.569710031
1495	0.574550796
1481	0.564655286
1467	0.60094665
1452	0.546543756
1438	0.598118046
1424	0.570738808
1410	0.549604146
1396	0.610981255
1382	0.583625729
1368	0.539621381
1354	0.538669024
1340	0.627888514
1333	0.426307419
1331	0.437510172
1325	0.470311047
1324	0.453201048
1318	0.466379581
1317	0.462684989
1311	0.492986714
1304	0.50856593
1297	0.493782768
1290	0.543217084
1282	0.568522462
1275	0.429038956
1268	0.529950818
1261	0.443980532
1254	0.590028572
1247	0.545775311
1240	0.586051261
1232	0.5523795
1225	0.623072948
1218	0.634647363
1211	0.710334937

Table A- 12. Algal mixing model data for Valette pond.

Year (AD)	% Algal Contribution
2006	0.741366481
1996	0.715756368
1985	0.672755039
1975	0.636966677
1965	0.610599556
1954	0.624419694
1944	0.562914857
1934	0.553721121
1924	0.606025568
1913	0.558496259
1903	0.63405646
1899	0.560280011
1893	0.60199679
1883	0.659462919
1881	0.692526852
1872	0.678797204
1864	0.718113858
1862	0.672451901
1856	0.718773876
1839	0.734914423
1817	0.727000982
1799	0.718607758
1781	0.711293389
1764	0.726294352
1743	0.722585397
1732	0.682056714
1699	0.635535243
1689	0.624489384
1678	0.659000439
1657	0.611029918
1645	0.724037199
1632	0.788496783
1619	0.765959896
1606	0.699655624
1593	0.714775376
1580	0.648489537
1567	0.630311365
1554	0.702920099

1541	0.646931039
1528	0.671536956
1515	0.659598992
1502	0.650923345
1495	0.642134111
1482	0.668229834
1469	0.634699017
1456	0.600910192
1443	0.596251546
1437	0.637954339
1432	0.621954021
1426	0.513703385
1420	0.54961916
1414	0.642345671
1401	0.636176752
1386	0.595636178
1357	0.65987307
1343	0.752936516
1328	0.730288645
1314	0.687762551
1299	0.741258999
1284	0.704796483

Table A- 13. Precipitation data.

Year (AD)	Fall (mm)	Winter (mm)	Spring (mm)	Summer (mm)
1509	225.742	179.24	214.3336364	229.9109091
1510	225.621	180.4654545	213.6372727	239.0936364
1511	222.284	180.1145455	214.9018182	237.5563636
1512	219.594	181.1427273	220.1290909	239.8736364
1513	207.779	179.5754545	225.05	243.2281818
1514	210.833	182.5181818	231.2972727	258.6718182
1515	211.355	184.1936364	233.6245455	250.87
1516	203.048	186.21	229.5418182	252.7209091
1517	202.214	186.5490909	228.3963636	251.5581818
1518	200.541	185.4854545	227.2927273	250.1790909
1519	208.213	183.3454545	229.9918182	253.3109091
1520	214.025	183.5454545	223.7254545	250.4736364
1521	209.904	177.8572727	221.9090909	244.2045455
1522	212.117	181.8490909	222.47	249.77

1523	224.173	186.27	219.5536364	252.7
1524	219.504	186.0209091	219.3045455	254.8881818
1525	218.376	184.0427273	218.2945455	247.3009091
1526	221.895	179.0390909	217.9072727	250.6263636
1527	226.041	177.1409091	223.2354545	252.6963636
1528	230.28	176.0018182	223.2590909	260.0118182
1529	230.19	174.7181818	219.1954545	252.9927273
1530	225.042	177.3309091	218.3936364	252.6527273
1531	226.446	182.8818182	220.3736364	252.1918182
1532	224.56	188.7409091	220.8090909	253.9445455
1533	220.991	187.1254545	216.5272727	241.87
1534	224.219	180.2054545	222.2236364	240.2827273
1535	228.664	177.6118182	216.7827273	230.14
1536	223.872	178.0254545	217.1272727	231.4981818
1537	222.131	179.74	217.1245455	228.2209091
1538	219.055	179.2381818	221.3363636	227.2836364
1539	219.301	180.5463636	211.4072727	207.4709091
1540	212.431	180.5027273	214.2272727	211.9181818
1541	216.98	180.4290909	216.5681818	215.8409091
1542	215.45	174.9427273	216.5118182	220.8009091
1543	215.442	169.5727273	211.08	221.3345455
1544	215.624	169.9654545	215.5036364	228.9527273
1545	204.834	168.25	209.3527273	228.41
1546	207.009	165.4572727	212.5245455	236.8463636
1547	206.947	163.1072727	211.1809091	232.3336364
1548	203.557	165.0809091	210.2909091	235.1218182
1549	199.563	167.9845455	212.2763636	236.7454545
1550	209.552	167.6572727	225.6290909	249.2681818
1551	208.911	170.5845455	227.5136364	255.7127273
1552	213.092	169.2527273	226.0990909	250.92
1553	214.047	166.9554545	221.6690909	247.0081818
1554	214.412	170.3	225.1563636	248.1509091
1555	226.012	172.4372727	223.2245455	244.1590909
1556	234.441	174.5381818	220.5663636	242.1736364
1557	231.571	181.0918182	217.08	239.4627273
1558	229.096	179.6209091	214.6681818	234.5318182
1559	230.609	177.4754545	215.3527273	241.8763636
1560	230.387	174.0836364	205.3845455	232.0427273
1561	229.559	173.5545455	203.7218182	232.7963636
1562	225.218	171.6981818	200.8590909	229.33
1563	221.688	170.7845455	200.5263636	230.5872727
1564	224.756	175.1390909	208.0309091	233.6581818
1565	219.827	173.5681818	208.1836364	228.3563636
1566	213.162	168.1681818	200.8018182	226.9872727
1567	212.318	167.47	201.8763636	232.4272727
1568	217.406	170.0027273	204.4390909	242.7945455
1569	218.339	176.4045455	198.1863636	249.5309091
1570	222.549	181.2509091	187.1709091	244.9236364
1571	223.026	185.5536364	183.2118182	250.5863636
1572	227.575	184.5236364	179.2327273	254.09

1573	235.791	187.3090909	178.0418182	248.47
1574	227.861	182.9427273	176.7372727	242.4690909
1575	221.164	181.3145455	175.4918182	245.0236364
1576	224.932	181.4227273	172.88	246.6172727
1577	229.09	182.1881818	179.3554545	254.8781818
1578	224.485	187.0654545	178.5436364	258.5454545
1579	231.767	181.2909091	174.8809091	254.2872727
1580	214.647	179.4618182	182.4118182	250.9909091
1581	209.349	180.4127273	192.5045455	249.7036364
1582	209.547	177.3836364	194.4009091	245.3045455
1583	205.622	181.72	191.33	245.3009091
1584	210.745	174.57	190.0327273	252.8245455
1585	219.917	181.0654545	190.7372727	256.3954545
1586	212.851	181.7663636	186.1309091	249.6027273
1587	213.048	178.2090909	185.4063636	256.1654545
1588	215.894	178.3681818	186.3036364	256.2318182
1589	199.947	180.6609091	186.5009091	240.2127273
1590	201.184	182.0963636	187.5727273	242.8981818
1591	200.384	176.7272727	186.3727273	242.4036364
1592	199.582	172.7554545	183.2372727	244.7990909
1593	198.266	174.5372727	184.3	249.0254545
1594	201.809	169.1345455	184.6954545	247.5409091
1595	198.793	175.3745455	178.7609091	245.2445455
1596	208.07	174.7590909	167.3881818	250.1590909
1597	213.618	179.7936364	161.5681818	249.36
1598	217.538	183.1563636	156.7927273	237.8963636
1599	213.272	178.3654545	146.8863636	234
1600	225.887	172.3590909	142.3745455	244.0872727
1601	231.967	175.4227273	138.6390909	240.7781818
1602	232.445	173.2654545	127.0609091	237.4009091
1603	225.037	170.7318182	125.3872727	231.3972727
1604	219.471	170.2481818	125.5918182	230.8181818
1605	214.198	171.3109091	125.9681818	233.5745455
1606	209.434	165.9518182	124.8618182	225.3972727
1607	203.037	171.4890909	127.3890909	224.6745455
1608	203.851	160.4836364	127.2854545	228.4063636
1609	211.416	159.6136364	129.0972727	232.0363636
1610	211.638	162.9054545	126.4181818	234.6190909
1611	212.542	165.23	125.5454545	232.4827273
1612	209.643	163.6463636	128.7209091	234.6845455
1613	213.25	172.3618182	134.2181818	238.1036364
1614	219.457	170.7327273	136.0945455	232.4109091
1615	218.93	167.6818182	138.6054545	222.6972727
1616	218.526	165.2027273	139.8863636	218.0281818
1617	217.609	169.0581818	142.9936364	226.0363636
1618	217.803	158.3090909	145.6681818	221.4336364
1619	220.949	162.3027273	146.6218182	218.6418182
1620	211.898	160.4072727	148.2318182	221.6090909
1621	204.716	161.3818182	157.2927273	220.4445455
1622	201.35	157.15	162.1718182	214.8190909

1623	199.406	157.8181818	161.3863636	209.3763636
1624	192.164	155.6445455	164.6536364	208.1763636
1625	195.633	154.1709091	162.8909091	219.4063636
1626	187.054	162.6554545	162.5981818	233.4990909
1627	191.632	166.5745455	158.6263636	232.8509091
1628	189.145	167.9	161.2154545	225.1772727
1629	184.593	174.2472727	146.5081818	225.0481818
1630	186.8	172.7354545	138.31	223.0045455
1631	184.051	175.7163636	123.2609091	225.5072727
1632	182.385	172.7836364	108.7090909	230.7572727
1633	184.112	173.4281818	92.41818182	241.4236364
1634	175.092	170.7845455	85.9	242.5354545
1635	177.146	172.5318182	76.14545455	243.9672727
1636	191.298	178.1036364	78.41272727	239.6172727
1637	190.596	171.9627273	76.89090909	236.4854545
1638	192.046	168.4372727	73.29272727	242.9872727
1639	187.565	169.7290909	74.95636364	251.2209091
1640	200.601	169.3436364	85.87	258.6490909
1641	208.822	174.2272727	85.35181818	265.4681818
1642	210.224	173.7227273	88.87	261.1627273
1643	214.587	177.21	96.76363636	255.2036364
1644	225.178	178.1218182	104.7554545	249.8890909
1645	228.5	178.1227273	109.7890909	249.4090909
1646	232.848	176.5418182	107.54	257.7236364
1647	226.154	176.7836364	103.2209091	267.0736364
1648	226.638	175.2227273	98.32818182	269.1309091
1649	240.229	176.3	99.57181818	264.5936364
1650	236.706	177.1954545	93.75727273	260.0327273
1651	246.071	174.63	93.04727273	252.57
1652	243.303	168.1872727	103.2172727	243.8136364
1653	246.483	163.1809091	113.54	241.4854545
1654	244.975	165.5490909	120.7672727	241.81
1655	243.508	164.7745455	121.8818182	240.8790909
1656	236.96	167.3418182	119.9672727	239.8109091
1657	245.081	168.7627273	127.8454545	231.4890909
1658	244.234	168.8718182	122.6509091	227.3427273
1659	256.834	168.2272727	114.2472727	223.07
1660	253.178	171.8845455	111.5090909	223.3263636
1661	234.734	167.1672727	104.4545455	225.37
1662	242.926	168.8063636	101.5963636	251.2572727
1663	240.879	167.4745455	89.25818182	270.6772727
1664	257.336	179.8372727	87.79727273	277.04
1665	264.676	174.1354545	87.09727273	266.8718182
1666	256.985	173.9654545	90.22454545	275.5236364
1667	257.152	176.1918182	93.95090909	283.0381818
1668	246.403	168.7181818	91.13454545	285.7263636
1670	229.098	164.9318182	94.24545455	281.6663636
1671	223.395	175.9036364	94.75363636	282.98
1672	240.949	173.6827273	93.09909091	291.5981818
1673	236.724	171.3009091	102.4636364	292.1309091

1674	233.756	163.23	105.8327273	276.5218182
1675	221.679	163.8727273	112.9854545	252.6309091
1676	205.471	162.5527273	100.6054545	256.51
1677	210.513	169.6272727	95.47363636	262.8354545
1678	203.252	170.5154545	93.91454545	263.7281818
1679	212.177	166.1245455	90.48	257.6009091
1680	201.057	170.1518182	89.98636364	244.63
1681	198.853	172.7236364	90.97363636	245.9381818
1682	189.359	169.2418182	96.45545455	242.1172727
1683	189.54	166.1727273	97.61818182	221.38
1684	197.174	166.2045455	86.49363636	220.6218182
1685	196.882	161.67	76.69181818	210.5572727
1686	185.241	170.4209091	69.60272727	215.2372727
1687	192.092	156.1463636	78.43727273	205.23
1688	207.686	156.97	72.36181818	217.9481818
1689	216.606	157.5181818	76.83545455	215.7136364
1690	232.298	149.1854545	77.51545455	213.7609091
1691	230.878	145.8090909	79.50363636	239.6281818
1692	228.264	146.0809091	83.13545455	238.6727273
1693	237.575	145.6372727	98.49363636	248.5663636
1694	233.2	140.4872727	94.57181818	262.4390909
1695	235.154	130.4081818	101.38	259.9
1696	254.532	138.1281818	118.1490909	265.0781818
1697	251.528	134.4209091	127.4036364	270.4381818
1698	254.452	142.0036364	135.9290909	266.6881818
1699	235.626	134.4672727	140.5345455	259.1054545
1700	236.251	138.1172727	134.9027273	249.3627273
1701	233.483	142.9263636	135.6290909	250.5854545
1702	234.2	145.7281818	138.2354545	239.8145455
1703	223.492	139.9745455	141.4245455	229.98
1704	215.263	126.5190909	134.3	214.0590909
1705	211.74	129.3081818	145.7290909	194.1072727
1706	204.488	136.8290909	145.8081818	203.33
1707	204.544	146.7745455	141.0127273	203.2790909
1708	182.439	147.1363636	144.8481818	202.4763636
1709	197.072	137.2390909	150.1127273	200.0054545
1710	182.213	149.25	151.9381818	193.8381818
1711	203.116	152.1409091	160.1945455	193.3481818
1712	211.114	161.7345455	162.26	204.3654545
1713	221.371	153.4354545	158.6845455	198.1781818
1714	224.82	158.9881818	152.6336364	207.5836364
1715	222.921	163.6536364	145.36	215.9109091
1716	236.967	165.7045455	137.2772727	228.3963636
1717	228.842	175.0590909	135.5636364	207.7945455
1718	230.987	181.91	137.4790909	190.88
1719	232.136	194.9418182	131.8372727	200.8545455
1720	249.917	213.6372727	126.7890909	205.6554545
1721	241.934	206.5727273	128.7418182	204.8736364
1722	233.02	205.9945455	120.6254545	207.1809091
1723	216.112	199.7936364	105.6436364	182.0190909

1724	198.082	213.3763636	104.3354545	188.6418182
1725	195.04	226.3190909	95.52272727	178.4754545
1726	194.978	236.1627273	86.10090909	174.0936364
1727	203.739	242.0009091	88.50545455	168.1845455
1728	202.595	243.3909091	93.83818182	168.5745455
1729	206.78	227.0336364	88.25454545	179.0981818
1730	197.957	215.38	88.93181818	163.4154545
1731	192.488	208.7763636	71.35545455	164.2736364
1732	198.295	201.8927273	68.51090909	164.3318182
1733	204.618	196.1763636	70.96727273	167.2809091
1734	224.092	201.0981818	85.08363636	180.1109091
1735	222.854	193.7981818	88.97272727	168.8781818
1736	201.442	184.7909091	91.60272727	184.34
1737	203.858	175.9463636	103.6627273	194.1418182
1738	198.33	175.82	107.4854545	195.3981818
1739	191.644	166.3854545	103.51	202.2936364
1740	192.365	177.3981818	100.9281818	194.5336364
1741	199.575	169.3054545	91.71181818	188.0736364
1742	206.376	158.1872727	93.47727273	185.2290909
1743	203.801	148.2045455	98.79181818	182.8
1744	212.282	142.4690909	98.71090909	179.8254545
1745	212.075	133.9990909	95.48727273	171.0981818
1746	221.657	141.0081818	95.97818182	181.8318182
1747	213.41	138.5518182	103.0954545	179.1090909
1748	219.131	149.5254545	107.8572727	171.26
1749	198.452	138.5063636	110.2763636	178.0927273
1750	200.528	143.7436364	116.7363636	182.5618182
1751	199.012	131.6736364	137.1345455	196.4554545
1752	170.065	135.9272727	147.8463636	203.0027273
1753	175.559	144.71	153.7327273	200.6990909
1754	152.319	149.4290909	146.2645455	208.8954545
1755	172.754	153.1645455	145.6254545	210.1663636
1756	170.174	148.8590909	153.7454545	217.0763636
1757	170.775	146.5227273	153.3990909	221.2263636
1758	175.91	144.62	152.4781818	213.7836364
1759	193.888	139.5109091	143.6027273	214.3672727
1760	198.293	146.6909091	137.0736364	211.7772727
1761	203.652	146.1954545	135.4890909	204.8918182
1762	227.501	140.0345455	117.53	202.4463636
1763	229.859	149.8409091	118.2172727	208.5254545
1764	246.026	155.33	122.3781818	213.2118182
1765	233.432	157.5872727	131.7018182	210.8872727
1766	224.663	159.75	133.3590909	211.7172727
1767	225.427	163.3572727	130.6672727	221.8463636
1768	242.525	158.9772727	127.59	218.1763636
1769	240.972	155.1954545	126.0227273	222.7
1770	249.213	153.48	130.6954545	227.9718182
1771	232.069	162.8036364	128.8381818	225.2554545
1772	232.37	163.5790909	133.3454545	227.8981818
1773	241.014	181.5118182	135.2718182	225.5545455

1774	246.373	174.9545455	141.8063636	230.9136364
1775	254.106	172.1090909	139.0190909	232.8254545
1776	255.704	181.5418182	132.4472727	238.0927273
1777	247.668	180.4672727	139.9990909	230.51
1778	244.765	178.2927273	138.5854545	224.5318182
1779	246.172	182.4	139.0481818	219.2081818
1780	238.291	186.6281818	144.7272727	214.7390909
1781	248.641	180.5863636	136.8927273	208.5454545
1782	242.965	172.7163636	156.8536364	210.4472727
1783	228.814	170.0636364	153.0572727	212.3409091
1784	218.467	159.6936364	156.4109091	213.4536364
1785	205.725	154.18	142.3654545	210.4109091
1786	222.392	146.6190909	146.6045455	204.2827273
1787	235.488	145.7336364	151.3672727	201.1290909
1788	214.802	148.5263636	140.3209091	210.7481818
1789	221.691	150.8127273	141.9654545	210.1736364
1790	209.831	154.8063636	145.9318182	208.51
1791	205.212	157.1609091	143.17	216.9336364
1792	206.202	163.6336364	158.0181818	215.5090909
1793	204.983	162.5509091	144.0745455	214.0709091
1794	214.778	162.5072727	145.6427273	219.3236364
1795	212.675	166.5309091	143.1827273	219.2963636
1796	210.783	165.9936364	146.5927273	219.7936364
1797	212.171	170.3754545	153.1881818	224.9745455
1798	221.969	167.4118182	148.6372727	221.9909091
1799	216.497	162.9090909	155.3309091	212.84
1800	230.521	168.4581818	154.0963636	211.7127273
1801	246.389	166.7054545	152.15	208.4118182
1802	244.114	161.7536364	148.0781818	199.2827273
1803	247.533	166.6354545	142.4345455	209.95
1804	244.996	172.4209091	143.54	213.8518182
1805	247.314	178.56	137.7190909	206.6954545
1806	243.261	179.3636364	137.9409091	201.7836364
1807	248.726	181.7163636	144.3427273	199.3163636
1808	249.268	187.08	136.4936364	200.3381818
1809	245.302	186.5372727	138.3209091	202.2109091
1810	239.291	192.3509091	139.9290909	210.2490909
1811	223.574	192.1445455	137.5854545	209.4463636
1812	226.793	182.9463636	142.9245455	214.1945455
1813	231.678	184.2872727	146.2763636	215.7763636
1814	224.847	176.4645455	138.69	206.4127273
1815	223.229	170.92	131.7590909	212.4054545
1816	225.473	168.36	134.0836364	215.9654545
1817	210.761	166.8263636	132.6427273	211.8009091
1818	203.933	166.77	136.4836364	211.1072727
1819	211.722	163.91	131.4945455	206.5627273
1820	207.742	164.0790909	129.4863636	209.4427273
1821	208.972	159.5772727	129.1090909	207.1245455
1822	208.724	162.5445455	125.4581818	208.23
1823	198.483	166.3954545	119.5063636	210.2036364

1824	217.173	165.2990909	121.1118182	208.9690909
1825	227.52	164.2745455	121.9372727	211.3463636
1826	230.964	167.5345455	122.1281818	201.9736364
1827	237.588	167.77	127.7890909	204.5618182
1828	234.3	165.54	128.3636364	217.6709091
1829	234.678	163.4363636	121.2263636	219.6854545
1830	234.137	164.3363636	127.4936364	226.0545455
1831	237.071	162.2809091	129.1872727	221.0336364
1832	232.723	160.8109091	123.6772727	222.4754545
1833	238.63	161.5290909	127.8172727	227.9345455
1834	215.225	158.7863636	124.1618182	224.4363636
1835	212.663	158.1018182	129.1145455	223.8454545
1836	217.434	158.8163636	141.1881818	228.0627273
1837	211.923	157.2881818	150.4118182	225.7345455
1838	220.466	157.18	149.5890909	217.9545455
1839	222.474	163.2963636	153.7654545	206.1545455
1840	231.648	166.4672727	152.4545455	202.8518182
1841	241.079	162.9490909	153.4327273	198.9609091
1842	251.772	171.21	153.3745455	207.6172727
1843	250.921	174.2672727	157.4281818	206.1572727
1844	266.084	169.0627273	155.7763636	204.7363636
1845	264.116	177.0381818	165.4963636	204.1545455
1846	261.486	182.1363636	167.7245455	210.8327273
1847	259.169	180.6172727	160.5027273	214.6018182
1848	259.995	175.8772727	163.99	219.3854545
1849	255.278	172.9609091	164.6536364	225.8518182
1850	244.345	163.9463636	161.5218182	231.7281818
1851	232.615	160.7590909	172.3809091	245.5027273
1852	233.617	160.5409091	166.1109091	248.4927273
1853	235.018	153.3736364	171.0581818	246.46
1854	226.174	154.01	166.7136364	250.9236364
1855	226.012	153.6172727	171.1436364	246.3790909
1856	222.308	145.9463636	180.9154545	249.1454545
1857	225.503	133.7963636	175.4281818	242.1690909
1858	220.975	132.6454545	176.8245455	235.2818182
1859	222.817	137.7163636	175.6472727	245.7
1860	227.195	138.57	175.75	245.2081818
1861	225.846	139.7236364	175.9727273	248.38
1862	220.027	138.9518182	170.41	235.2627273
1863	221.211	134.9936364	175.7227273	228.3827273
1864	223.782	137.1745455	169.9154545	223.52
1865	220.93	135.2609091	169.5854545	222.4181818
1866	217.682	141.7872727	176.1563636	220.8936364
1867	215.463	141.3381818	171.6927273	214.2309091
1868	220.474	151.5627273	168.99	210.9345455
1869	215.291	151.7245455	173.5354545	200.7454545
1870	220.037	146.5072727	159.7881818	192.8263636
1871	216.998	143.8990909	152.3918182	193.9118182
1872	223.597	149.0045455	162.0936364	192.2854545
1873	223.535	147.1427273	161.75	189.4445455

1874	219.375	153.6618182	158.4918182	200.0963636
1875	225.935	149.9263636	155.0090909	198.68
1876	226.975	153.7018182	168.8972727	197.7036364
1877	229.042	148.4572727	170.7090909	202.0509091
1878	227.592	160.2009091	169.2581818	208.8618182
1879	225.665	154.4436364	174.88	220.0654545
1880	227.417	159.9527273	166.1409091	227.3390909
1881	232.338	158.6209091	178.6509091	227.4636364
1882	243.512	162.8963636	182.0818182	225.7518182
1883	242.45	158.2436364	168.3290909	218.5163636
1884	237.311	165.4872727	164.6727273	221.6945455
1885	241.907	162.2863636	172.5309091	214.67
1886	245.196	166.2836364	179.7363636	214.1636364
1887	245.74	160.67	169.36	223.5027273
1888	243.924	156.9518182	163.9018182	225.1127273
1889	245.428	143.6290909	160.7345455	229.8972727
1890	232.147	142.2318182	162.8509091	230.6
1891	234.702	143.1436364	172.6254545	232.4163636
1892	219.559	147.3045455	164.7418182	227.22
1893	222.459	140.7627273	156.6418182	221.3263636
1894	231.635	145.0709091	161.4354545	227.7118182
1895	219.266	139.97	165.79	232.9927273
1896	227.239	146.5172727	160.4345455	237.2272727
1897	222.908	144.8509091	162.4845455	236.2927273
1898	219.303	147.5427273	168.1745455	223.1981818
1899	213.839	156.9581818	165.9136364	220.6772727
1900	216.997	163.7036364	161.5636364	216.34
1901	219.269	175.0627273	168.3172727	218.5381818
1902	211.114	163.1909091	169.6963636	221.7609091
1903	204.503	161.4454545	178.05	223.8145455
1904	195.877	164.0436364	187.8672727	225.9327273
1905	206.47	165.2518182	188.5790909	216.3190909
1906	202.325	170.2363636	189.0445455	207.1418182
1907	210.852	167.9527273	192.1263636	204.9990909
1908	204.669	168.3181818	189.9254545	206.7972727
1909	214.383	180.8190909	190.3654545	220.9636364
1910	217.64	176.4363636	190.1336364	219.4454545
1911	216.2	182.4181818	187.7363636	229.5454545
1912	213.87	177.2090909	177.6909091	225.3636364
1913	219.4	180.9545455	178.4363636	231.6
1914	225.83	188.9181818	184.2545455	231.7545455
1915	211.44	194.1818182	186.9272727	239.3
1916	215.49	188.4636364	187.8727273	258.2363636
1917	212.25	182.0272727	193.7818182	255.0181818
1918	222.98	186.7	200.5454545	244.3363636
1919	217.82	188.5454545	203.7909091	241.5727273
1920	209.59	166.3181818	206.0363636	231.2181818
1921	193.34	164.4909091	203.4909091	236.6
1922	198.21	157.4454545	218.7	214.7090909
1923	203.84	160.0454545	221.9	217.2909091

1924	208.9	158.7272727	212.3545455	212.0272727
1925	210.97	157.0272727	208.5090909	207.0181818
1926	205.52	149.3727273	213.1363636	213.3454545
1927	205.41	151.3454545	215.5545455	201.1909091
1928	211.02	149.4545455	217.2363636	205.1727273
1929	208.88	146.3636364	206.0454545	220.8636364
1930	227.57	148.0090909	207.6727273	233.5090909
1931	239.4	152.2181818	207.2	235.6818182
1932	243.86	149.5181818	219.5454545	227.2090909
1933	240.41	143.8181818	207.4181818	236.3727273
1934	239.12	145.8181818	203.9818182	229.1454545
1935	246.9	164.4818182	210.7	230.8272727
1936	237.59	161.2909091	205.5909091	231.9454545
1937	237.9	164.6727273	204.8727273	226.6909091
1938	229.24	165.7272727	191.6	236.8818182
1939	238.28	172.7	188	237.7818182
1940	232.93	178.9636364	197.2909091	238.8909091
1941	226.04	174.3272727	196.2545455	230.8181818
1942	224.95	178.8636364	188.6363636	223.3181818
1943	226.83	178.4636364	173.9363636	230.6363636
1944	241.09	183.1727273	168.4090909	225.7181818
1945	226.26	180.1545455	163.7727273	227.2909091
1946	220.71	165.6545455	160.5818182	225.7727273
1947	212.22	168.5545455	164.5636364	230.1727273
1948	205.22	161.0272727	158.7	210.8181818
1949	197.12	159.0181818	170.6181818	205.7090909
1950	189.15	161.1454545	165.8636364	215.4909091
1951	198.43	152.6181818	173.4909091	201.2454545
1952	215.42	154.3181818	170.9727273	203.9545455
1953	201.97	148.1545455	163.9727273	212.5
1954	184.55	163.1909091	165.3545455	211.7636364
1955	188.29	166.5636364	165.6818182	225.0818182
1956	200.51	164.4909091	171.3	235.8272727
1957	202.94	172.5545455	165.6	237.0090909
1958	214.22	172.9	168.2727273	234.9454545
1959	210.07	183.8181818	169.1545455	255.9636364
1960	223.74	187.6454545	165.4363636	248.4818182
1961	218.83	189.6909091	162.1090909	228.1363636
1962	191.63	186.7545455	159.1454545	244.6909091
1963	193.08	181.0636364	157.8181818	235.5090909
1964	185.36	182.7454545	164.9545455	231.9636364
1965	201.04	183.7727273	178.9181818	230.5454545
1966	194.84	184.1909091	190.0181818	218.8454545
1967	204.98	189.4454545	189.0454545	209.3
1968	212.08	185.5	200.8636364	203.7909091
1969	210.59	187.2909091	204.3363636	208.0090909
1970	193.83	178.0545455	205.8454545	205.9909091
1971	186.53	174.2454545	208.2363636	212.6636364
1972	192.08	168.0272727	209.7272727	225.1090909
1973	196.11	169.2272727	197.9727273	211.6545455

1974	218.32	173.9545455	197.3818182	219.2454545
1975	218.63	175.3636364	202.2909091	206.0636364
1976	232.33	174.0545455	184.6454545	222.1727273
1977	226.09	180.9909091	189.6	221.3
1978	202.36	186.6272727	197.4909091	222.8909091
1979	211.02	190.4363636	202.4181818	222.5
1980	213.51	187.9454545	195.5727273	230.3272727
1981	231.29	204.8545455	195.4181818	226.8181818
1982	241.92	213.1181818	195.1909091	223.7363636
1983	237.55	217.9545455	221.0818182	218.9545455
1984	234.58	219.1090909	225.1454545	217.1181818
1985	212.15	226.5727273	234.0909091	216.4636364
1986	201.07	230.0454545	246.8363636	241.2909091
1987	211.28	225.8545455	252.4090909	222.6727273
1988	224.44	211.2363636	257.2545455	226.8545455
1989	216.51	202.6090909	255.2181818	223.0090909
1990	221.14	192.6727273	244.0181818	222.7363636
1991	219.07	180.5909091	239.1	223.8545455
1992	216.05	159.4	239.2727273	223.1636364
1993	228.5	165.1636364	240.7727273	222.8545455
1994	220.03	169.0727273	222.2181818	226.1
1995	234.12	174.9090909	232.9909091	229.7090909
1996	231.07	169.0909091	223.9090909	236.0363636
1997	219.61	171.2181818	202.5272727	213.3181818
1998	223.8	164.5454545	210.7090909	214.1
1999	233.88	176.6545455	204.3909091	214.1454545

Table A- 14. Temperature data.

Year (AD)	Temperature Anomaly
1370	-0.17
1371	-0.01
1372	-0.37
1373	0.41
1374	-0.29
1375	0.45
1376	-0.12
1377	0.34
1378	-0.06
1379	0.05
1380	0.17
1381	0.16

1382	0.97
1383	1.98
1384	1.98
1385	1.72
1386	0.43
1387	0.24
1388	-0.37
1389	-0.06
1390	0.97
1391	0.86
1392	-1.33
1393	2.48
1394	-1.11
1395	0.52
1396	-0.17
1397	0.32
1398	0.07
1399	-0.05
1400	1.37
1401	0.58
1402	0.87
1403	0.56
1404	-0.54
1405	-0.37
1406	-0.12
1407	-0.37
1408	-0.54
1409	0.57
1410	0.77
1411	-1.02
1412	0.43
1413	0.99
1414	-0.46
1415	0.24
1416	-0.17
1417	0.24
1418	1.52
1419	0.44
1420	3.26
1421	-0.06
1422	1.36

1423	-0.12
1424	1.23
1425	0.91
1426	1.12
1427	0.01
1428	-1.02
1429	0.11
1430	1.05
1431	0.6
1432	0.65
1433	1.49
1434	3.09
1435	-0.02
1436	-2.3
1437	-0.24
1438	-0.18
1439	-0.18
1440	-0.37
1441	0.72
1442	1.32
1443	-0.06
1444	0.18
1445	-0.96
1446	-1.51
1447	-1.49
1448	-1.97
1449	-0.37
1450	-0.01
1451	-1.2
1452	-0.01
1453	-1.02
1454	-0.78
1455	-0.54
1456	-0.78
1457	1.18
1458	0.71
1459	-0.96
1460	0.29
1461	0.92
1462	1.88
1463	-0.89

1464	1.04
1465	-1.33
1466	-0.18
1467	-0.19
1468	-0.68
1469	0.5
1470	-1.02
1471	1.56
1472	0.12
1473	3.63
1474	-1.2
1475	-0.54
1476	-0.37
1477	-1.33
1478	0.59
1479	0.94
1480	-1.22
1481	-1.76
1482	0.91
1483	1.04
1484	0.34
1485	-1.49
1486	0.51
1487	0.31
1488	-1.5
1489	-0.54
1490	0.03
1491	-1.6
1492	-0.62
1493	-0.89
1494	0.72
1495	1.44
1496	-1.49
1497	-1.33
1498	-0.07
1499	-0.23
1500	1.02
1501	0.61
1502	-0.37
1503	-0.2
1504	1.08

1505	-1.5
1506	-0.21
1507	0.38
1508	-0.54
1509	0.51
1510	-0.46
1511	-1.56
1512	0.03
1513	0
1514	-1.02
1515	-0.89
1516	1.29
1517	-0.07
1518	-0.62
1519	-1.22
1520	-0.96
1521	2.64
1522	2.48
1523	4.1
1524	1.03
1525	0.38
1526	-0.17
1527	-0.89
1528	-0.96
1529	-1.49
1530	1.04
1531	-0.06
1532	0.36
1533	-0.96
1534	-0.22
1535	-1.11
1536	1.82
1537	-1.11
1538	0.52
1539	-0.06
1540	-0.89
1541	-0.78
1542	-1.94
1543	-0.54
1544	-0.37
1545	1.17

1546	-0.01
1547	-0.37
1548	-0.62
1549	-0.78
1550	-1.02
1551	-0.21
1552	1.16
1553	-0.89
1554	0.32
1555	-1.43
1556	2.32
1557	-0.68
1558	-0.46
1559	2.64
1560	-0.89
1561	-0.02
1562	-0.06
1563	-0.21
1564	-1.86
1565	-0.62
1566	-0.46
1567	0.48
1568	-0.89
1569	-0.05
1570	-0.46
1571	1.13
1572	0.2
1573	-1.33
1574	-0.22
1575	-0.06
1576	-0.54
1577	-0.68
1578	0.29
1579	-1.2
1580	-0.62
1581	-0.68
1582	-0.24
1583	1.29
1584	-0.05
1585	-1.02
1586	-0.62

1587	-1.49
1588	-0.04
1589	-0.06
1590	1.67
1591	-0.62
1592	-0.68
1593	-0.54
1594	-0.68
1595	-0.01
1596	-0.89
1597	-1.49
1598	0.16
1599	1.16
1600	-1.58
1601	-1.11
1602	-0.26
1603	0.92
1604	0.17
1605	0.58
1606	-0.89
1607	0.08
1608	-0.62
1609	-0.21
1610	0.48
1611	1.03
1612	-0.62
1613	-0.04
1614	-0.96
1615	0.35
1616	1.31
1617	-0.68
1618	-0.96
1619	-0.06
1620	-0.37
1621	-1.7
1622	0.11
1623	0.93
1624	1.04
1625	-0.78
1626	-0.54
1627	-1.61

1628	-1.59
1629	-0.18
1630	0.48
1631	0.55
1632	-0.89
1633	-1.02
1634	-0.68
1635	0.36
1636	2.48
1637	2.82
1638	1.81
1639	0.51
1640	-0.62
1641	-0.68
1642	-0.68
1643	-0.54
1644	0.89
1645	1.55
1646	0.84
1647	0.69
1648	-0.62
1649	-1.11
1650	-0.78
1651	0.34
1652	0.39
1653	1.55
1654	-0.62
1655	0.2
1656	-0.19
1657	0.3
1658	-0.46
1659	-0.46
1660	-0.54
1661	1.05
1662	0.34
1663	-1.11
1664	0.55
1665	1.04
1666	1.66
1667	-0.23
1668	0.47

1669	1.54
1670	0.31
1671	0.93
1672	-0.37
1673	-0.89
1674	0.54
1675	-1.52
1676	1.69
1677	-0.18
1678	0.5
1679	0.19
1680	1.7
1681	1.79
1682	-0.22
1683	1.26
1684	2.48
1685	1.4
1686	2.64
1687	-0.37
1688	-0.22
1689	-0.19
1690	0.29
1691	0.82
1692	-1.22
1693	-0.46
1694	1.01
1695	-0.68
1696	-0.62
1697	0.13
1698	-1.49
1699	-0.24
1700	-0.78
1701	-0.12
1702	0.44
1703	-0.21
1704	0.97
1705	-0.46
1706	1.88
1707	-0.07
1708	-0.12
1709	-0.46

1710	0.29
1711	-0.12
1712	-0.46
1713	-1.02
1714	-0.54
1715	-0.28
1716	-0.89
1717	-0.18
1718	2.17
1719	2.09
1720	-0.46
1721	-0.78
1722	-0.12
1723	0.68
1724	0.43
1725	-1.6
1726	1.51
1727	1.23
1728	0.56
1729	-0.78
1730	-0.54
1731	0.19
1732	-0.12
1733	-0.12
1734	0.68
1735	-1.22
1736	0.17
1737	0.32
1738	-0.78
1739	-0.28
1740	-1.94
1741	-0.46
1742	-0.96
1743	-0.37
1744	-0.89
1745	-0.54
1746	-0.37
1747	-0.68
1748	-0.46
1749	-0.54
1750	-0.21

1751	-1.22
1752	-0.62
1753	0.17
1754	-0.89
1755	0.31
1756	-1.29
1757	-0.29
1758	-0.12
1759	-0.06
1760	0.3
1761	0.57
1762	0.58
1763	-1.22
1764	0.46
1765	-0.62
1766	-0.37
1767	-1.29
1768	-0.62
1769	-0.54
1770	-1.43
1771	-0.37
1772	-0.46
1773	-0.62
1774	-0.07
1775	-0.46
1776	-0.68
1777	-0.89
1778	-0.12
1779	-0.06
1780	0.07
1781	0.97
1782	-0.89
1783	0.43
1784	0.57
1785	-0.12
1786	-0.46
1787	-1.02
1788	0.59
1789	-1.22
1790	-0.37
1791	0.32

1792	-0.96
1793	-0.2
1794	0.77
1795	-0.54
1796	-1.11
1797	-1.11
1798	0.68
1799	-1.43
1800	-0.08
1801	-0.54
1802	0.5
1803	0.19
1804	-0.62
1805	-1.76
1806	0.05
1807	0.11
1808	-0.46
1809	-1.48
1810	-0.62
1811	1.4
1812	-1.02
1813	-1.11
1814	-0.89
1815	-0.07
1816	-2.21
1817	-1.7
1818	0.43
1819	-0.06
1820	-1.11
1821	-1.64
1822	2.97
1823	-1.43
1824	-1.46
1825	0.32
1826	-0.54
1827	-0.06
1828	-0.37
1829	-1.33
1830	-0.12
1831	-0.21
1832	-0.78

1833	-0.2
1834	0.69
1835	-0.78
1836	-0.96
1837	-0.96
1838	-1.02
1839	-0.17
1840	0.07
1841	-0.12
1842	1.08
1843	-1.5
1844	0.18
1845	-1.02
1846	1.35
1847	-0.62
1848	-0.37
1849	-0.46
1850	-1.11
1851	-1.02
1852	-0.62
1853	-1.11
1854	-0.62
1855	-0.96
1856	-1.02
1857	0.45
1858	0.31
1859	0.42
1860	-1.33
1861	0.06
1862	0.32
1863	-0.46
1864	-0.62
1865	1.72
1866	-0.68
1867	-0.37
1868	1.36
1869	0.07
1870	0.76
1871	-0.89
1872	-0.62
1873	-0.54

1874	-0.05
1875	-0.29
1876	-0.89
1877	-0.54
1878	-0.96
1879	-1.64
1880	-0.62
1881	-0.16
1882	-0.68
1883	-0.96
1884	-0.54
1885	-0.12
1886	-0.46
1887	-0.46
1888	-1.11
1889	-0.04
1890	-0.68
1891	-1.43
1892	0.17
1893	3.26
1894	-0.46
1895	0.06
1896	-0.37
1897	0.32
1898	-0.59
1899	-0.18
1900	-0.46
1901	0.86
1902	-0.62
1903	-0.96
1904	0.24
1905	0.06
1906	0.24
1907	-0.78
1908	0.19
1909	-0.68
1910	-0.89
1911	1.38
1912	-0.46
1913	-0.62
1914	-0.89

1915	0.76
1916	-1.11
1917	1.4
1918	-0.04
1919	-0.3
1920	-0.19
1921	0.19
1922	-0.06
1923	-0.17
1924	-0.04
1925	0.17
1926	-0.12
1927	0.19
1928	-0.46
1929	-0.07
1930	-0.28
1931	-0.2
1932	-1.22
1933	-0.37
1934	0.7
1935	-0.62
1936	-0.59
1937	0.42
1938	-0.78
1939	-1.6
1940	-0.12
1941	-0.96
1942	0.24
1943	0.24
1944	-0.78
1945	0.76
1946	0.18
1947	0.85
1948	-0.21
1949	0.18
1950	0.3
1951	-1.02
1952	0.69
1953	0.16
1954	-1.11
1955	-0.62

1956	-1.49
1957	-0.62
1958	-0.46
1959	0.86
1960	0.31
1961	-0.06
1962	-1.11
1963	-0.96
1964	0.24
1965	-1.43
1966	-0.17
1967	-0.46
1968	-0.54
1969	-0.89
1970	-0.46
1971	0.68
1972	-1.02
1973	0.06
1974	0.08
1975	0.07
1976	2.17
1977	-0.78
1978	0
1979	-0.01
1980	-1.22
1981	0.02
1982	0.71
1983	0.12
1984	-0.78
1985	-0.2
1986	-0.07
1987	-0.62
1988	0.08
1989	0.88
1990	0.6
1991	0
1992	0.6
1993	0.49
1994	0.42
1995	-0.06
1996	0.38

1997	1.04
1998	0.63
1999	0.63
2000	1.03
2001	0.5
2002	0.71
2003	5.86

Table A- 15. Livestock data.

Year (AD)	Cattle AU	Sheep AU	Pigs AU	Goats AU	Horses AU	Donkeys AU	Total Livestock	Livestock Density (AU/km^2)
1836	980.0	528.0	560.0	14.0	10.0	4.0	2096.0	63.5
1841	460.0	780.0	240.0	50.2	-	-	1530.2	46.4
1903	1230.3	154.9	587.6	15.0	34.7	47.3	2069.8	62.7
1925	2142.0	66.1	862.0	26.0	114.0	60.0	3270.1	99.1
1934	2485.0	55.5	454.0	26.0	195.0	25.0	3240.5	98.2

Table A- 16. Population data for Uxeau Commune.

Year (AD)	Population	Population Density (people/km2)
1836	1050	31.81818182
1841	1073	32.51515152
1902	1012	30.66666667
1903	1012	30.66666667
1904	986	29.87878788
1925	746	22.60606061
1934	672	20.36363636

Table A- 17. Land use data for Uxeau Commune.

Year (AD)	Woods (Ha)	Pasture (Ha)	Cropland (Ha)
1836	614	197	2230
1847	614	197	2245
1866	613	306	2180
1880	614	463	2134
1902	601	507	1485

1904	598	508	1529
1915	548	516	1869
1925	586	550	1320
1934	586	600	1247

Table A- 18. Pollen data for Lucenier pond.

	4		3d	3c		3b			
depth (sm):	10-11sm	20-21sm	40-41sm	60-61sm	90-91sm	110-11sm	130-131sm	155-156sm	160-161 sm
slide number:	N60	N63	N71	N79	N60(box2)	N33	N26	N?	N13
a. Trees and shrubs of dump soils									
Alnus	173	163	15		6	10	31	25	18
Frangula Alnus									
Salix	14	17			5	7	5	7	3
b. Shade-tolerant trees and shrubs									
Acer							1		
Fraxinus	17	21	3		2	3	5	2	3
Quercus	93	151	22	10	18	57	73	87	55
Tilia	1		1					1	
Ulmus	2	3					1		1
Hedera helix	2	3	1						
Fagus		2	1		2	3	3	5	
Carpinus	1	3	2	1	3	1	1	4	2
Picea abies	2						1		
Cornus sanguinea									
Crataegus									
Lonicera caprifolium type									
Sambucus nigra	5	11	4	1	1	6	2		
Taxus									
Viburnum									
c. Light-demanding trees and shrubs									
Corylus	18	16	6			9	20	16	10
Betula	15	32	3		2	10	10	14	3
Pinus	15	27	6	1	2	2	2	6	3

Populus tremula	1		2			4		1	3
Evonymus									
Prunus						2		4	3
Rhamnus cathartica									
Rosaceae (Cotoneaster, Malus, Sorbus intermedia, Rosa)		1				1	4	3	2
Rubus									
Sorbus aucuparia	1	2		1		1	1	3	1
d. Cultivated trees and shrubs									
Aesculus hippocastaneum	1	2	4					1	
Buxus sempervirens	1								
Castanea	23	28	12	5	11	49	53	45	9
Juglans regia	4		1	1	1	3	2	3	1
Ligustrum vulgaris/ Syringa									
Ribes alpinum									
e. Forest herbs and ferns									
Dryopteris type	1	1	1		1	1	2	6	3
Dryopteris filix-mas			1						
Polypodium vulgare								2	
Pteridium aquilinum	1	2	2	1	2	7	8	7	2
f. Dry pastures-heath-"Alvar" vegetation									
Calluna		1	2		1	3	2	10	5
Centaurea nigra type	2					2	1		2
Dianthus type						1			
Erica tetralix									
Ericaceae undiff.									
Genista type									
Jasione montana			4		2	6	8	3	5
Juniperus						1	3	4	
Ononis type (total rows 63-64)									
Ononis type (cf. Hedysarum hedisaroides)									
Plantago media type								2	
Vaccinium (total rows 66-68)						1			

(Vaccinium cf. V. myrtillus)						1			
(Vaccinium cf. V. vitis-idaea)									
g. Fresh meadow and pastures		4	3d	3c	3b			3a	
Poaceae undiff	62	87	32	1	25	22	36	54	34
Aegopodium podagraria									
Anthriscus sylvestris	1				1				
Aster type (Eupatorium and others)		1	3			2	4	4	2
Bellis perennis								2	
Campanula type									
Caryophyllaceae undiff.	1								
Cerastium type									
Cerastium fontanum type									1
Cirsium									
Cirsium type	1	1							
Filipendula	4	4			1			2	
Fragaria vesca							1		
Galium type		2	1					2	1
Geranium		1							
Geum	3	1	1			2	1	6	
Heracleum sphondylium type		1				1			
Hypericum perforatum type		1			1		2		
Lamium type									1
Lathyrus									
Lotus type		1				1	2		
Onobrychis type									
Peucedanum palustre type		1				1		3	1
Plantago lanceolata	14	15	9		4	11	10	10	11
Potentilla type								1	
Prunella type									
Ranunculus acris type, R.acris gr.	2		2	2	1	2	3	1	
Ranunculaceae undiff.						1			
Ranunculus acris type									
Ranunculus acris type Anemone nemorosa gr						2	2	2	
Rhinanthus type					1				

Rumex acetosa type, R. obtusifolius group		2					1		
Rumex acetosa type, R. acetosa gr./R. acetosella		10	38	10	25	31	62	43	29
Scabiosa									
Succisa pratensis									
Leguminosae undiff.		1							
Trifolium campestre								1	
Trifolium pratense	1						1		
Trifolium repens	3	5	2			1		2	
Trifolium type					1		1		
Umbelliferae undiff.	1	3							
Veronica									
Vicia cracca type									
Vicia sylvatica type									
h. Wet meadows, lake/pond shore - ditches (telmatophytes)									
Cyperaceae	2	4	11	1		6	9	16	6
Caltha palustris	1				1				
Chrysosplenium	1				2				
Epilobium			1						
Equisetum	1						1	1	
Mentha type					1	2	3	2	
Oenanthe fistulosa type									
Peplis portula		1			1	2			
Phragmitis type	18	36	16	1	13	14	26	37	14
Sparganium type	2						1	1	
Sanguisorba officinalis									
Solanum dulcamara			1		1		1	1	
Thalictrum									1
Typha latifolia	1	2					3	1	1
Angelica Archangelica									
i. Ruderal communities									
Anthemis type	1	1	3		1	3		3	
Artemisia		3	2			1	3	3	1
Centaurea Scabiosa									
Chenopodiaceae	1	3					3	1	2
Compositae SF		2							

Asteroideae									
Compositae SF Cichorioideae	4	2	10	5	6	14	29	10	7
Cynoglossum									
Echium vulgare				1					
Euphorbia					1				
Hornungia type									
Plantago major								2	1
Polygonum aviculare type		2	1		3		4	4	3
Polygonum persicaria type (= Persicaria maculosa t.)			1						1
Sagina procumbens type									
Scleranthus perennis		1	4	8	1	8	17	8	1
Sinapis type		6	2		1	4	2	7	
Tragopogon pratensis type			1						
Urtica		4	1			1			
j. Cultivated land (cultivated plants and related weeds)									
g. Fresh meadow and pastures		4	3d	3c	3b			3a	
Avena type									
Hordeum type	3	3	2					4	1
Secale cereale	7	14	12	7	9	39	37	36	21
Triticum type	5	3			2				
Cerealia type			2					2	1
Cannabis type	9	13	26	3	15	53	16	106	57
Centaurea cyanus	1		1	1	1	2	3	1	2
Fagopyrum esculentum	1					3			
Medicago									
Zea mays		1							
k. Aquatics									
Alisma plantago-aquatica									
Apium inundatum									
Isoetes					1				
Lemna minor									
Nuphar hair			1				2	1	
Nymphaea						1	1	2	3
Polygonum amphibium (= Persicaria amphia)									
Potamogeton Eupotamogeton									

Ranunculus acris type, R. flammula gr/R. sceleratus gr.									
Trapa natans	1	1				1		1	
Undiff.	5	3	9	1	2	2	14	8	4
Pediastrum without holes	8	6						4	4
Pediastrum with holes	1	3						1	2
Charcoal >25 µm	59	115	25	16	30	44	122	59	24
Charcoal >10-25 µm	244	382	222	117	216	344	487	360	156
Lycopodium spores	108	187	66	33	23	67	129	105	45

Lucenier 2	3a							2c					
depth (sm):	165-166 sm	170-171sm	175-176	180-181sm	185-186sm	200-201sm	210-211 sm	220-221sm	225-226sm	230-231 sm	235-236 sm	240-241sm	245-246sm
slide number:	N10	N8	N5	N3	N1-2	II.5	II.10	II.14	II.16	II.17	II.19	II.22	II.24
a. Trees and shrubs of dump soils													
Alnus	30	26	23	14	31	17	38	24	41	45	18	73	60
Frangula Alnus													
Salix	5	7	6	4	11		3	3	1				
b. Shade-tolerant trees and shrubs													
Acer					2								
Fraxinus		2	3	2	3				2		1	1	
Quercus	104	69	65	39	71	35	60	47	76	67	31	68	45
Tilia	2	1											

Ulmus		1	2				1		2			1	
Hedera helix	1												
Fagus	8	5	2	5	3	5	13	5	7	7	2	1	1
Carpinus	2	5	7	2	6		3	1	8	5	3	2	1
Picea abies													
Cornus sanguinea													
Crataegus													
Lonicera caprifolium type													
Sambucus nigra	1	3			5	4	5				1		1
Taxus							1		2				
Viburnum				1									
c. Light-demanding trees and shrubs													
Corylus	9	19	13	8	12	11	4	7	10	10	6	4	10
Betula	10	7	9	7	9	3	17	11	20	13	10	7	5
Pinus	3	2	1	2	5	3	5	6	8	4	2		
Populus tremula	4	6	7		3		4	1					1
Evonymus													
Prunus		4	2			1	2	1					
Rhamnus cathartica													
Rosaceae (Cotoneaster, Malus, Sorbus intermedia, Rosa)		3					3		2	2			
Rubus													
Sorbus aucuparia	2	1	3	1	6		6		3	1			
d. Cultivated trees													

and shrubs													
Aesculus hippocastaneum								1					
Buxus sempervirens													
Castanea	34	25	14	14	15	5	16	1	4	1		3	
Juglans regia	3	3	2	1	2	1	4		3				
Ligustrum vulgaris / Syringa													
Ribes alpinum								1					
e. Forest herbs and ferns													
Dryopteris type	1	5		1	7		11	2	2	1	3	5	3
Dryopteris filix-mas													
Polypodium vulgare													
Pteridium aquilinum	10	3	5	4	4	4	9	8	8	6	2	3	9
f. Dry pastures-heath-"Alvar" vegetation													
Calluna	10	10	9	6	10	5	18	7	21	16	8	12	10
Centaurea nigra type	1	2	2				1	1	3	1			
Dianthus type													
Erica tetralix							1		1				

Ericaceae undiff.													1
Genista type							1						
Jasione montana	4	4		2	4	3	4	1	1	2	1	1	2
Juniperus	4	3	1	1		2	6	2	3	3	1	2	2
Ononis type (total rows 63-64)			2						3				2
Ononis type (cf. Hedysarum hedisaroides)													1
Plantago media type		1											
Vaccinium (total rows 66-68)		1		1									
(Vaccinium cf. V. myrtillus)		1											
(Vaccinium cf. V. vitis-idaea)				1									
g. Fresh meadow and pastures						2c					2b		
Poaceae undiff	32	35	39	33	73	29	78	43	70	57	31	64	51
Aegopodium podagraria													
Anthriscus sylvestris													
Aster	1	2		2		1	1	7	2	5	6	8	1

type (Eupatorium and others)													
Bellis perennis	2	2			2		3						
Campanula type					1								
Caryophyllaceae undiff.	1								2				2
Cerastium type	1						1			1			
Cerastium fontanum type													
Cirsium			1										
Cirsium type													
Filipendula			3	2	2	1	1	1				3	1
Fragaria vesca		3	1		2		1						
Galium type		2		1		1	1		1	3		1	
Geranium													
Geum							4					1	
Heracleum sphondylium type			1										
Hypericum perforatum type													
Lamium type	1	1											
Lathyrus												1	
Lotus type	2	1	1										
Onobrychis type									1		1		
Peucedanum palustre	1	1		1									

type													
Plantago lanceolata	4	5	16	4	10	6	23	14	19	23	9	10	4
Potentilla type				3	4	1	1	2			1		3
Prunella type							1						1
Ranunculus acris type, R.acris gr.	3						2		1		1	2	
Ranunculaceae undiff.													2
Ranunculus acris type		4	2	2									
Ranunculus acris type Anemone nemorosa gr		2	2	1								4	2
Rhinanthus type							2						
Rumex acetosa type, R. obtusifolius group	1		1									1	
Rumex acetosa type, R. acetosa gr./R. acetosella	23	19	28	15	22	18	45	33	50	29	12	23	20
Scabiosa										1			
Succisa pratensis			1	1									
Leguminosae undiff.		1					1		2			2	

Trifolium campestre	1												
Trifolium pratense								1					
Trifolium repens	1		1	3	2	2	5		2	3			1
Trifolium type	2	1											
Umbelliferae undiff.			1		2	1			1				
Veronica										2			
Vicia cracca type													
Vicia sylvatica type													
h. Wet meadows, lake/pond shore - ditches (telmatophytes)													
Cyperaceae	13	6	13	5	8	1	20	14	12	18	5	18	11
Caltha palustris													
Chrysosplenium													
Epilobium													
Equisetum	3	3	1	1					1				1
Mentha type		1			1	1	2						
Oenanthe fistulosa type									2				
Peplis portula	2						1		1	1	1	10	
Phragmitis type	15	13	12	10	6	11	34	19	26	17	12	20	28
Sparganium type		1			2		2	1					

Sanguisorba officinalis								1				2	
Solanum dulcamara						1	1						
Thalictrum													
Typha latifolia			1							1			
Angelica Archangelica													
i. Ruderal communities													
Anthemis type	2		5			1	6	2	6	2	1	2	
Artemisia	1	2	2		5	1			2				1
Centaurea Scabiosa													2
Chenopodiaceae	1	1	1		1	1	4			2			1
Compositae SF Asteroideae					1								
Compositae SF Cichorioideae	2	12	5	7	7	11	25	17	27	8	7	9	11
Cynoglossum							2						
Echium vulgare							1						
Euphorbia													
Hornungia type													
Plantago major				1			1		1			1	
Polygonum aviculare type	3	1	1	1	1	4	4	2	1			1	

Polygonum persicaria type (= Persicaria maculosa t.)													
Sagina procumbens type					1								
Scleranthus perennis	8	6	4	3	5	7	8	4	5	4	5	4	2
Sinapis type	6	3	3		4		2	1	2	6		1	
Tragopogon pratensis type													
Urtica	4		1	5	3		2		1				
j. Cultivated land (cultivated plants and related weeds)													
g. Fresh meadow and pastures						2c					2b		
Avena type													
Hordeum type		2				1	8	5	7		2	2	6
Secale cereale	21	19	14	17	21	10	20	27	17	12	4	14	9
Triticum type					1					1			
Cerealia type	3	2	4	2		1	5	4	12	7	3	14	1
Cannabis type	40	81	96	75	46	26	29	55	41	23	4	9	5
Centaurea cyanus	2	1		2	3		4		3	2	3	1	
Fagopyrum esculentum	1				1								
Medicago	2												
Zea mays													
k. Aquatics													

Alisma plantago-aquatica				2	1	2		1				1	
Apium inundatum													
Isoetes													
Lemna minor													
Nuphar hair													
Nymphaea	4	2								1			
Polygonum amphibium (= Persicaria amphia)													
Potamogeton Eupotamogeton							1		1				
Ranunculus acris type, R. flammula gr/R. sceleratus gr.	1						2	3	5	5		2	1
Trapa natans			2	1								1	
Undiff.	6	15	11	5	22	4	18	10	18	9	3	10	15
Pediastrum without holes	2	1	1	4	2	1	2	7	3	3	1	2	1
Pediastrum with holes	2		3	2	9		1		2				1
Charcoal >25 µm	40	37	41	45	82	85	63	19	55	48	24	45	34
Charcoal >10-25 µm	276	237	251	206	199	157	208	118	218	203	82	162	167

Lycopodium spores	78	63	58	43	92	28	81	34	89	102	38	52	40

Lucenier 2	2b					2a			1	
depth (sm):	254-255sm	260-261sm	265-266sm	270-271sm	280-281sm	290-291sm	300-301sm	310-311sm	320-321sm	335-336sm
slide number:	II.25	II.28	II.30	II.32	II.36	II.39	II.43	II.48	II.51	II.57
a. Trees and shrubs of dump soils										
Alnus	10	54	73	19	11	6	15	104	111	137
Frangula Alnus					1					
Salix	6	2	3	1			1		1	1
b. Shade-tolerant trees and shrubs										
Acer										
Fraxinus									1	
Quercus	47	41	41	25	15	9	36	31	31	22
Tilia							1	1		4
Ulmus		2	1							
Hedera helix										
Fagus		4	7	3	4		3	12	18	6
Carpinus	1	2		1		1	2	2		2
Picea abies							1			
Cornus sanguinea										
Crataegus										
Lonicera caprifolium type				1						
Sambucus nigra	2		1	1	1					
Taxus		1								
Viburnum										

c. Light-demanding trees and shrubs										
Corylus	7	13	3	3	6	5	3	14	41	24
Betula	8	14	5	5	2	7	6	4	9	2
Pinus	6	4	7		4	1	2		3	
Populus tremula		1	3	2						
Evonymus										
Prunus										
Rhamnus cathartica										
Rosaceae (Cotoneaster, Malus, Sorbus intermedia, Rosa)	3	2		1	2					
Rubus										
Sorbus aucuparia	1	2						1		
d. Cultivated trees and shrubs										
Aesculus hippocastaneum										
Buxus sempervirens										
Castanea	20	3	2	1	2		2			
Juglans regia	4			1	1					
Ligustrum vulgaris/ Syringa										
Ribes alpinum										
e. Forest herbs and ferns										
Dryopteris type	1	4		1	1		1	117	66	88
Dryopteris filix-mas										
Polypodium vulgare	1									
Pteridium aquilinum	6	6	7	8	9	11	9	5	1	1
f. Dry pastures-										

heath- "Alvar" vegetation										
Calluna	6	16	13	13	14	35	5	2	1	1
Centaurea nigra type						2	1			1
Dianthus type	1				1					
Erica tetralix										
Ericaceae undiff.										
Genista type										
Jasione montana	8		2			3			1	
Juniperus		1	2				1	1		
Ononis type (total rows 63-64)										
Ononis type (cf. Hedysarum hedisaroides)										
Plantago media type			2			1				
Vaccinium (total rows 66-68)				1						
(Vaccinium cf. V. myrtillus)										
(Vaccinium cf. V. vitis-idaea)										
g. Fresh meadow and pastures						2a		1		
Poaceae undiff	49	68	43	41	102	74	105	59	17	10
Aegopodium podagraria										
Anthriscus sylvestris							1			
Aster type (Eupatorium and others)	4	8	4	6	2	3	1		2	1
Bellis perennis										

Campanula type										
Caryophyllaceae undiff.		2								
Cerastium type									1	
Cerastium fontanum type										
Cirsium		1			1					
Cirsium type								2	1	
Filipendula	2		5	2	3			2		
Fragaria vesca										
Galium type	1	2	1	1	1		3	2	1	1
Geranium				1		2				
Geum	2				1					
Heracleum sphondylium type										
Hypericum perforatum type		2		3	2					
Lamium type										
Lathyrus		1	1					1		
Lotus type	1			1	2					
Onobrychis type					1					
Peucedanum palustre type										
Plantago lanceolata	12	17	13	16	16	13	12	5	8	6
Potentilla type	2	3	1		3	1	4	3		
Prunella type										
Ranunculus acris type, R.acris gr.	1	1	1	3	4		5	2	1	
Ranunculaceae undiff.										
Ranunculus acris type										
Ranunculus acris type Anemone nemorosa	3		1		4					

gr										
Rhinanthus type			2							
Rumex acetosa type, R. obtusifolius group	1									
Rumex acetosa type, R. acetosa gr./R. acetosella	28	27	22	20	22	24	16	12	8	
Scabiosa								4		
Succisa pratensis										
Leguminosae undiff.			1							
Trifolium campestre										
Trifolium pratense				1				1		
Trifolium repens	3	2			2		1		1	
Trifolium type					2			1		
Umbelliferae undiff.	1	1				2	1	1	1	2
Veronica										
Vicia cracca type										1
Vicia sylvatica type				2						
h. Wet meadows, lake/pond shore - ditches (telmatophytes)										
Cyperaceae	10	21	16	27	14		17	11	14	3
Caltha palustris			1	3						
Chrysosplenium										
Epilobium										
Equisetum	1						1			
Mentha type	1									
Oenanthe fistulosa type										
Peplis portula	1	1	3	2						

Phragmitis type	36	11	34	35	13	5	12	1	1	
Sparganium type	1	1		2			1			1
Sanguisorba officinalis										
Solanum dulcamara			2							
Thalictrum										
Typha latifolia	1			1						
Angelica Archangelica				4	2					
i. Ruderal communities										
Anthemis type	1	1	3	1	2		1	3		
Artemisia	2	2	1	3	3				1	
Centaurea Scabiosa										
Chenopodiaceae		2	1	1				1		
Compositae SF Asteroideae										
Compositae SF Cichorioideae	13	7	19	12	25	36	11	8	11	3
Cynoglossum				2						
Echium vulgare										
Euphorbia										
Hornungia type			1							
Plantago major										
Polygonum aviculare type		1						2		
Polygonum persicaria type (= Persicaria maculosa t.)										
Sagina procumbens type										1
Scleranthus perennis	2	2	7	4	4	4	4	8	4	5
Sinapis	2	1		3	2	3	2			

type										
Tragopogon pratensis type										
Urtica	1			1						
j. Cultivated land (cultivated plants and related weeds)										
g. Fresh meadow and pastures						2a		1		
Avena type					1					
Hordeum type	1	7		2	2				2	
Secale cereale	19	12	14	10	20	18	12	9	2	
Triticum type					2	3	2			
Cerealia type	4	12	5		11	17	17	3	2	1
Cannabis type	29	13	7	6	5	5	7	3		
Centaurea cyanus	3	1	4	2	2		1			
Fagopyrum esculentum										
Medicago										
Zea mays										
k. Aquatics										
Alisma plantago-aquatica	1	2								
Apium inundatum		1					7			
Isoetes										
Lemna minor						1				
Nuphar hair										
Nymphaea										
Polygonum amphibium (= Persicaria amphia)			1						1	
Potamogeton Eupotamogeton										
Ranunculus acris type, R. flammula		2	1	8	3	2	17	3		

gr/R. sceleratus gr.										
Trapa natans	1		1							
Undiff.	14	5	12	19	11	2	5	15	14	3
Pediastrum without holes	3	2	4	2	7					
Pediastrum with holes		3	4	5	1					
Charcoal >25 µm	47	23	35	38	60	59		23	32	42
Charcoal >10-25 µm	256	156	254	148	198	153		113	168	199
Lycopodium spores	66	52	52	32	63	51		72	152	264

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