



## EFFECTS OF HUMAN IMPACTS AND CLIMATE VARIATIONS ON FOREST: THE RIETI BASIN SINCE MEDIEVAL TIME

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**ABSTRACT** – A number of recent paleoenvironmental studies have argued that abrupt changes in climate have been the primary cause for societal collapse. Many social scientists, including anthropologists and environmental historians, reject environmental explanations as deterministic and overly simplistic. They argue that socio-political decisions contribute to environmental change and that efforts to study societal vulnerability within a human-environment system must include analysis of complex social structures. There is a gap in our understanding of how past societies responded to climate change because there are very few interdisciplinary studies that integrate both physical and behavioral sciences in paleoenvironmental reconstructions. While there is a general sense that modern societies are more insulated than pre-industrial societies from the effects of climate change, this may not prove to be true. A more complete understanding of how both natural and human-caused changes have affected the environment in the past can potentially guide decisions aimed at promoting future sustainability. Here we present a project funded by the United States National Science Foundation that will explicitly integrate paleoenvironmental reconstruction with socioeconomic history in a local context to identify linkages between social and environmental change associated with climate variability.

**KEYWORDS:** CLIMATE CHANGE, SOCIETAL COLLAPSE, PALEOENVIRONMENTAL RECONSTRUCTION, POLLEN ANALYSIS, FOREST HISTORY

### INTRODUCTION

#### Environmental change and human history

There is clear evidence that climatic variability and abrupt environmental change can impact human affairs (Lamb, 1995), but different approaches have evolved to study the relationship between humans and climate. Climatologists and paleoecologists commonly take the view that climate is the primary causal factor constraining societies sensitive to famine, disease, and war driven by drought, flood, frost, or fire (Büntgen et al., 2011). Recent paleoenvironmental studies have shown correlations between climate change and cultural collapse (Diamond, 2005). Although these studies

usually include descriptions of societal factors, the correlation of climate change with cultural decline (or expansion) often is interpreted as cause and effect (Berglund, 2003), and explanations for collapse are unicausal (e.g., society was overwhelmed by climate, a natural threshold was exceeded and the community was unable to respond) (O'Sullivan, 2008). Many social scientists view environmental explanations with suspicion (Erickson, 1999) and reject environmental factors as deterministic (O'Sullivan 2008). Archeologists, anthropologists, and environmental historians stress the importance of political events, social classes, and economies in contributing to environmental change (e.g., Cifani, 2002; Aimers, 2011).

There remains a large gap in our understanding of how

societies respond to climate change. Studies that integrate contributions from physical and social sciences to address the coupled human-environment system remain the exception (Dearing et al., 2008; Büntgen et al., 2011). Paleoecologists have made significant advances in developing proxies to reconstruct long-term environmental history, but the environment is often treated as a separate system and analysis of socioeconomic conditions are left out of most paleoenvironmental studies (Harris, 2011).

A key question is “How [do] climate and other environmental changes affect the vulnerabilities of coupled human-environment systems?” (National Research Council, 2010). Our research addresses this question by reconstructing socioeconomic history from written documents along with paleoenvironmental history from paleoecologic proxies to examine societal response to past environmental change. Such an approach promises to provide a more complete understanding of how past societies adapted to a changing climate and may be instructive within the context of future climate change.

There is a sense that modern societies are more insulated than pre-industrial societies from natural environmental variation but this may not prove true (Büntgen et al., 2011). A more complete understanding of how both natural and human-caused changes have affected the environment in the past can potentially guide policy decisions aimed at promoting future sustainability (National Research Council, 2010).

## MATERIALS AND METHODS

### An interdisciplinary project in the Rieti Basin: high resolution environmental and historical data

Our study includes three elements. First, we take an interdisciplinary approach and include anthropologists and historians with paleoecologists and climatologists. Second, we develop high-resolution records of environmental change and socio-cultural history in relation to climatic change. Third, we consider multiple scenarios of culture-environment interactions to move beyond unicausal explanations. This approach includes the key elements of a geographical perspective on vulnerability: coupled human-environment systems, interdisciplinary research, place-based studies, multiple interacting drivers and shifting vulnerabilities across time (National Research Council, 2010).

Europe has a well-studied climate history that includes periods of climatic change, often associated with cultural expansion or crisis: the Roman Warm Period (~300 BC to AD 300), the Migration Period/Dark Age Cold Period (~AD

300–800), the Medieval Climate Anomaly (~AD 950 to 1250), and the Little Ice Age (~AD 1250 to 1850 AD) (e.g. Büntgen et al., 2011; Christiansen and Ljungqvist, 2012). There is also a well-developed knowledge of Roman and Medieval culture, but little is known about the landscape evolution that resulted from these cultures (Horden and Purcell, 2000; Harris, 2011). There are many paleoecologic studies from northern Europe, but surprisingly few high resolution paleoecologic studies spanning the last 2500 years from near the center of the Roman Empire where environmental impacts might be expected to be most severe (Roberts et al., 2004; Magri, 2007).

Our site, the Rieti Basin, is located in central Italy 80 km north of Rome (Fig. 1) near the heart of the former Roman Empire. The Rieti Basin has been nearly continuously utilized for agriculture for >2,300 years. We have identified a series of three lakes (Lago Lungo, Lago di Ventina and Lago di Ripasottile) with very high sedimentation rates that will allow us to reconstruct environmental change at decadal resolution. Physical proxies include forest history from pollen analysis, flood and erosion history from geochemistry, paleomagnetism and sediment analysis, lake history from diatom and geochemical analysis, and fire history from charcoal analysis.

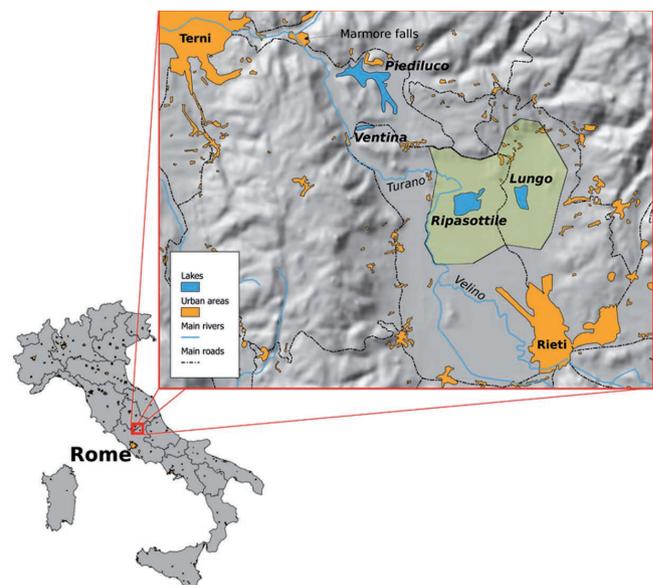


Fig. 1. Site location. Green polygon delineates the Nature Reserve of the Lungo and Ripasottile lakes.

The region has experienced different socio-political structures that have influenced land use history. These include colonization by small landowners in the early Roman period; followed by establishment of large, absentee-owned estates (latifundia); the migration period (~4<sup>th</sup> through 6<sup>th</sup>

century AD) with land abandonment and fortified living areas; the medieval period with a feudal system, aristocratic orders, and autonomous cities (comuni); and eventually industrialized modern Italy (Coccia et al., 1992, 1995). This range of different socio-cultural structures will allow us to test multiple models of environment-culture interactions. Written records for the site include classic literary sources from the first century BC, monastic documents from the 8<sup>th</sup> through 13<sup>th</sup> century AD (mainly from the nearby Benedictine Farfa Abbey), and municipal records from the 13<sup>th</sup> century forward (Lorenzetti, 1989; Leggio, 1994; Dondarini, 2006 and references therein). Written records serve as eyewitness accounts to verify the accuracy and timing of paleoecologic and archaeological reconstructions (e.g., Büntgen et al., 2011). Perhaps more importantly, they provide the social history that can determine whether environmental changes are most closely associated with climatic change or socioeconomic change (e.g., land tenure, adoption of new technology, population changes associated with war).

By comparing the timing of significant environmental changes in the paleoenvironmental reconstruction to the timing of social history from written records and climate history from independent regional reconstructions, we will be able to test whether environmental change was caused by humans, by climate, or some complex nonlinear interaction of the two. In cases when climate change appears to have resulted in socioeconomic collapse, we will explore different models of socio-political structures that influenced how the local population was able to respond to the crisis.

## RESULTS AND DISCUSSION

We have recovered multiple sediment cores from Lago Lungo and Lago di Ripasottile. To date, we have only analyzed cores from Lago Lungo, and here we present preliminary data from LUN-09-1 which extends to Medieval time. Pollen counts are not yet definitive, therefore we present only total pollen concentration data along with sedimentary analyses. Cores from Lago Lungo taken in 2009, 2010 and 2012 have been correlated through high resolution magnetic susceptibility profiles (Fig. 2). Our longest core, LUN-12-2B is 15 m long. A 1100 year sedimentary sequence from core LUN-09 (Lago Lungo, Lazio, 379 m a.s.l.) was sampled for pollen and charcoal. We constructed a preliminary age model (Fig. 3) using biostratigraphic markers (van der Knaap 2000), including the first appearance of *Zea mays* in 1760 AD (Covino, 1995), and the rise of *Cannabis* production in the 17<sup>th</sup> century and eventual decline by 1840 AD (Galli, 1840; Zuccagni-Orlandini, 1843; Nigrisoli 1857; Celetti, 2007). We also used changes in *Alnus* (alder) pollen.

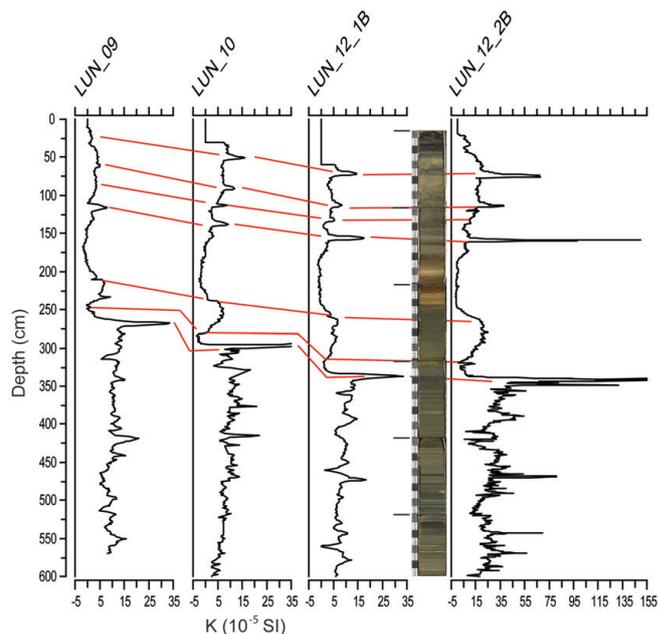


Fig. 2. Magnetic susceptibility measures for Lago Lungo sediment cores LUN-2009, LUN-2010, LUN-2012-1B and LUN-12-2B. Red lines represent correlations between peaks, determined by analysis of significant peaks and troughs in the data. Image is a high resolution scan of core LUN-12-2B.

*Alnus* requires standing water, and previous studies have shown that *Alnus* disappeared during dry periods (Calderoni et al., 1994). During the Medieval period, written records precisely date the construction of new canals intended to drain the basin. Increased flooding was described in 1277 AD and the first recorded canal was built in 1325 AD (Leggio and Serva, 1991). We attribute the *Alnus* pollen peak at 300 cm depth to this time period (Fig. 3 and 4). The last documented canal was built in 1601 AD (Lorenzetti 1989), and we attribute that date to the permanent decline in *Alnus* beginning at the 140 cm depth. Three other canals were built in 1422, 1547 and 1575 AD (Lorenzetti, 1989), and when we compare these dates to the age model, they appear to align well with declines in *Alnus* pollen, however improvements in drainage appear short lived as percent *Alnus* continued to rise. We have not yet been able to confirm our age model using radiocarbon dating. The lake biogeochemical cycles are characterized by hard water effects and the bulk sediment of the lake contains reworked humic organic material associated with soil erosion. Because of these issues, we are now isolating pollen concentrates for accelerator mass spectrometry (AMS) radiocarbon analysis to develop an independent check on our age model and analyzing paleomagnetic secular variation (PSV) (Sagnotti et al., 2011), an alternative method for developing chronologies.

We calculated a sedimentation rate of 2.8 yr cm<sup>-1</sup> for the

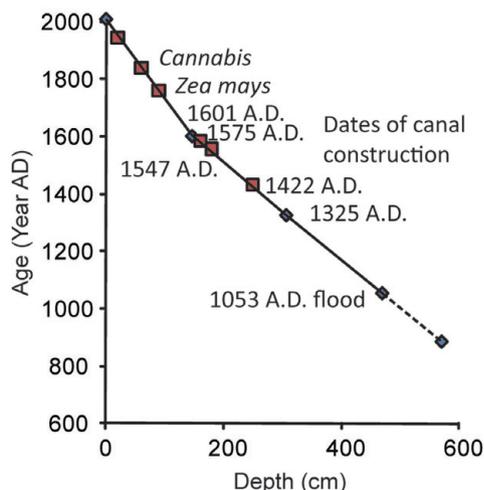


Fig. 3. Preliminary age model for Lungo Lake (2009 sampling) based on biostratigraphic markers.

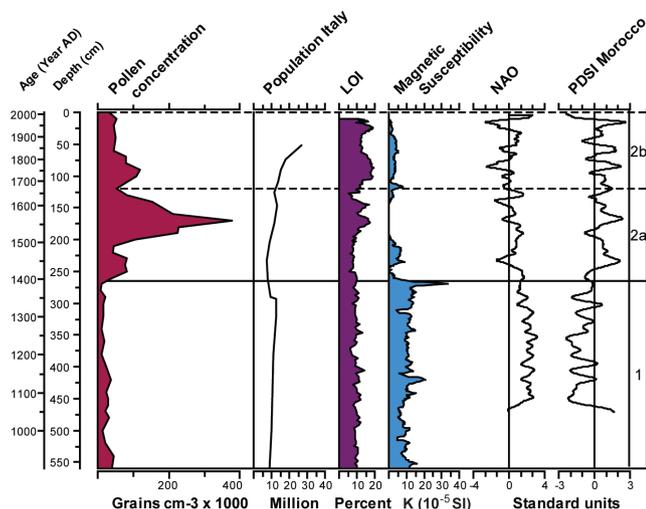


Fig. 4. Pollen concentration, loss on ignition (LOI) and magnetic susceptibility for core LUN-09-1 with changes in population (LoCascio and Malanima, 2005), North Atlantic Oscillation (NOA) (Trouet et al., 2009) and palmer drought severity index (Esper et al., 2007) reconstructed from a Moroccan tree-ring chronology.

upper meter and  $1.7 \text{ yr cm}^{-1}$  between 300 and 140 cm depth. Our sedimentation rates are consistent with previous studies. Calderoni et al. (1994) calculated sedimentation rates of  $1.4 \text{ yr cm}^{-1}$  from a core taken on the shore of Lago Lungo. We recognize that this chronology needs independent verification, however as a first approximation, our age model is consistent with previous efforts.

We analyzed 44 pollen samples from core LUN-09-1 at a resolution of 16-32 years between samples. We identified three phases of landscape change (Fig. 4). From 885 to 1400

AD (Zone 1) pollen concentration is low, magnetic susceptibility values are high, and percent organic material (LOI) remains about 10%. Pollen types are dominated by herbs and ferns with generally low quantities of tree pollen, suggesting woodlands of scattered trees and forest openings. Cereal pollen is relatively abundant. Pollen percentages support historical documents that describe periodic deforestation and agricultural expansion during the Medieval Climate Anomaly (MCA). The North Atlantic Oscillation (NAO) is in a positive phase (Trouet et al., 2009) and Palmer Drought Severity Index (PDSI) reconstruction from tree rings in the western Mediterranean indicates a period of extended dry climate (Esper et al., 2007). Fluctuations in percent arboreal pollen suggest possible periods of rapid deforestation and afforestation. We hypothesize that these changes are caused by periodic depopulation of the landscape associated with political instability from frequent invasions (Leggio, 1989; Coccia et al., 1992).

Forests recovered about 1400 AD (Zone 2a). Following depopulation associated with the black plague and socio-economic instability, pollen concentration, predominantly of mixed deciduous forest taxa, reached a maximum in 1550 AD, approximately one century later than many sites across Western Europe. Closed forest replaced the formerly open woodland in most of the landscape. Expansion of *Alnus* indicates that the valley became increasingly marshy. At the same time the increase of *Castanea* pollen is consistent with the spread of a late Medieval chestnut landscape (Mercuri and Sadori, 2012). Magnetic susceptibility values near zero indicate a drastically reduced terrigenous input into the basin. LOI measures increase along with pollen concentration. Cereal pollen declines suggesting that agricultural land may have decreased. This period coincides with a switch in the North Atlantic Oscillation from a positive to a negative phase (Trouet et al., 2009), increased precipitation, and decreased temperature associated with the Little Ice Age. We hypothesize that climate, famine and plagues forced people to largely abandon agriculture following this climatic change. The third phase (Zone 2b) began about 1650 AD and extended to the present. In general pollen concentration declines, but is still higher than during the Medieval period. At the beginning, there is a period of settlement abandonment, marked by an increase of pollen concentration and percentage of forest taxa, associated with a period of demographic crisis, famine, disease and wars (the Thirty Years' War). By the period of the early industrial revolution (around 1750 AD) forest cover and species richness declined and grass and herbs increased, indicating a more open canopy but with fewer openings than during the medieval period. The valley was drained, deforested, and agriculture intensified. Magnetic susceptibility values again increase, an indication of higher rates of erosion. Percentage of organic material (LOI) also increases, possibly in association with local

intensification of agriculture. During the modern/industrial period it is difficult to separate the human and climatic signal. There is no evidence that excessive cutting, burning and erosion during the medieval period caused permanent degradation of the landscape. Forests appear to have recovered rapidly when land use declined and climate became favorable. Comparison of the pollen data with reconstructed PDSI of Morocco and the NAO indicate periods of deforestation and woodland regeneration coincide with climate change. During warm dry climate, deforestation accelerated and agriculture expanded, and during extended cool wet climate, conditions for cereal cultivation deteriorated, forests and wetland expanded, and the local agricultural system collapsed.

By comparing the physical and historical records, we are reconstructing the complex interaction between human impacts and climate forcing on ecologic changes during the pre-industrial era. These results suggest that in the Mediterranean, in some cases, collapse of local agricultural systems may have occurred during extended periods of cool/wet climate. We are now in the process of extending our results back in time through the Roman period, analyzing data from our other lakes, and adding new proxy measures.

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