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Research paper

Modern vegetation, pollen and climate relationships on the Mediterranean island of Cyprus

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ABSTRACT

This research investigates patterns of plant species distributions, modern pollen deposition, and climate on the island of Cyprus in the eastern Mediterranean, and explores the potential for using these modern pollen–vegetation–climate relationships for paleoenvironmental interpretation. Vegetation and pollen data were collected at 56 locations along elevational gradients from the southern coast across the Troodos Mountains, to the Kyrenia Range, and to the northern coast of Cyprus. Elevation, mean annual precipitation and mean annual temperature were interpolated for each sample locale. Discriminant analysis, cluster analysis, non-metric multi-dimensional scaling and indices of plant-pollen fidelity and dispersibility are used to characterize the vegetation and pollen of Cyprus.

The main vegetation types in Cyprus — oak forests, pine forests, orchards, and coastal scrub and salt lake vegetation can be distinguished in modern pollen samples; samples from disturbed garigue vegetation could not be separated from surrounding vegetation types. Pollen taxa demonstrate clear relationships with climatic variables. *Pinus*, Cyperaceae, *Cistus*, *Quercus* and *Prunus* are found associated with greater amounts of precipitation and higher elevations. Higher temperatures are linked particularly to Cupressaceae, *Olea*, *Cerealia*-type, Liguliflorae, and Chenopodiaceae pollen. The majority of the pollen taxa show moderate to moderately high fidelity, signifying the close link between the vegetation of Cyprus and its pollen. Many pollen taxa also reflect high dispersibility, which in some cases demonstrates over representation in the pollen rain. The relationships between the main modern pollen taxa of Cyprus and broad climatic variables can provide the basis for interpreting paleoenvironmental records.

1. Introduction

An understanding of the relationship between contemporary vegetation, modern pollen rain and climate is essential for the interpretation of fossil pollen spectra to characterize past vegetation and paleoclimates. Many studies demonstrate the value of this approach in a variety of geographic settings (e.g., Anderson, 1970; Birks, 1973; Markgraf et al., 1981; Prentice et al., 1987; Jackson, 1990; Fall, 1992; Islebe and Hooghiemstra, 1995; Ren and Beug, 2002; Ma et al., 2008; Marcos and Mancini, 2012). Investigations of taxonomic over- and under-representation of pollen types have been explored (e.g., Davis, 1984), including the calculation of palynological indices of dispersibility and fidelity (McGlone and Meurk, 2000) to help understand the patterns of pollen deposition and modern vegetation.

Studies of modern pollen rain have a long tradition in the eastern Mediterranean region. Surface pollen data, often collected as modern analogs for paleoenvironmental interpretations based on fossil pollen data, come from forested areas in Greece (Bottema, 1974; Gerasimides et al., 2006), Turkey (van Zeist et al., 1970, 1975; Vermoere et al., 2001; Kaniewski et al., 2007) and Iran (Wright et al., 1967; Ramezani et al., 2008; Djamali et al., 2009). Similarly, modern pollen studies from more arid regions in the Levant often are designed to support the interpretation of fossil pollen data (e.g., Horowitz and Baum, 1967; Rossignol, 1969; Weinstein, 1976; Bottema and Barkoudah, 1979; El-Moslimany, 1990; Horowitz, 1992; Davies and Fall, 2001). On the island of Cyprus, however, no previous studies compare extant vegetation with its modern pollen rain. Although the vegetation of the Mediterranean reflects a legacy of human impact, modern plant species distributions retain portions of their natural distributions (Zohary, 1973), thereby reflecting contemporary climatic conditions. Thus, the spatial distribution of modern pollen can be linked to the vegetation that produced it, as well as to climatic conditions.

2. Vegetation and climate of Cyprus

2.1. Climate

The climate of Cyprus is decidedly Mediterranean; relatively mild, moist winters stand in sharp contrast to hot, dry summers. Seasonal variability in precipitation is compounded by variations in annual

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rainfall, leading occasionally to multi-year droughts. The Troodos Mountains rise to over 1950 m, drawing increased precipitation off the Mediterranean Sea as air rises over this massif. The lower elevation Kyrenia Range (reaching just over 1000 m) running along the northern coast of Cyprus similarly supports a moister climate at higher elevation. The mean annual precipitation for Cyprus is about 480 mm, with values as high as 1100 mm at the top of the Troodos, about 550 mm in the Kyrenia Range, and as low as 300 mm on the Mesoria Plain (Tsintides et al., 2002). Snow generally occurs only at elevations above about 1000 m. The island's topography similarly affects temperatures, with mean daily values reaching 29 °C in summer along the coasts and on the central Mesoria plain, and cooler daily means of about 22 °C in the mountains.

2.2. Vegetation of Cyprus

The flora of Cyprus and the eastern Mediterranean is characterized by relatively high biodiversity, with many areas in which species are endangered (e.g., Quézel, 1995, 1999). Like most Mediterranean islands and coastal areas, Cyprus has experienced millennia of human exploitation. As a result, much of the original pine and oak forests have been modified heavily (Pons and Quézel, 1998). The landscape has been transformed by deforestation, fire and the introduction of domestic animals and agriculture, particularly intensive arboriculture. Hence, most vegetation communities have evolved in concert with human manipulation. Coastal Mediterranean forests often have been altered, particularly in stature, to become maquis or garigue (Burnie, 1995). Maquis is defined here as forest vegetation that has not fully regenerated and is comprised of evergreen shrubs or small trees (up to 3–5 m high). Common maquis shrubs include *Myrtus communis*, *Genista*, and *Calcycotome*. Similarly, garigue is composed of low-growing evergreen shrubs up to about 50 cm high. Throughout the Mediterranean region characteristic plants of garigue include *Thymus* and *Cistus*, both of which are unpalatable to goats (Burnie, 1995). Cyprus represents a mixture of regenerated forests, extensive areas of maquis and garigue, and orchards and agricultural fields amid a landscape of villages, towns and cities. Aside from the capital of Lefkosia (Nicosia), most of the larger towns and cities and new tourist developments are in coastal environments. Some of the lands surrounding mountain villages appear to be regenerating, as shrubs and forest species take over former fields and orchards (particularly olive and almond), as observed similarly in the western Mediterranean (e.g., Pons and Quézel, 1998). The exceptions to this forest regeneration are well-maintained vineyards and fruit orchards. In spite of this landscape modification, the potential vegetation of Cyprus is still reflected in its remnant forests and pockets of natural vegetation (Quézel and Barbéro, 1985).

2.2.1. Conifer forests

Two species of *Pinus* dominate the forests of Cyprus (Barbéro et al., 1998). *Pinus nigra pallasiana* (black pine) dominates the highest elevation pine forests of the Troodos Mountains from about 1400 m elevation to their summit at Mt. Olympus (1952 m). Tsintides (1998) notes that *Pinus nigra* can grow as low as about 1200 m elevation in wetter locations. Understory plants in the black pine forest include *Sorbus aria*, *Juniperus foetidissima*, *Rosa canina canina*, *Berberis cretica*, *Alyssum cypricum*, *Hypericum repens*, *Cotoneaster racemiflorus*, *Cistus cretica*, *Rubus sanctus* and *Pterocephalus multiflorus*. *Pinus brutia* (Calabrian pine) is a component of the black pine forest below about 1750 m elevation, which becomes a co-dominant below about 1600 m elevation. *Pinus nigra* grows in the Troodos Mountains where annual precipitation ranges between 800 and 1000 mm (falling mainly as snow) and winter temperatures drop to −10 °C (Tsintides, 1998).

Pinus brutia forests are found in the Troodos Mountains and foothills primarily between about 600–1200 m elevation, and from about 300–800 m elevation in the Kyrenia Range. Individual *Pinus brutia* trees can be found growing as low as sea level and up to about 1750 m elevation. Common trees and shrubs within the *Pinus brutia* forests in the Kyrenia Range of northern Cyprus are *Cupressus sempervirens*, *Genista spaeceolata*, *Sarcopoterium spinosum*, *Cistus* sp., *Olea europaea*, *Asphodelus* sp., *Lithodora* sp., *Pistacia lentiscus*, *Pistacia terebinthus*, *Rhamnus oleoides*, *Arbutus andrachne* and *Crataegus azarolus*. *Pinus brutia* dominates some forest stands accompanied by relatively few understory species, which include *Cistus* spp., grasses and occasional *Pistacia* spp. shrubs. In other parts of the Troodos Mountains and the southern part of Cyprus, *Pinus brutia* grows amid a wide range of species, including *Cistus* spp., *Pistacia terebinthus*, *Crataegus azarolus*, *Myrtus communis*, *Rhus coriaria*, *Ceratonia siliqua*, *Helichrysum italicum*, *Ptilostemon chamaepeuce*, *Rubia* cf. *tenuifolia*, *Pterocephalus multiflorus*, *Calicotome villosa* and *Rhamnus oleoides*.

The endemic tree *Cedrus brevifolia* (Cyprus cedar) has a restricted geographical distribution in the Cedar Valley of the Paphos Forest from 900 to 1400 m elevation (Tsintides et al., 2002). It is now planted extensively along roads, villages and monuments in the forests of the Troodos Mountains. Its relative, the exotic *Cedrus libani* (Cedar of Lebanon), is planted occasionally in the mountains. The evergreen tree *Cupressus sempervirens* (Mediterranean cypress) is indigenous to Cyprus. *Cupressus sempervirens* is planted widely in Cyprus, but also occurs naturally in forests, particularly in the Kyrenia Range where it grows alone or with *Pinus brutia* (Tsintides et al., 2002).

2.2.2. Oak forests

Two evergreen species dominate the oak forests of Cyprus, *Quercus alnifolia* (golden oak) and *Quercus coccifera* (holly or Kermes oak). A third species, *Quercus infectoria*, is less common than the other two today, but was noted historically in both the Troodos and Kyrenia mountains as growing up to 1400 m elevation (Meikle, 1985). *Quercus alnifolia* is endemic to Cyprus and grows only on the ultrabasic igneous substrates of the Troodos Mountains (Meikle, 1985). *Quercus alnifolia* generally grows between about 800 and 1500 m elevation. This oak is found with *Pinus brutia* in drier locales, but forms dense stands with other evergreen maquis species in wetter places with deeper soils (Barbéro and Quézel, 1979; Meikle, 1985). *Quercus coccifera*, distributed widely through the Mediterranean region, is closely related to *Quercus calliprinos* (Palestine oak) to the degree that in Cyprus it is classified occasionally as *Q. coccifera* subsp. *calliprinos*. *Quercus coccifera* grows primarily on limestone substrates and is common in a wide range of habitats. *Quercus coccifera* can grow from the coastal plain in southern Cyprus up to about 1400 m elevation in the Troodos Mountains, sometimes on igneous soils within the elevational range of *Quercus alnifolia*. Where they grow together, these two oaks can hybridize (Neophytou et al., 2007). Much of the elevational range of the oak forests of southern Cyprus has been converted to *Vitis vinifera* vineyards and fruit orchards.

2.2.3. Maquis and Garigue

Maquis vegetation generally occurs in areas with about 450–1000 mm of annual precipitation. Common species include *Juniperus phoenicea*, *Pistacia lentiscus*, *Ceratonia siliqua*, *Olea europaea*, *Cistus* spp. and *Salvia fruticosa*, with occasional *Pinus brutia* trees (Tsintides, 1998). At higher elevations in the Troodos Mountains, the maquis blends into the oak forests, where it is dominated by *Quercus alnifolia*, *Arbutus andrachne*, *Pistacia terebinthus*, *Quercus coccifera* and *Crataegus azarolus*.

Garigue vegetation consists of shrubs growing from sea level up into the Troodos Mountains. Characteristic plants include *Genista spaeceolata*, *Calycotome villosa*, *Cistus* spp., *Lithodora hispidula*, *Prasium majus*, *Pterocephalus multiflorus*, *Ephedra fragilis*, *Thymus capitatus*, *Fumana* spp., *Asperula cypria* and *Lavandula stoechas*, with scattered *Pistacia* spp., *Ceratonia siliqua* and *Pinus brutia* (Tsintides, 1998). On the drier, eroded slopes of the Mesoria Plain, and around Lefkosia and Larnaca, garigue plants consist of *Crataegus azarolus*, *Ziziphus lotus*, *Noaea mucronata*, *Phagnalon rupestre*, *Thymus capitatus*, *Fumana* spp., *Sarcopoterium spinosum*,