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2700 years of Mediterranean environmental change in central Italy: a synthesis of sedimentary and cultural records to interpret past impacts of climate on society

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ABSTRACT

Abrupt climate change in the past is thought to have disrupted societies by accelerating environmental degradation, potentially leading to cultural collapse. Linking climate change directly to societal disruption is challenging because socioeconomic factors also play a large role, with climate being secondary or sometimes inconsequential. Combining paleolimnologic, historical, and archaeological methods provides for a more secure basis for interpreting the past impacts of climate on society. We present pollen, non-pollen palynomorph, geochemical, paleomagnetic and sedimentary data from a high-resolution 2700 yr lake sediment core from central Italy and compare these data with local historical documents and archeological surveys to reconstruct a record of environmental change in relation to socioeconomic history and climatic fluctuations. Here we document cases in which environmental change is strongly linked to changes in local land management practices in the absence of clear climatic change, as well as examples when climate change appears to have been a strong catalyst that resulted in significant environmental change that impacted local communities. During the Imperial Roman period, despite a long period of stable, mild climate, and a large urban population in nearby Rome, our site shows only limited evidence for environmental degradation. Warm and mild climate during the Medieval Warm period, on the other hand, led to widespread deforestation and erosion. The ability of the Romans to utilize imported resources through an extensive trade network may have allowed for preservation of the environment near the Roman capital, whereas during medieval time, the need to rely on local resources led to environmental degradation. Cool wet climate during the Little Ice Age led to a breakdown in local land use practices, widespread land abandonment and rapid reforestation. Our results present a high-resolution regional case study that explores the effect of climate change on society for an under-documented region of Europe.

1. Introduction

The extent to which past abrupt climate change has directly resulted in societal disruption or cultural collapse, and the ability of societies to adapt to these changes is strongly debated (Berglund, 2003; Diamond, 2005; Munoz et al., 2010), but is potentially significant for modern communities facing future climate change (Büntgen et al., 2011). Studies concerned with the link between climate and human affairs have increasingly recognized the need to examine societal change in parallel with climate change (Dearing et al., 2008; Coombes et al., 2009; Munoz et al., 2010; McCormick et al., 2012), although the tendency persists among physical

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scientists to link cultural shifts directly to climate change (O'Sullivan, 2008; Aimers, 2011). Detailed historical analyses based on precisely dated documents have identified instances when climate has led to significant societal disruption or 'collapse', but these analyses also detail multiple examples in which socioeconomic factors played the larger role in environmental change, with climate being secondary or inconsequential (Ladurie, 1971). For this reason, it is critical that studies attempting to elucidate the impact of climate on society closely couple paleoecologic methods with historical and archaeological methods (Dearing et al., 2008; O'Sullivan, 2008; Coombes et al., 2009; Harris, 2013).

The relationship between climate change and cultural response can be addressed in areas where multi-proxy studies of cores from lakes with very high sediment accumulation rates can be examined within the context of a well-documented written history (Berglund, 2003). Such a history may provide insights into human adaptive strategies that allowed societies to cope with past climate change (Fraser, 2011). Several recent high-resolution syntheses have drawn a link between climate stability and the expansion, and eventual contraction, of the Roman Empire (Büntgen et al., 2011; McCormick et al., 2012). These studies note that focused regional case studies with highly resolved datasets are still needed to test the potential effect of rapid climate change on human societies. Such datasets are particularly needed in under-documented regions of the Roman Empire, including southern Europe, and the regions near Rome.

In central Italy, archival materials are nearly continuously available from ~700 CE (common era) in the records of the Farfa Abbey (Leggio, 1995a) in northern Lazio, Central Italy, with some written records extending back to the Roman period (De Santis and Coarelli, 2009). These documents provide a written environmental history that can be compared with physical paleoecologic reconstructions. Paleoecologic reconstructions for the last 3000 years are still underrepresented in Italy (Roberts et al., 2004; Magri, 2007) with studies from the southern Alps and North Italy (Kaltenrieder et al., 2010; Joannin et al., 2014), the northern and central Apennines (e.g. Mercuri et al., 2002; Brown et al., 2013; Branch and Marini, 2014), the Tiber Delta (Di Rita et al., 2010), and southern Italy, Sicily and Sardinia (e.g. Russo Ermolli and di Pasquale, 2002; Di Rita and Magri, 2009; Tinner et al., 2009; Di Rita and Melis, 2013; Sadori et al., 2013). These studies record the major changes in vegetation in relation to human activity during this time period but present very different impacts depending on sites and historical periods. In addition, the sampling resolution is generally at the centennial or millennial scale and cannot be easily compared with historical records. The last 3000 years are of particular interest because they encompass several important climatic changes often associated with cultural change, including the Roman Optimum (100 BCE – 200 CE; BCE – before common era), the Medieval Warm Period (MWP), ~950 to 1250 CE, and the Little Ice Age (LIA) ~1250 to 1850 CE, (Büntgen et al., 2011; Christiansen and Ljungqvist, 2012; McCormick et al., 2012).

In this paper, we present multiple physical proxies (pollen, non-pollen palynomorphs, paleomagnetism, sedimentology, geochemistry and charcoal) from a small lake in the Rieti Basin, Central Italy, to reconstruct a high-resolution record of environmental history from the present through the pre-Roman period. The basin, located approximately 80 km north of Rome, has a well-documented archeological record from pre-Roman times (Coccia et al., 1992) and historical documents from early Roman times (Coccia et al., 1992; Leggio, 1995a). We compare our physical proxies with the well-documented historical record of human activity and cultural change, and with independent climate records to explore the link between the timing of climate change, environmental change, and historical events. This study complements previous high-resolution regional syntheses from central and northern Europe (Ladurie, 1971; Büntgen et al., 2011; McCormick et al., 2012) by providing a new site in southern Europe at the center of the Roman Empire. The results contribute to our understanding of Mediterranean forest dynamics and can be used to verify recent efforts to model the history of deforestation in Europe (Kaplan et al., 2009).

2. Study area

Lago Lungo (369 m above mean sea level) is one of four remnant lakes of ancient *Lacus Velinus* in the Rieti Basin (Fig. 1), an intermontane depression in the Central Apennines that locally reach an elevation of 2217 m at Monti Reatini (Calderoni et al., 1994). The Velino, Salto and Turano Rivers flow into the basin, which is then drained by the Velino River, which plummets over a travertine sill at Marmore Falls. Other sources of inflow into the basin are numerous artesian springs that lie along the eastern edge of the basin. Water level in the basin is controlled by the elevation of the travertine sill (Calderoni et al., 1994). During prehistoric time, travertine built up during warm periods, raising the sill and expanding wetlands, and alternatively eroded during cold periods draining the valley (Calderini et al., 1998; Soligo et al., 2002). Between ~6000 and 3000 yr BP a large shallow lake (*Lacus Velinus*) filled the basin (Calderoni et al., 1994). Written documents suggest that the Romans cut a channel through the travertine sill to drain the land in ~270 BCE (Coccia et al., 1992). Since that time, water level in the basin has been controlled periodically by maintaining existing channels and cutting new channels (Lorenzetti, 1989). Historical maps suggest that the size and shape of lakes, their proximity to the Velino River, and the extent of wetlands in the basin has changed through time. Today, Lago Lungo has a maximum depth of up to 7 m with a surface area of 0.78 km^2 and surface level maintained at 369 m above sea level (Riccardi, 2006). Inflow is from a network of ditches that drain surrounding wetlands, springs, and farmland. Lago Lungo is protected within Riserva Naturale dei Laghi Lungo e Ripasottile (Riccardi, 2006).

The geology of the region is characterized by recently uplifted marine sediments. The Central Apennines are primarily composed of Upper Triassic to Middle Miocene carbonates (Parotto and Praturlon, 1975; Cosentino et al., 2010). Rieti is a seismically active extensional basin within the Apennine thrust system and is partially filled with Upper Pliocene and Holocene continental and marine sediments (Cavinato and De Celles, 1999; Soligo et al., 2002). Travertine outcrops are present across the basin, associated with past periods of warm wet climate. Seismic activity has influenced the location and discharge of springs responsible for depositing the travertines (Soligo et al., 2002). The largest spring in the basin, Santa Susanna Spring, has a discharge of 4.1 $m^3\ s^{-1}$ and is located ~3 km northeast of Lago Lungo (Spadoni et al., 2010).

Modern vegetation is dominated by agriculture in the basin and heavily managed forest on the surrounding slopes. *Phragmites* and *Salix* species grow in a narrow (~15 m) band of protected land within the reserve, while beyond the reserve border the basin floor is nearly entirely devoted to agriculture (Casella et al., 2009). Forest vegetation at lower elevations within the basin is characterized by temperate deciduous forest (e.g. *Carpinus betulus* L., *Fraxinus* spp., *Ulmus campestris* Auct.) with an important submediterranean component (*Quercus pubescens* Willd., *Quercus cerris* L.; *Carpinus orientalis* Miller; *Ostrya carpinifolia* Scop.); in the foothills on steep/shallow soils some patches of Mediterranean trees and shrubs (*Quercus ilex* L., *Phyllirea variabilis* L., *Pinus halepensis* Miller) are present while in the mountain belt (above 800–900 m) beech (*Fagus sylvatica* L.) forests are common. Climatically the area is within a transition zone between warm and cool temperate climates with a Mediterranean precipitation pattern characterized by low precipitation during summer. Mean annual temperature varies