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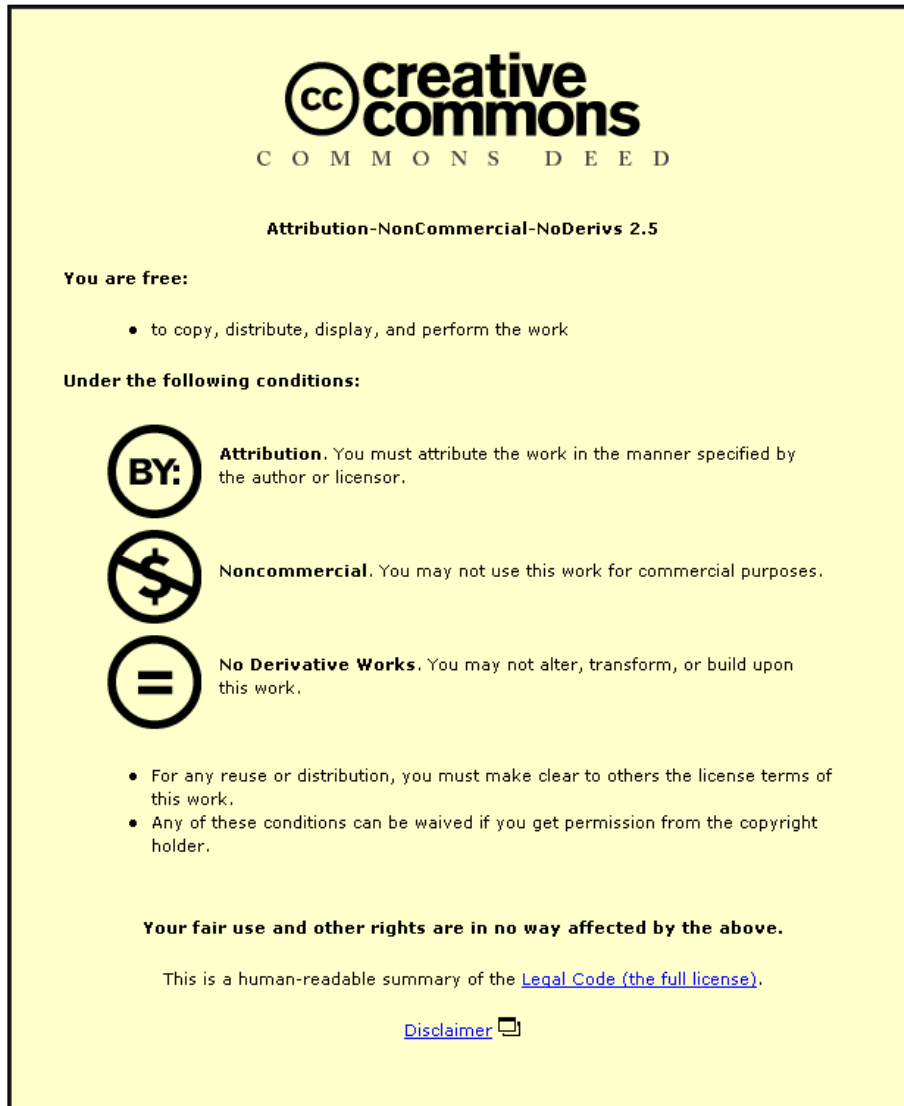
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Late Holocene Environmental Change at Castelporziano

By

Fiona Sarah Jane Brown

Doctoral Thesis

Submitted in partial fulfilment of the requirements of

For the award of

Doctor of Philosophy (Geography) Loughborough University

October 2010

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Certificate of Originality

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Signed *fjbrown*

Date 01.10.2010

Acknowledgements

I would like to thank Helen Rendell in her role as my supervisor throughout the last three years, showing good humour, understanding and helping when needed. I simply could not hope for a better or friendlier supervisor. Thanks to those on the AHRC project, a great team of people, and special thanks to Andy Bicket, Amanda Claridge, Peter Rose and James Andrew. I also would like to give thanks to the AHRC for funding the PhD and The Presidential Estate of Castelporziano for allowing me to undertake such an interesting project in such a magical location, making the research unique in so many ways.

Thanks also to my colleagues at Loughborough University's Geography department for their support and friendship, as well as the use of equipment that made my PhD possible. Within the department I would like to give warm thanks Barry, Fenguian, and Stuart in their laboratory support throughout this thesis, David Ryves for chats on palaeoenvironmental matters and Stephen Rice as my director of research, helping me see the "wood from the trees".

Outside the department but integral to this thesis the following thanks go to: Wolverhampton University's Jennie Millington for her XRF aid and John Thompsett for carrying out the XRF analysis; the unsung heroes of Beta Analytic for analysing my samples for ^{14}C , and answering my prayers for some Roman dates; Jane Bunting for our numerous emails discussing pollen.

Another big thanks to my friends and family outside of academia particularly: My graphics angels, for helping me adapt and draw some of the figures within the thesis, especially Laura R.; Farah and her family for giving me a bed and food as I finished writing this thesis; Claire my housemate for sharing the ups and downs of PhD life; Ginny and Juliette for keeping my sanity at bay; Kristy for helping me find a healthy way to de-stress and lose weight, and the musicians who wrote all the music listened to whilst writing up (especially J&S).

Abstract

The Mediterranean has long been recognised as an area that is particularly sensitive to climate change. It is also an area that has been impacted by human activity for millennia. Disentangling climatic and anthropogenic influences on the history of vegetation change in the Mediterranean remains an important challenge. As a contribution to this ongoing debate, this thesis explores the late Holocene environment of part of the coast in Central Italy using a multiproxy approach to investigate the archives of change preserved in dune slack deposits.

Distinguishing between natural and anthropogenic signals presents a real challenge in most environmental reconstruction work; however, due to the extensive archaeological research carried out at Castelporziano, it is possible to examine human-environmental interactions in some detail. In order to understand these interactions part of the thesis examines how management has affected recent environmental changes and the current vegetation and whether there is a legacy of Roman landuse at the Castelporziano estate.

The key findings of the thesis showed that dune slacks are suitable for palaeoenvironmental reconstruction with proxies such as plant macrofossils, ostracods, molluscs and bryozoans statoblasts. However, the pH and seasonality of the slacks meant proxies such as pollen were badly preserved or absent, and diatoms did not preserve due to the high levels of carbonate on site. Overall the results show the impact of the Romans on site in terms of localised eutrophication and increased fires, but with abandonment, came the formation of wet woodlands.

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Chapter 1: Introduction

The Mediterranean has long been recognised as an area that is particularly sensitive to climate change. It is also an area that has been impacted by human activity for millennia. Disentangling climatic and anthropogenic influences on the history of vegetation change in the Mediterranean remains an important challenge. As a contribution to this ongoing debate, this thesis explores the late Holocene environment of part of the coast in Central Italy using a multiproxy approach to investigate the archives of change preserved in dune slack deposits.

This chapter introduces the study site, its contemporary vegetation and climate and what is known of its history, particularly during of the Roman period (100 BC to 420 AD). The chapter also reviews the main ideas concerning the nature of the Mediterranean landscape together with the current understanding of Holocene environmental change in the northern Mediterranean. The chapter ends by outlining the main questions addressed by the thesis together with the thesis structure.

1.1 Study Area

Along the coastline of the Tyrrhenian Sea in central Italy, to the south of the mouth of the River Tiber and the Roman site of Ostia Antica is the area known as the Castelporziano Estate, which currently belongs to the President of the Italian Republic (figure 1). The coastal portion of the estate comprises the southern distal part of the Tiber delta and is characterised by dune ridges and slacks (Rendell *et al.* 2007). The dune slacks have the potential for preserving organic rich material and provide the opportunity for palaeoenvironmental reconstruction to be undertaken. Public access to the Castelporziano Estate has been restricted for centuries. A large number of plant species typical of the Mediterranean area survived because intense agricultural activity and extensive urbanization were prevented as the site has been managed first as a royal park and then, after the establishment of the Italian Republic, as a state park. Although today the estate is surrounded by dense residential areas, the estate authorities have devoted considerable efforts to preserve the various ecosystems present within it by limiting anthropogenic activities as much as possible.

What makes the Castelporziano Estate unique is that the lack of modern development allows access to the remains of a remarkable Roman period coastal

settlement comprising villas, including an imperial villa, service settlements and a road (Via Severiana). The work outlined in this thesis forms part of a larger AHRC-funded research project (*Rome's Maritime Façade*) that aims to investigate the nature and chronology of physical changes affecting the *litus Laurentinum* (the Laurentine shore) and its immediate hinterland, located between the territory of Ostia at the Tiber mouth and that of Lavinium to the south, before, during and immediately after the Roman period. Archaeological, geophysical and geomorphological methods are being combined in the survey and analysis of a seven-kilometre length of the Roman seafront. This whole area now lies several hundred metres inland from the current coastline, within a sequence of sand dune ridges, and densely forested within the confines of the Castelporziano estate (figure 1).



Figure 1 Location of study area in relation to Italy and Rome. (Tele Atlas 2009)

1.1.1 History

1.1.1.1 Site History

Earliest History

The earliest known settlement at the Castelporziano estate lies some 300 m further inland from the Roman period coastline and comprises a series of three swamps or shallow lakes and low mounds. The excavation of this site showed a group of low mounds containing shell middens and potsherds of late Bronze Age/early Iron age date (900-700 BC), close to Pozzo Napoliello (see figure 3) (Claridge pers. comm.).

This discovery contrasts with the views of Forni (1990) who assumes that Bronze Age farmers avoided wet/marsh areas. A timeline (figure 2) shows the known events in the history of the Castelporziano estate based on pottery dates and coinage, as well as written records.

Roman History

The Roman coastal winter-resort of the late Republic and Empire lay between Ostia and Lavinium. While many of the better-known centres of the *otium* (the concept of leisure, the elaborate social and cultural refiner Roman elite away from its business of political and military power) are on the fringes of cities, the *Litus Laurentinum* (Laurentine shore), as it was called, extends sufficiently far from the urban centres to make it difficult for its functioning to be seen as in any real sense suburban (Purcell 1998). In Roman times, the Castelporziano Estate, along with the neighbouring Capocotta¹ Estate formed part of the *Ager Laurens* (territory of the Laurens or Laurentinum); this refers to the people of the place, rather than its location (Claridge 2002). The seafront was called *Itus Laurentinum* (The Laurentine Shore); most importantly it was the location of a series of villas belonging to the Roman elite including the emperor (figure 3).

The larger AHRC project from which the work from this thesis stems, examined the nature and chronology of physical changes affecting the *Litus Laurentinum* before, during and immediately after the Roman period. The most intensive period of

¹ Capocotta is the area adjoining the Castelporziano estate, and has been annexed to Castelporziano since 1986 (Claridge 2002).

settlement was that of the Romans from ca. 100 BC to 420 AD. Their presence is still visible today from the ruins of an aqueduct, villas, fishponds and thermal baths.

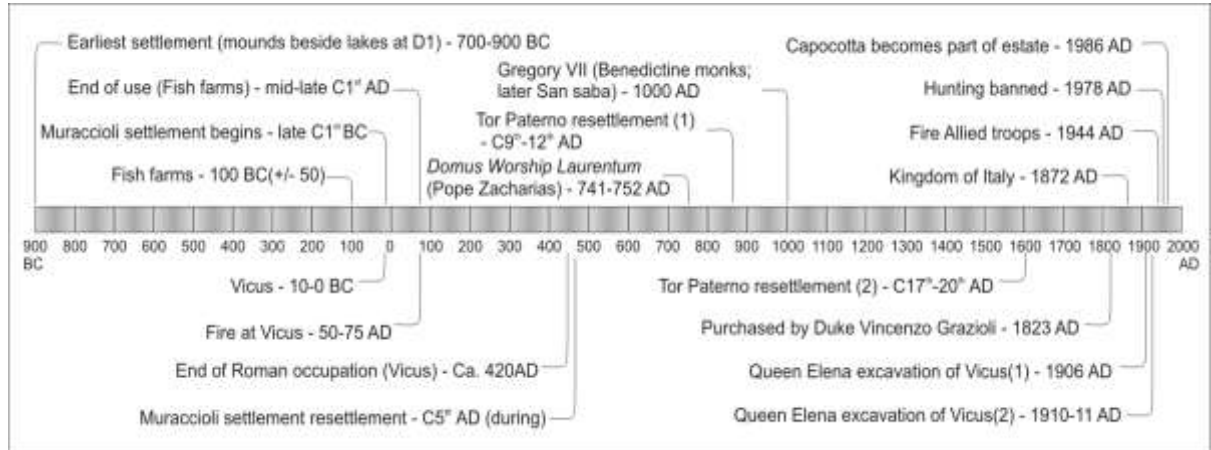


Figure 2 Time line of known events at Castelporziano

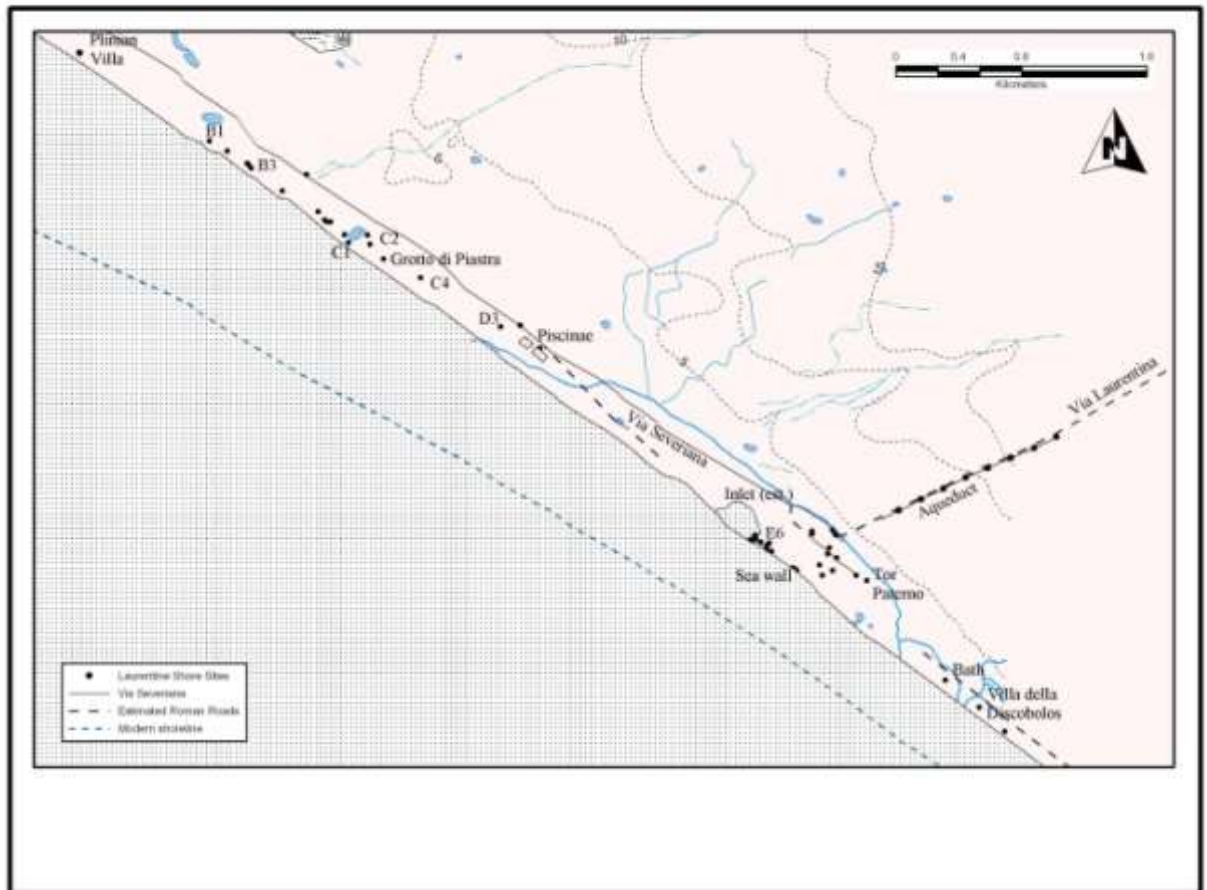


Figure 3 Location of main archaeological sites at Castelporziano (Bicket 2010)

The economy of villas, such as those at Castelporziano, has sometimes been privileged at the expense of the cultural aspects of Roman life, e.g. theatres, gymnasiums, taverns, and brothels, the remains of which can be found further up the coast at Ostia Antica (Purcell 1998)

1.1.2 Local Landscape in Roman Times

The best visual description of the area is that of the younger Pliny, and describes the landscape on the way to his Laurentinum villa as follows:

"It is seventeen miles removed from the city, so that you can stay there with some of the day left, when you have transacted your business in Rome. There is more than one approach, since both the Via Laurentina and the Via Ostiensis lead there, though you need to leave the former at milestone 14 and the latter at milestone 11. The road from both is sandy in places and a bit on the sticky side for a vehicle, but quick and easy if you are on horseback. The view is quite different from place to place: at one time the road is hemmed in by the encroaching woods, at another it runs out into the open through great expanses of meadow. There are numerous flocks of sheep, many herds of horses and cattle: they are driven from the mountains by the cold weather and grow sleek on the vegetation in the spring warmth" (Pliny the Younger and Radice 2003, p46-51).

From Pliny's letter it can be seen that the site is close to Rome, but within a different world. It is hard to find and communications are practicable, but not of the ease that would be normal with a suburban villa. The visual aspect of the landscape is stressed, and it is tranquil but unpopulated - no hint of the people tending the animals - and the productive aspect is wild, the burgeoning of the vegetation and its grazing by flocks from elsewhere (Purcell 1998). However, even with its natural resources of game and the like, this environment is regarded as poor; the wild boar, nourished on reeds and mast, are scrawny, and the lagoons produce only the most meagre catch of fish (Pliny the Younger and Radice 2003). Furthermore, this landscape has often been described as a "wilderness", but what exactly does this mean? This concept will be examined in the following section.

Roman Wilderness

The Laurentine Shore marked by Virgil as the arrival point for Aeneas, is described as *lucus ingens*, a wilderness, which other classical authors including Pliny the Younger seized upon. Therefore, it is likely that during the Roman period of

settlement at Castelporziano, others may have viewed this area as a wilderness. Indeed, much later, Lanciani (1909 p309) described the wilderness of the area as: *“The fascination of this green wilderness cannot be expressed in words. The forest, in which the "amans littora pinus" towers above all other sylvan giants, offers certain recesses so shady and mysterious that they charm the eye and gladden the soul. Sometimes their stillness is broken by the inrush of wild boars, or deer, or gazelles”* Therefore, just what was this wilderness in Roman times, and what is the ideology behind it? To answer these questions, using Purcell (1998) as a source for some of the classical works cited, the three strands of thought on as to what this may mean are: a) The wilderness relates to a distinctive (rural) landscape; b) A place inhabited by wild beings ; c) A poor marshland. .

a) The area as noted above is described in detail by Pliny the Younger. From Pliny’s letter it can be seen how close the site is to Rome but it is a different world away. Furthermore, Pliny himself only visits occasionally, in the early months of the year. He sets out a visual feast for the eyes, stressing how tranquil the area is with flocks of sheeps and herds of cattle, thus suggesting a more pastoral landscape. Pastoralism was seen by the Romans as inferior to, and simpler than, arable land (Purcell 1998), thus suggesting (comparatively) untamed landscape – but is this really a wilderness?

b) The fauna, real or imagined, match the landscape descriptions of Silvia's deer in the Aeneid, or the portentous wild sow (Dionysius) and the numerous other boar (Horace), both of which can be found at the modern Castelporziano estate. Hostilius Mancinus set out on his disastrous campaign to Numantia in 137 B.C. via Lavinium and its Forum, where he received the terrible omen of a flight of the sacred chickens away from human control straight into the wild woods (Purcell 1998). The priests who officiated at the holy places wore hats with huge tassels to frighten the birds that would otherwise carry the sacrificial offerings into the nearby wilderness.

The woodlands may have provided a natural place for the creation of game reserves by the villa-owners. Other evidence for a game reserve comes from inscriptions such as one from the Vicus Augustanus naming a “college of Imperial gamekeepers”, who had a meeting house there - where a large mosaic shows scenes of wild animals being trained for organised hunts and/or the amphitheatre (CP III). The Emperors of the second century AD from Trajan to Commodus were particularly fond of hunting - not just local indigenous wildlife like boars, but imported wild animals lions etc, on their own estates. Recent research by Richard Neudecker (of the German archaeological institute in Rome) on other Vici Augusti which are attested epigraphically in Latium and Campania shows that they are all associated with imperial estates and that those estates include amphitheatres - and thus are likely to have been training animals (Pers. Comm. Claridge 2009). Additionally, Quaternary deposits in the Valle Latina in inner southern Latium,

in 1864, by O.G. Costa, are rich in faunal finds. These include elephant bones, which have since been discovered at some 20 sites, the youngest dating to the lower Palaeolithic (Biddittu and Celletti 2001). Elephant bones were also found at Infernetto in 1935, close to the Castelporziano. Therefore, it is possible Castelporziano was used for training animals for the amphitheatre at Ostia. However, no animal bones have been found at Castelporziano during the archaeological excavations.

c) However, the environment is regarded as 'poor'; "*the wild boar, nourished on reeds and mast, are scrawny, and the lagoons produce only the most meager catch of fish*" (Virgil as cited by Purcell 1998, p.9). The sterility of the ager Laurens became an important commonplace of the Romans' traditions about their origins already in the second century B.C. Furthermore, the place was regarded as the '*ager macerrimus litorosissimusque*', i.e. '*extremely poor and beachlike*' (Purcell 1998 p. 10). However, the west coast of Italy has been found to have an abundance of Roman Piscinae (fish ponds/tanks), including 2 at Castelporziano itself, which in themselves were status symbols. One of Martial's favourite satirical points, that the decadent villa-owner is not a producer but dependent on the city market, is developed in a poem that contrasts the abundance of Spain with the characteristic fish and game of the Laurentine shore: frogs and minnows, and foxes and badgers (Purcell 1998). Pliny the younger noted that he can grow a purely ornamental box only in protected places, though the more useful but less prestigious figs and mulberries do well. Additionally, Cato describes pasture as a "*marshy place of being most suitable for the raising hogs and meat cattle pasture is best in groves where there is brushwood and much leafage: and so when wintered by the sea*" (Cato as cited by Purcell 1998 p10-11).

This discourse also feeds into a debate about the "ruined landscape", which is discussed in more detail section 1.2. As to which of these three interpretations best describes the Laurentine Shore at Castelporziano during the Roman period, this question will be examined in relation to the results to the palaeoenvironmental reconstruction, in chapters 6 and 7 (discussion and synthesis of Roman-Environment interactions).

Regional history (in Roman times)

Within close proximity of Castelporziano are the noted Roman sites of Portus. Ostia Antica, Rome and the Roman Campagna (the first three are ca. 12km, 14km and 23km respectively away from the modern estate of Castelporziano), and it is important to consider Castelporziano in relation to its neighbouring areas.

By the time of earliest Roman settlement at Castelporziano in ca. 100 BC, Rome was in its Late Republic stage (ca. 147 BC - 30 BC). At this time there was great internal

unrest, with a general trend of soldiers becoming increasingly loyal to their generals rather than to the state (Santosuosso 2003). In addition, between 135 BC and 71 BC there were three "*Servile Wars*" involving slave uprisings against the Roman state, the third and final uprising killing the most (quoted from sources as of being between 120,000 (Appian 1913) and 150,000 (Santosuosso 2003)). However, this had also become a time when mobility had become normal for the upper classes, and led to an expansion of villa building in Italy (Frazer 1998). It was at this time that fish ponds like those found at Castelporziano were developed. Writing about 37 BC, Varro provides the earliest account of fish farming, although it is Columella, writing almost a century later, who gives the most detailed description, and it is in this period, from the first century BC until the end of the first century AD, that fishponds enjoyed their greatest popularity. Such a conspicuous display of wealth, common in the late republic, was discouraged by Augustus, and later emperors came to assume the prestige associated with these properties for themselves (Higginbotham 1997).

The growth and transformation of Ostia in the late Republic, and its wholesale reconstruction between the Flavian and Antonine periods, must be seen in its ideological and theoretical context, against the background of this richly symbolic landscape, and this is even truer of the more schematically planned harbour-town at Portus (Purcell 1998). The expansion of Ostia should be seen as the creation of a fine new city in the heart of the "*wilderness*" that was also Rome's *façade maritime*, and not as a process that had relevance only to Rome or the Tiber (Purcell 1998). The urban development of Ostia in the late Republic went hand-in-hand with the establishment of the estates, with the private and the public interest working in tandem. The villas of the coastal strip transformed the countryside as benefaction and state expenditure did the town. The proprietors of villas were conscious that their villas were in their refinement urban, and that it was an achievement to bring such urbanity into so wild a place. The achievement consisted in managing an intractable environment for their convenience, comfort and profit. The move down to the Laurentine shore offered a change of air and climate, and for that reason the coast became primarily a winter-resort (as per the letter of Pliny the Younger). The *salubritas* of the coast was part of its general attraction, but there were special features too: the doctors of Commodus recommended that he should take refuge from the plague in Rome in the scented groves of bay on the Laurentine shore (Herodian cited by Purcell 1998 p12).

Development of Portus

In AD 42, the Emperor Claudius initiated work on the construction of a new artificial harbour a short distance to the north of the mouth of the Tiber. The harbour facilities were enlarged at the insistence of the Emperor Trajan at the beginning of the second century AD, and Portus remained the principal port for the City of Rome into the Byzantine period (Keay *et al.* 2007). On its landward side, the harbour was provided with a series of wharves and porticoes to accommodate traders and the storage of goods in transit. It was also connected to the Tiber to the east by two canals. This site was a curious choice since this stretch of coast is very exposed to both wind and currents, while the Tiber itself constantly deposits silt that would clog up the harbour unless it was continually dredged. Moreover, its exposed seaward location, and the huge area that it enclosed, led to a major disaster in AD 62 when a great storm wrecked 200 ships moored in the harbour. The surviving archaeological remains and comments by ancient sources make it clear that Portus lay at the heart of Rome's maritime façade. As well as being a key Mediterranean centre for passengers and for the loading, unloading, transshipment and storage of products from across the Empire, it was also designed to make an ideological statement about the supremacy of Rome in the world (Keay *et al.* 2007).

The Roman Campagna

The Roman Campagna was the countryside immediately surrounding Rome (Sallares 2002) and was described in detail by Lanciani (1909), as it was at that time reflecting on how it varies from that described in the classical sources. This area includes the modern area surrounding the Castelporziano estate. The Roman expansion reached the Campania area approximately 340 BC (Scullard 1967), and was a popular residential area, but with the expansion of Rome, came the destruction of large parts of the Campagna, especially east and south of the city. Post-Roman it was abandoned during the Middle Ages due to malaria and insufficient water supplies for farming needs. The region was reclaimed in the 19th and 20th centuries for use in mixed farming and new settlements have been built. Most of the research from this area has focused on Malaria (Celli 1933 and Sallares 2002) in relation to the Romans, which may be a reason for the Romans abandoning settlement at Castelporziano.

Regional Geography (The coastline nearby Castelporziano)

The Tiber delta (figure 1), in the Roman period, did not extend as far into the Tyrrhenian Sea as it does at present; it constituted an indented and lagoon-like

stretch of coast not very different from other low-lying zones to the north and south (Segre 1981). The coastline surrounding and including the Castelporziano Estate was until the early twentieth century characterized by a series of lagoons and marshes (figure 4). These began with the long seawater inlet or *stagnum* which once spread three miles south of Ostia and continued further south as a series of smaller freshwater pools and swamps, widening into the Pontine Marshes towards Anzio (Purcell 1998). Intermittently, over the centuries, these low-lying zones became dangerously malarial, which led to major drainage works in the late 19th century, which in turn altered the landscape and patterns of drainage. In order to understand the pattern of Roman settlement research is needed to reconstruct the environment of Roman times, how sea, inland water and a possible forest were combined and how they hindered, encouraged or enhanced the built environment (Claridge 2002). There are many classical authors, who refer to the Laurentine Shore; one important example, as noted earlier, is Pliny the Younger (c.61 AD - c.112 AD) who describes not only the coast and his house but the local area as well ca. 2000 years ago.

“The sea-front gains much from the pleasing variety of the houses built either in groups or far apart; from the sea or shore these look like a number of cities. The sand on the shore is sometimes too soft for walking after a long spell of fine weather, but more often it is hardened by the constant washing of the waves” (Pliny Letters II.17 (to Gallus), from Pliny the Younger and Radice 2003 p46-51).



Figure 4 The marshes surrounding the Castelporziano estate at Tor Paterno (Gell and Bunbury 1846)

1.2 Roman Agriculture

Columella's *On Agriculture (De Re Rustica)* is the most comprehensive, systematic and detailed of Roman agricultural works. Rome was favoured with a rich if limited and fragile soil. Romans, like the citizens of other city-states in the Latin plain, quickly learned to cultivate their three to seven acre farms intensively (Wolf 1987). When pressures on the land's productivity appeared, the people were willing to expend great efforts to maintain and increase it. Archaeological evidence shows extensive drainage tunnels and dams built to save a few acres (Tenny 1962). Purcell (1998) concluded that the environment of this coastland was not favourable for the large-scale production of staple foods or the more familiar cash crops, and that any agricultural activity is therefore represented in the Roman period only in rather specialised forms. The three forms practised: i) the extraction of the natural products of the area, fish and fowl, timber, brushwood and marsh plants, especially reeds; ii) the improvement of that first category through pisciculture, forestry, the preservation of game and the introduction of specialised wetland agriculture such as flax, certain

sorts of viticulture, or intensive horticulture (including the intensive cultivation of fine wheat); and iii) the pasturing, seasonal or not, of animals. Writers in the 2nd century BC describing the history of Rome termed the area as “*ager macerrimus litorosissimusque... 'extremely poor and beach like'*” (Purcell 1998 p 10).

Section 1.5 will explore the broader context of the nature of the Mediterranean landscape together with our current understanding of late Holocene environmental change in the northern Mediterranean.

1.3 Current vegetation

1.3.1 Current vegetation with the Castelporziano Estate

The majority of the forest at the centre of the Castelporziano estate consists of commercial plantations of Mediterranean 'umbrella' pines/*Pinus pinea* (harvested for their timber and pine nuts); but towards the sea there are large tracts of Mediterranean 'macchia' of shrubs and tree-shrubs (*Erica*, *Phylleria*, *Quercus ilex* or *Q. holm*, *Lentiscus*, *Myrtus*, *Juniperus*, *Ruscus*, *Cistus*, *Arbutus*, and *Laurus*) together with deciduous woods, mostly *Quercus* of one variety or another (*Q. rubur*, *Q. cerris*, *Q. ilex*, *Q. suber*, and *Arbor Vitae*), with *Ulmus*, *Populus*, *Fraxinus*, *Carpinus* and *Betula* (Allegrini *et al.* 2006). The contemporary vegetation and management issues within the estate are examined in more detail in chapter 6, but a map of vegetation of the whole estate is shown in figure 5.

1.3.2 Current vegetation within study location

Previous literature on the modern vegetation of the Castelporziano estate (e.g. Bruno (1980), Anzalone *et al.* (1990), Della Rocca *et al.* (2001), Allegrini *et al.* (2006)), within the coastal strip that contains the archaeological remains, show that this area is dominated by “*Macchia*”, as called by the Italians. However, to describe what macchia is in English is not straightforward; it derives from the French “maquis” and is often used in literature to indicate the shrubby, stiff-leaved, evergreen vegetation, typical of an ecosystem adapted to the Mediterranean climate. The Mediterranean macchia is closely linked with precise local conditions, mainly with respect to local climate. It can be found in other Mediterranean-type environments, where annual precipitation is irregular over the course of the year, with the majority falling in late

autumn and winter, alongside more or less prolonged aridity in summer. Other countries use words other than *macchia* or *maquis* to describe this type of vegetation, for example: *matorral* in Spanish-speaking countries (Spain and Chile), *chaparral* in California, *strandveld* and *renosterveld* (depending on the dominant floristic composition) in South Africa, and *mallee* in Australia. In the strict sense, the word *macchia* is mainly applied to its Mediterranean version - that grows as a result of anthropogenic impact direct or indirect intervention on the environment of coastal belts - burning scrub and woodland, felling trees, and grazing livestock over several thousand years. Within the Mediterranean, evergreen *macchia* is currently the main vegetal formation in coastal and subcoastal areas of the Mediterranean, and it thus covers much of the Italian peninsula and its islands (Paola and Peccenini 2003).

This is not the only form of *macchia* though in the Mediterranean, there is another type which is not anthropogenically induced, it is primary or high *macchia*, and an example of this type of *macchia* was found at the Castelporziano estate (see Polunin and Huxley, 1972, for a greater discussion of the two types). This is the original type, not the result of the evolution of preceding forest vegetation, and is rarer. It has two aspects: 1, it is found in areas where holm oak forest is not the present-day climax, e.g., at the geographical and altitude limits of the area covered by holm oak; 2, the *macchia* grows in situations which limit its expansion, e.g., steep slopes, high contents of salt in the soil, or the continual drying capacity of wind, which means that woody plants cannot grow tall (Touring Club Italia 1958). These cases may be interpreted as permanent stages of vegetation, or "subclimax". The holm-oak wood of Castelporziano (about 100 ha) is a rare example of holm-oak forest belonging to the *Viburno-Quercetum ilicis* (Br.-Bl. 1936) Rivas-Martinez (1975) association. This association is the warmest and most thermophilous type of such woods in Italy (Pignatti 1998), which was found at Pozzo Napoliello and Muraccioli.

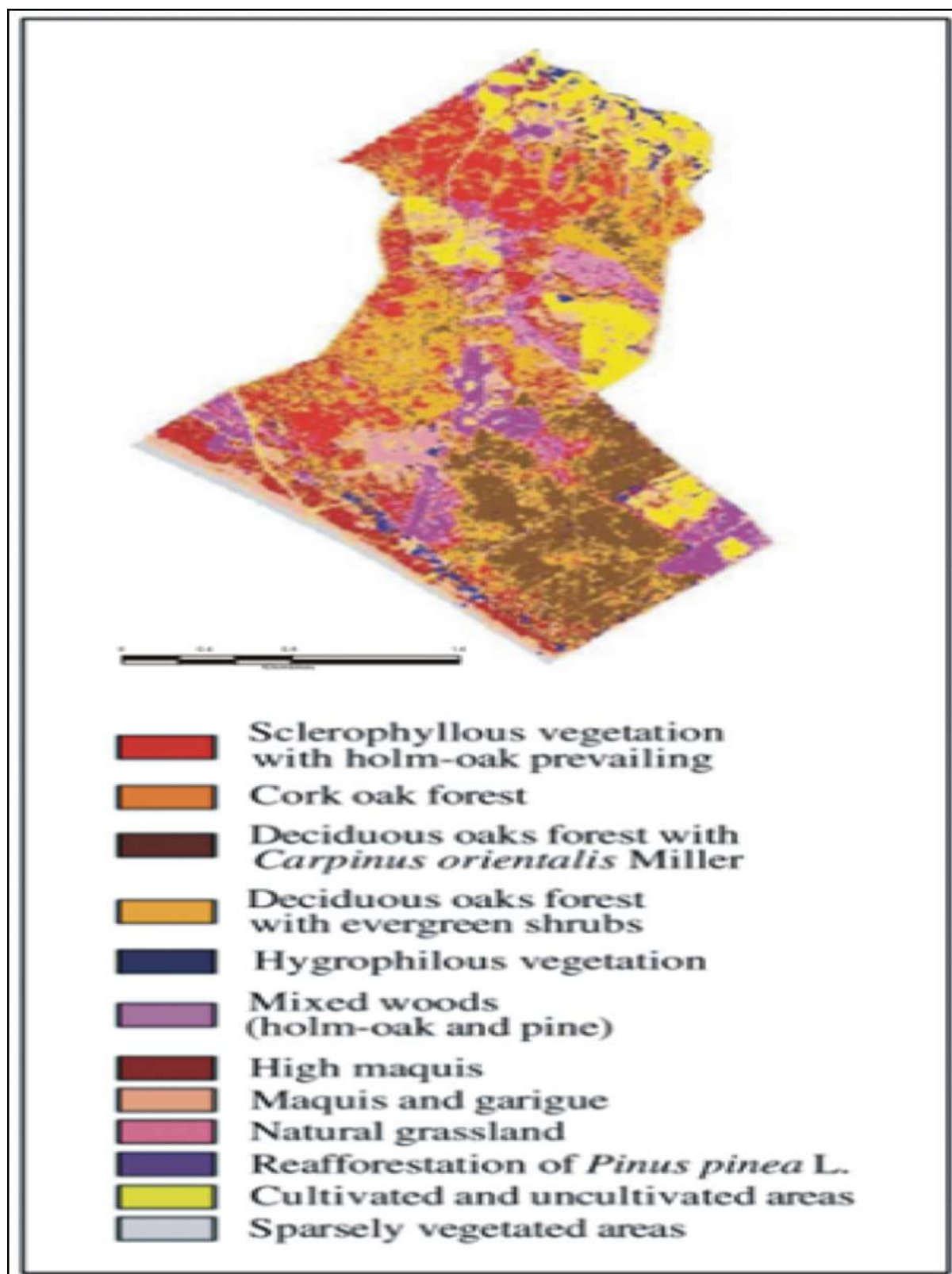


Figure 5 Modern Vegetation at the Castelporziano estate Map (Allegrini et al. 2006)

1.4 Current Climate

On the basis of air temperature and precipitation, the current climate at Castelporziano can be defined as typically Mediterranean. This type of climate is extra-tropical with seasonal and daily photoperiodism. Precipitation is concentrated in the autumn and winter months, while summers are comparatively dry (Emberger 1954). Average monthly temperatures, taken from the Italian Air Force base ~1km to the south of the estate at Pratica di Mare (figure 3), show the average summer temperatures reach 25°C and average winter temperatures of 6 to 12°C. The mean annual precipitation (figure 3) is 740mm, with a period of summer aridity lasting from mid-May to mid-August. Blasi (1993, 1994) classified the climate of the area of Lazio, in which the Castelporziano lies by using a series of phytoclimatic indicators. Using his classification, Castelporziano estate is “*lower Mediterranean thermotype*”, and “*superior dry-inferior sub-humid ombrotype*²”, and thus making the estate a “*Thermo-Mediterranean/Mesa-Mediterranean sub-region*”, due to the presence of long, pronounced period of summer aridity (May-August), as noted above.

² Ombrotype - given by the ombrothermal index I_o . This index is given by the relation between the sum of the rainfall figures in the months with a mean temperature of more than 0°C and the sum of the temperatures in the same months.

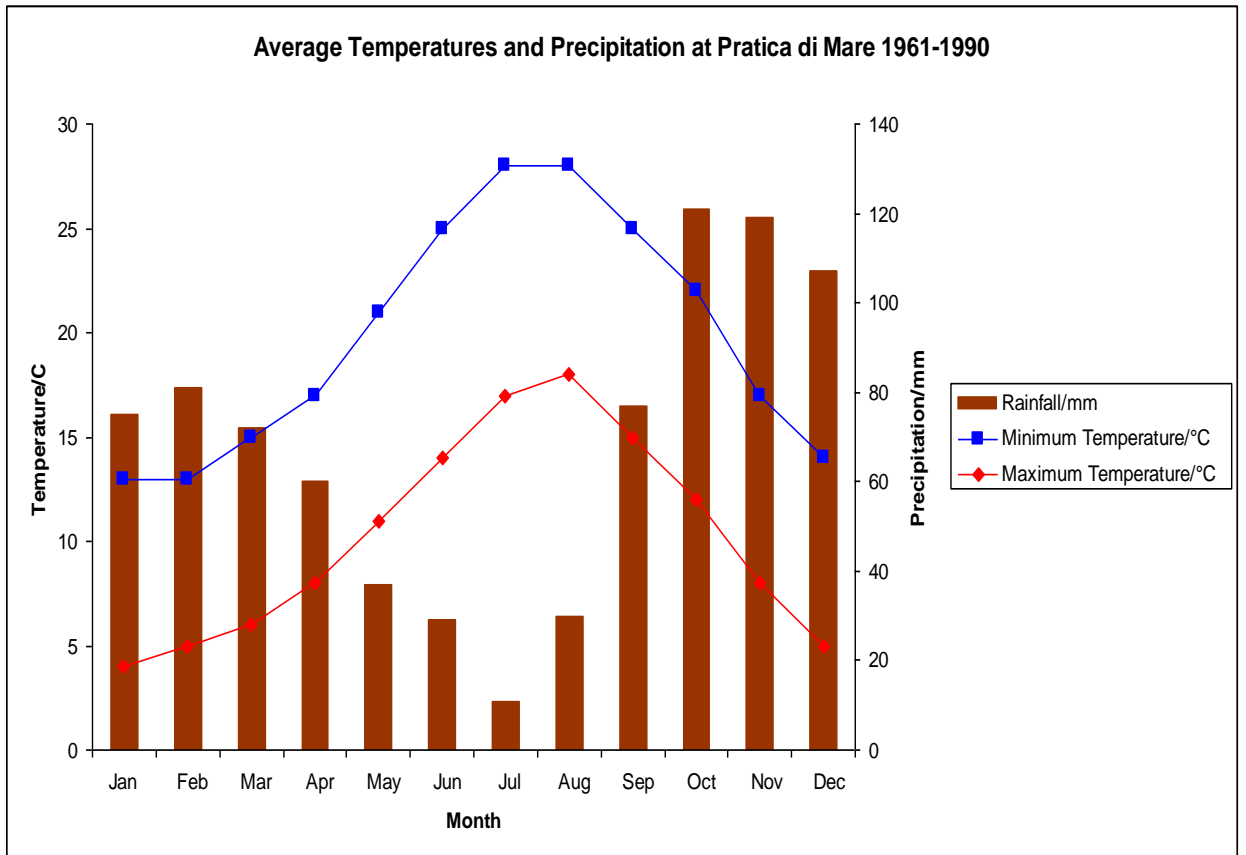


Figure 6 Average Temperatures and Precipitation at Pratica di Mare 1996-2008

During winter the synoptic scale of atmospheric circulation³ dominates general air mass circulation with frequent strong, cold winds blowing from the N-NE sector taking the pollutants from the city of Rome directly towards Castelporziano. During the

³ The synoptic scale is a scale of the high and low-pressure systems of the lower atmosphere, which typical dimensions range approximately from 1000 to 2500 kilometres (synoptic-scale circulation).

summer season, high pressure dominates together with the sea-land breeze system. The contemporary air quality data shows that the land breeze is active from 3 to 4 am until 11 am when the sea breeze takes over until early evening (7 pm) (Manes *et al.* 1997). Although at night the heat island created over the city of Rome together with low turbulence prevents the transport of large amounts of pollutants towards Castelporziano, the site is certainly under the influence of polluted air masses in the early morning hours. This may lead to high levels of organic compounds and NO, (especially NO₂) before noon but not to large concentrations of ozone (Manes *et al.* 1997).

1.5 The Mediterranean Landscape

The Mediterranean basin has a long history of human occupation that has contributed to the structure of the modern landscape. The landscape we observe today is the result of subtle interactions between ecological and anthropogenic processes (Zavala and Burkey 1997). The development of ancient societies and civilisations is well reflected in the archaeological record, although the broader impact of human activity on the landscape is less clearly understood. Studies of anthropogenic impacts on vegetation have been mainly confined to more remote coastal and mountain areas (see Leveau *et al.* 1999 for examples). In historical times there appear to have been cycles of degradation and regeneration in the Mediterranean landscape that may be related to human pressure.

1.5.1 Anthropogenic Impacts on the Mediterranean Landscape

The extent to which a climatic change signal can be observed within records of vegetation during the Holocene in the Mediterranean is the subject of on-going, vigorous, debate (e.g., Jalut *et al.* 1997, 2000, 2009; Medail and Quézel 1999, Roberts *et al.* 2001). The impact of human activity on ecosystem structure and composition clearly increases through the Holocene, but the severity of this impact is unclear (Allen 2003). Discussion continues as to whether Mediterranean ecosystems can be regarded as fragile and '*ruined landscapes*' or are, in fact, resilient (Grove and Rackham 2001).

The '*Ruined Landscape*' or '*Lost Eden theory*' argues that human action resulted in a cumulative degradation and desertification of Mediterranean landscapes. This was first advocated by painters, poets, and historians in the sixteenth and seventeenth

centuries, and later by a large number of ecologists, who argued that anthropogenically-driven deforestation and overgrazing resulted in the cumulative degradation and desertification of Mediterranean landscapes (Blondell 2006). This theory denounces the destruction of formerly magnificent forests, which were supposedly so lush and extensive that a monkey could have travelled from Spain to Turkey almost without leaving the canopy (as claimed by Attenborough (1987; also see McNeil 1992; Naveh and Dan 1973; Thirgood 1981, for similar arguments)).

A second school of thought argues that humans have actually contributed to keeping Mediterranean landscapes diverse since the last glacial episode (Blondell 2006). Grove and Rackham (2001) showed that, in many cases, the '*Ruined Landscape*' hypothesis is false, and that the landscape of Mediterranean Europe today is mainly a product of its geology, past and present climate, soils and other physical factors. In those cases where human influence is clearly seen, the authors point out that it is difficult, if not impossible, to show a clear distinction between natural and artificial factors. Furthermore, Smith (1996 p155) wonders if "*there was ever an Eden in post-glacial Italy. Would there have been enough time at the end of the ice age optimum for ecological and living conditions while human activity was expanding?*" The archaeological record can be read in this way: given the widespread distribution of human settlement and the land use on the one hand, and Italy's environmental tendencies on the other, it could be suggested the "wilderness" (as noted in the previous section) is more likely not to be 'untamed nature' but rather nature derelict or nature-degraded (Smith 1996).

As Blondell (2006) points out, although the likelihood is that the truth lies between these two extremes, this debate is fundamental to any discussion of the two processes that influence natural and human systems in this region of the world, namely; their resistance and resilience. Resistance, as defined by Blondell (2006 p.714), for human-environmental interaction, is "*the amount of change following a disturbance event*", c.f. resilience, which he defined as "*indicating the time required for a total recovery of the system following a disturbance event*". Of course, it is extremely difficult to reconstruct the full ecological trajectory of natural communities and, specifically, how living systems have accommodated both the intrinsic variability of Mediterranean bio climates and the long-term influences of human activity.

Human influence upon the Mediterranean landscapes is not an attribute of the past. These landscapes are currently undergoing structural changes (Ales *et al.* 1993;

Antrop 1993; Gomez-Sal *et al.* 1993). For example, Ales *et al.* (1993) found that “*intensive agricultural systems have concentrated in the more fertile areas, while marginal ones have been abandoned*” (p3). These changes have not altered the general patterns of soil use at the regional level, but the landscape has lost small scale heterogeneity, particularly at coastal locations many patches of ponds and surrounding grasslands and cultivated areas less than 1 ha have disappeared, where as larger ones continue to exist and have expanded. Given the strong association between human activities and ecological processes, and the variety of spatial and temporal scales at which these interactions operate, the Mediterranean region is a point of reference for considering human dominated habitats (Zavala and Burkey 1997).

1.5.2 The regional context of Late Holocene environmental change in Central Italy

Fluvial and coastal processes are extremely sensitive to variation in sediment supply, which, in turn, is strongly influenced by vegetation cover, especially during the second half of the Holocene, and by anthropogenic land use (Butzer 1977, 1982; Goudie 1981; Turner *et al.* 1990; Bintliff 2002; Butzer 2005). In Italy, as in other European countries, human activity has brought about major changes in sedimentary regimes (Becker and Schirmer 1977; Klimek 1987). Nevertheless, it is often difficult to measure precisely the scale of this effect and its consequences because of the lack of detailed information on the changes occurring in prehistoric times (Vita-Finzi 1969; Butzer, 1977, 1982; Delano-Smith 1979; Bintliff 2002; Butzer 2005). Inevitably, recourse has to be made to the geological, palaeoecological and archaeological record in order to estimate the impact of anthropogenic activity.

Central and Southern Italy provide a rich and sensitive region and a challenge for palaeoclimatologists, as there are numerous sites located in critical areas in terms of the pattern, periodicity and expression of Quaternary climatic change (Kelly and Huntley 1991; Francus *et al.* 1993; Guilizzoni and Oldfield 1996; Watts *et al.* 1996; Ramrath *et al.* 2000). The Mediterranean region is also potentially vulnerable to the combined effects of climate and human activities (Colombaroli *et al.* 2007), and also sensitive to climate change, due to its position at the transition between the westerlies and sub-tropical high pressure (Wright *et al.* 1994)

Reconstructions of past vegetation and climate changes in the central and southern Italian peninsula (figure 7) during the Holocene and late Pleistocene have been reported from several lakes (e.g. Hutchinson 1970; Kelly and Huntley, 1991; Follieri *et al.* 1993; Mergeai 1995; Guilizzoni and Oldfield, 1996 and references therein; Zolitschka and Negendank 1996; Allen *et al.* 1999). Climatic and tectonic histories of lakes in the Latium Region have also been studied (Niessen *et al.* 1993; Vigliotti *et al.* 1999; Ramrath *et al.* 2000). Most of the palaeoenvironmental reconstructions for Central Italy are from crater lakes: (figure 7) examples include Follieri *et al.* 1988; Follier *et al.* 1993; Magri and Sadori 1993; Magri 1998; Magri and Sadori 1999; Allen *et al.* 2000; Allen 2003; Sadori *et al.* 2004; Drescher-Schneider *et al.* 2007; Sadori and Gardini 2008. Several pollen-based studies have explored the vegetation history of Italy. However, the publication of the long sequence at Valle di Castiglione (Follieri *et al.* 1988), which provides a unique record of the last three glacial-interglacial cycles, led to intensive research in Italian crater lakes, giving reconstructions of vegetation from the early Pleistocene to the late Holocene. A number of papers note human impact on late Holocene ecosystems in central Italy. One example is from Allen *et al.* (2000), which was an *“attempt to separate the relative controls of climate change and anthropogenic activity on ecosystem changes”*. However, they conclude that: *“it remains an open question as to the relative importance of natural climatic changes and human activity as the cause of Holocene palaeovegetation change. Usually, where changes are associated with human activity, however, it is probable that the human activity provided the disturbance that acted as the proximal trigger for vegetation changes that were ultimately a response to climatic changes”* (Allen *et al.* 2000, p.11).

The published pollen records for Italy are mostly distributed in northern and central Italy, while in the southern part of the peninsula, although spatial coverage is restricted (Figure 7) a number of important records exists for these areas (e.g. Lago di Monticchio and Pergusa). As mentioned above, one central matter of debate is the interpretation of climatic versus human causes for vegetation changes in the last few millennia. The overall changes of vegetation appear to show different trends in different regions of Italy (Magri 2007). For example, the presence of prehistoric human settlements in areas with reduced tree coverage in sites located in temperate (northern and higher altitude) climate areas of the peninsula (Pini 2004; Finsinger and Tinner 2006; Valsecchi *et al.* 2006), contrasts with only moderate decreases of tree cover in sites with a more Mediterranean climate (Magri and Sadori 1999; Allen *et al.* 2002; Drescher-Schneider *et al.* 2007). In the latter sites, the impact of human

activity is mostly recorded by increasing values of cultivated plants and anthropogenic indicators (e.g. *Castanea*, *Rumex* and *Poaceae*), as well as of species of secondary forest canopy (e.g. *Pinus*). Most of these indicators are for species in Northern Europe (see Behre 1986); however, Bottema and Woldring (1990) adapted these for the Eastern Mediterranean and van Joolen (2003) undertook work in Bronze Age central and southern Italy and adapted these indicator species to cover different aspects of anthropogenic impact pertinent to Italy (Table 1).

Indicators of ignicoltura: pyrophytes	Primary agricultural indicators	Primary arboricultural indicators	Secondary indicators: weeds	Indicators for grazing	Indicators of a rise of second growth shrub
<i>Buxus</i>	<i>Avena</i> group	<i>Castanea</i>	<i>Artemisia</i>	<i>Apiaceae</i>	<i>Erica arborea</i>
<i>Cistus</i>	<i>Cannabis</i>	<i>Juglans</i>	<i>Atriplex</i>	<i>Asteraceae</i>	<i>Fraxinus</i>
<i>Erica arborea</i>	<i>Hordeum</i> -group	<i>Olea</i>	<i>Centaurea solstitialis</i>	<i>Brassicaceae</i>	<i>Ostrya</i>
<i>Quercus suber/ coccifera</i>	<i>Triticum</i> group	<i>Vitis</i>	<i>Chenopodiaceae</i>	<i>Caryophyllaceae</i>	<i>Quercus Coccifera</i>
<i>Tamarix</i>			<i>Cistus</i>	<i>Cupressus</i>	
<i>Urtica dioica</i>			<i>Compositae</i>	<i>Euphorbiaceae</i>	
			<i>Mercurialis Annu</i>	<i>Fabaceae</i>	
			<i>Plantago</i>	<i>Lamiaceae</i>	
			<i>Polygonum Persicaria</i>	<i>Liliaceae</i>	
			<i>Ranunculus</i>	<i>Polygonum Aviculare</i>	
			<i>Rhus</i>	<i>Ranunculus</i>	
			<i>Spergula arvensis</i>		
			<i>Stellaria</i>		
			<i>Vicia</i>		

Table 1 Anthropogenic indicators from pollen, focused on Italy (van Joolen 2003)



Figure 7 Location of late Pleistocene and Holocene Pollen records in Italy published from 1978 to 1995 (●), and since 1996 (▲) (Based on Magri 2007)*

* The key to the locations noted in figure 7 is in Appendix 1

Vegetation for the Late Holocene varies considerably between sites, and the climatic interpretations are somewhat divergent. A few papers examine the Holocene in greater depth, within Southern and Central Italy and a timeline summarising some of the changes noted is given below (figure 8). Although this figure shows changes in the bio climate (i.e. the relationship between living things and climate), and human impact, the record of the last 2-3,000 years is comparatively poor.

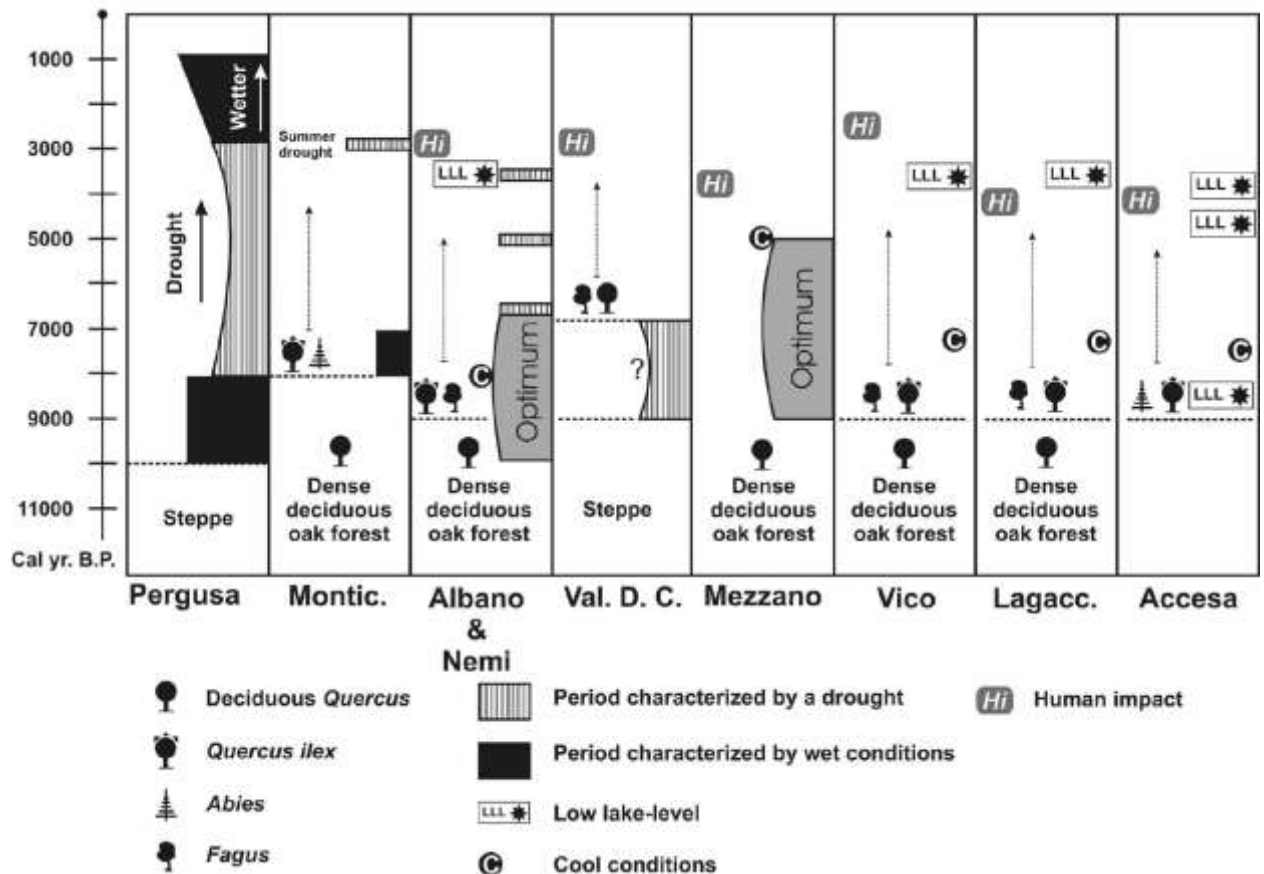


Figure 8 Instability of the Mediterranean bio climate: overview proposed for Italy. (Redrawn from Beaulieu et al. 2005)

At Lago di Pergusa, in Sicily, a sedimentary change from organic mud to marls at 6750 BP suggests increasing aridity till 2900 BP; however, a change to a wetter climate is suggested at this date from the sediment rather than the pollen. From 3150 BP (and possibly prior to this), the abundance of anthropogenic indicators shows that the vegetational dynamics is governed by the impact of man (Sadori and Giardini 2006). Allen *et al.* (2000) found a decline in *Abies* at 3000 BP at Lago Grande di Monticchio, this was followed by its extinction between 2000 and 1000 BP, although

they are unsure if this is due to summer drought or anthropogenic impact due to forest clearance for agriculture.

The crater lakes of Albano and Nemi, which are 15 miles southeast of Rome and thus comparatively close to Castelporziano, were investigated under an EU project, PALICLAS (Palaeoenvironmental Analysis of Italian Crater Lake and Adriatic Sediments). Several papers explore the palaeoecology and geochemistry of the two lakes. Guilizzoni *et al.* (2002) discussed a high lake productivity, which infers a climatic optimum between 10000 and 6500 BP, with low productivity at 8200 BP, and two others after the optima at 6400 and 3800 BP, which could be due to lowering temperatures and/or precipitation. A palaeolimnological study of a core at Lago di Mezzano, north of Rome, by Ramrath *al.* (2000) agrees that the climate optimum occurred between 9000 and 5000 BP, followed by a cooling between 5000 and 4000 BP, with anthropogenic impact becoming a major factor. At Valle di Castiglione, between 6250 and 3450 BP, Alessio *et al.* (1986) note evidence for a possible mixed deciduous forest, with abundant *Fagus*, at its optimum. The importance and (late) role played by this taxon is worth noting.

However, even sites in close proximity show differences in record. At lakes Albano and Nemi, for example, the main differences are:

1. *Carpinus betulus* and *Carpinus orientalis/Ostrya* show two peaks in the Nemi diagram, whereas only 1 is recorded in the Albano profile;
2. *Abies* percentages are continuous over the two *Carpinus* peaks at Nemi, but are reduced to zero in the Albano diagram;
3. A peak in *Fagus* (19% at 603.5 cm) is recorded in the Nemi profile, and an equivalent is not evident in the Albano profile;
4. A peak in *Quercus ilex* type (36.6%) is recorded in the Nemi profile at 437 cm, while there is no equivalent in the Albano profile;
5. The rise in *Poaceae* is gradual in the Nemi profile, whereas it is abrupt, at the suggested hiatus, in the Albano profile.

Magri and Sadori (1999) present another example from Central Italy with a well-dated pollen sequence from Lago di Vico. At 4000 BP, or slightly later, a fall in concentration of *Quercus ilex* and *Erica arboea* coincides with a discrete expansion of cultivated plants and thereby suggesting an anthropogenic inference, but a strong increase in the numbers and frequencies of anthropogenic indicators is only recorded from about 2750 BP. However, the concentration curves do not suggest a large

decline in arboreal pollen. A sequence at Lagaccione (Magri 1999) is marked with a succession of events, akin to those observed at Vico. At Lago di Mezzano, Sadori *et al.* (2004) found a reduction in tree pollen around 3800 BP, which was interpreted as a deforestation due to climate change, matching the absence of intense and local fires (which could have been caused by man) and precedes a period of strong human impact, with settlements by the lake shores. While at Lago de l'Accessa, the end of the Mid-Holocene is characterised by opposing fluctuations in the abundance of deciduous and sclerophyllous oaks. Two phases of lake lowering at 5000-4500 BP and 3800-3700 BP correspond to maxima in Mediterranean taxa. Aside from, *Quercus ilex*, *Quercus cerris/suber* (same pollen type) and *Erica arborea* are abundant from the early Holocene, suggesting patches of different forest ecosystems around the site.

This section has highlighted the results of the pre-existing vegetational histories and reconstructions from a range of sources within Central Italy, the debate of natural vs. anthropogenic changes, and reconstructions covering the time-frame of interest.

1.5.3 Late Holocene in the Mediterranean Basin

Beyond Italy, Late Holocene sequences have been constructed for the Mediterranean areas of Spain, France, Greece and Turkey as well as for Portugal, which although not geographically Mediterranean has a Mediterranean climate. It should be noted that Allen (2003) has advocated caution when interpreting pollen diagrams in the Mediterranean region, because it is an area with steep environmental gradients and spatial heterogeneity of ecosystems. One consequence of this is that disparate records of ecosystem change can come from catchments close to one another. Sanchez-Goni and Hannon (1999) compared the Holocene records of vegetation change from Las Pardillas Lake and a peat deposit at Quintanar, located in the Iberian Mountain chain, in Spain, and surrounded by the same vegetation types today, only 3 km apart. The differences may be the result of altitude and/or precipitation and not different altitudinal pollen transport due to wind. The earliest clear anthropogenic signal became apparent during the Roman period, i.e. "*reduced forest cover as indicated by a decrease in the AP/NAP quotient involving all the trees*" (Sanchez-Goni and Hannon 55:1999), which may actually be the result of other factors, for example fire regime and/or autogenic factors such as soil evolution and species competition.

Sclerophyllous or Mediterranean forests occur in areas where the climate is characterized by warm, wet winters and hot, dry summers. They are located along the western coastal regions of the continents. Annual precipitation ranges between 500 mm and 1000 mm, with an irregular pattern and prolonged periods of low humidity. Sclerophyll vegetation generally has small, dark leaves covered with a waxy outer layer to retain moisture in the dry summer months (Ciesla 2002). Much of the woody vegetation in modern Mediterranean-climate regions is sclerophyll, which means 'hard-leaved' in Greek. In the north-western Mediterranean, palynological data indicate the presence and even the dominance of deciduous trees at low altitude, close to the Mediterranean Sea during the early Holocene (Bernard 1971; Pérez-Obiol 1987). Evergreen trees and shrubs were rare at these times. Before 6000 BP, steppes and Mediterranean vegetation are thought to have been restricted to the Near East (Huntley and Prentice 1988). From 6000 BP, and more particularly from 4500–4000 BP, marked changes occurred in the vegetation cover. Evergreen sclerophyllous trees and shrubs developed at the expense of deciduous trees, along with evidence of anthropogenic factors (Jalut *et al.* 1997). Many authors have considered that this substitution and the establishment of the present Mediterranean vegetation were entirely the result of human activity (for example Bernard and Reille 1987; Planchais 1978; Planchais 1982; and Triat-Laval 1978). Whereas others authors consider that climatic factors were largely responsible for the major change in vegetation cover, and not solely anthropogenic influence (e.g. Huntley and Prentice 1988). At 6000 BP, the dominance of temperate forests, including temperate deciduous forests, instead of the present xerophytic vegetation implies a combination of colder than present winters and wetter than present conditions during the growing season for temperate trees (Huntley and Prentice 1988). Variations in macroclimate would thus be the most probable causes of the changes in vegetation rather than anthropogenic influence alone (Kelly and Huntley 1991), which would have only accentuated their consequences on the vegetation during the second half of the Holocene (Magri 1996), as suggested by Carrión and Dupré (1996) for northeastern Spain. The next section looks at changes within the Mediterranean basin with regard to climate, irrespective of anthropogenic influence, during the Late Holocene.

1.5.4 Late Holocene Climatic changes in the Mediterranean Basin

The climate in pre-historic north-western Europe is better known than that of northern and central Italy, and hardly any information on southern Italy. Therefore Smith (1996) suggests that, as in northern Europe, the end of the ice age showed an

increase in temperature which continued until about 3500 BC, and this was followed by a downturn from around 1300 BC to present (Lamb 1985, p182; Tooley 1978, p 131-136). Therefore, 3500 BC marks a thermal peak, a climatic *optimum*, characterised by greater annual warmth (+1-3°C), and greater annual precipitation (compared with today's). The general trend is composed of a series of oscillations, which in northern Europe at least, have been correlated with variations in sea-level (Tooley 1978). Goudie (1981) used botanical terms to describe these periods: Pre-boreal, Boreal, Atlantic, Sub-boreal and Sub-Atlantic, which are based on macrofossil evidence.

The end of the Atlantic period shows a climatic cooling and the transition from Sub-Boreal to Sub-Atlantic underlines the installation of present climatic conditions. Anthropogenic influence is visible from the middle of the Sub-Atlantic. Palaeoenvironmental variations are recorded in other European sites (Lac du Bouchet (France) SchalkenMehrener Maar (Germany), Lago di Monticchio (Italy), although slight differences may have occurred due to local effects.

Frenzel (1966) reviewed the botanical evidence of climatic change at the Atlantic/sub-Boreal transition in the Northern Hemisphere, and concludes that a short, rather weak cold spell occurred at the very end of Atlantic period and was followed by renewed Hypsithermal conditions, with a more continental climate than the warm part of Atlantic period. Frenzel's date of 3400 to 3000 B.C. (i.e. 5400 to 5000 B.P., because it is based on ¹⁴C) for the cooling is inferred from the span of Zoller's Pioru cool phase (Zoller 1960), which subsequent radiocarbon dating indicates was later, from ca. 5000 to 4500 B.P (Mercer 1967). Most of the Mediterranean most of the work has been concentrated on France. The Atlantic/Sub-aboreal transition was marked by an increased human impact and marked *Quercus ilex* expansion took place in France. This is confirmed by anthracological results obtained by Heinz (1988). At St-Paul Les Trois Chateaux (Drame), vegetation was locally characterized by the presence of *Quercus ilex* forests with *Buxus sempervirens*, *Erica arborea*, and *Arbutus unedo*. Anthracological studies use wood charcoal from archaeological sites in order to develop an understanding of the ways communities used the plants and trees around them.

Desprat *et al.* (2003) studied the climatic variability of the last three millennia in northwest Iberia via a high-resolution pollen analysis and found "*an alternation of three relatively cold periods with three relatively warm episodes*" (p63). They termed

the first of these changes, a cold phase, the "*Sub Atlantic Period*" (975-250 BC), which was marked by a decline in forests, which could equally be blamed on the greater influence of humans (Desprat *et al.* (2003). Some have called this period the "Iron Age Cold Epoch", for example Gutierrez-Elorza and Pena-Monne (1998), who noted that accumulation and incision phases affected the slopes and infilled valleys in the semiarid areas in NE Spain at around 900-300 BC. This was followed by the "*Roman Warm Period*" (RWP) (250 BC-450 AD) (Desprat *et al.* 2003 p 63). Martinez-Cortizas *et al.* (1999) showed several decadal-scale intervals during the Roman Warm Period were more than 2.5°C warmer than the 1968-98 period, while an interval in excess of 80 years during the Medieval Warm Period (800 to 1200 AD) was more than 3°C warmer. These changes have been corroborated by others, most recently Frisia *et al.* (2005), who believe that the warmest temperatures in the Late Holocene were reached between 400 BC and ca. AD 0, and in the past 100 years. Pla and Catalan (2005), who analyzed chrysophyte cyst data collected from 105 lakes in the Central and Eastern Pyrenees of northeast Spain produced a Holocene history of winter/spring temperatures in this region, revealing a significant climatic oscillation between warm and cold phases. Garcia *et al.* (2007) employed a multiproxy based approach: obtaining a high resolution pollen record and geochemical data from sediments, which was found to be composed mainly of layers of charophytes alternating with layers of vegetal remains. This work revealed the existence of five distinct climatic stages: "*a cold and arid phase during the Sub Atlantic (Late Iron Cold Period, 150 BC), a warmer and wetter phase (Roman Warm Period, 150 BC-AD 270), and a new colder and drier period coinciding with the Dark Ages (AD 270-900)*".

Desprat *et al.* (2003) suggest that the second cold phase followed this, a "*Dark Ages Cold Period*" (450-950 AD). Roberts *et al.* (2006) analyzed assemblages of minerals and microfossils from a sediment core taken from the Berre coastal lagoon in southeast France. The results of their analyses revealed three distinct climatic intervals: (1) a cold period that extended from about AD 400 to 900, (2) a warm interval between about AD 980 and 1370, and (3) a cold interval that peaked during the 16th and 17th centuries. These climatic intervals correspond, respectively, to the Dark Ages Cold Period, Medieval Warm Period (MWP) and Little Ice Age

Jalut *et al.* (2009) working in the Western Mediterranean, determined the pollen ratio of deciduous broad-leaf/evergreen sclerophyllous trees which indicates dry phases during the intervals 10900–9700 BP; 8400–7600 BP; 5300–4200 cal. BP; 4300–3400

BP; 2850–1730 BP, and 1300–750 BP (figure 9a). Some of them are correlated with phases of decreasing fluvial activity described by in the Western Mediterranean around 11500 BP, 10500 BP, 9000 BP, 7000 BP, 4000 BP, 3000 BP, 2000 BP, and 800 BP (Figure 9e). The succession of these phases agrees with the lake-level fluctuations at Lago dell'Accesa (Tuscany, Italy) (Magny *et al.* 2007) where three noticeable lake-level falls are recorded at ca 8600–7900 BP, 4600–4300 BP and 3700–2800 BP (Drescher-Schneider *et al.* 2007) (Figure 9h). The dry phase 4300–3400 cal BP is contemporaneous both with a decrease in pollen concentration recorded in central Italy at Lagaccione (Magri 1999) (Figure 9p) and with the hydrological changes at Lago Fucino and in other lakes in central Italy at 4200–4100 cal BP (Figure 9f).

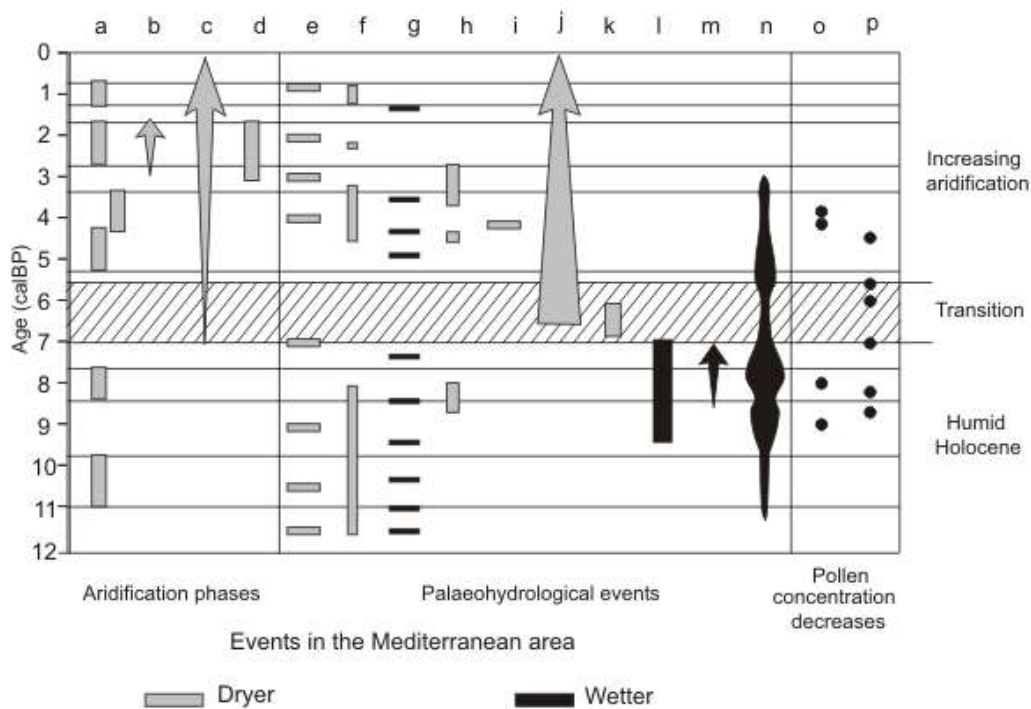


Figure 9 Correlation between Holocene climate, hydrological and pollen data concerning the Mediterranean basin. (Adapted from Jalut *et al.* 2009)

Aridification phases in the Western Mediterranean; (b) Installation of the Mediterranean climate in the North-western Mediterranean basin (c) Aridification process in the Eastern Mediterranean; ; (d) Dry episode in the Eastern Mediterranean; (e) Phases of decreasing fluvial activity in the Western Mediterranean; (f) Low lake levels at lake Fucino; (g) Major high lake levels at Lago dell'Accesa; (h) Low lake levels at Lago dell'Accesa; (i) Lake-level decreases in central Italy (Magri, 1997); (j) Lake-level decreases in the Mediterranean region; (k) Lake-level decrease at Eski Acigöl (Turkey); (l) Sapropel S1; (m) Increasing precipitation in the Eastern Mediterranean (Soreq cave); (p, o) Decrease in pollen concentration in Sicily and Balearic Islands.

Three different climatic cycles could exist within the time period immediately before, during and after the main period of Roman occupation examined in this thesis.

1.6 Research questions

Castelporziano represents a Late Holocene landscape, which has evidence of discontinuous human intervention and continuous environmental change. The Roman settlement at the site provides a unique opportunity to examine human-environmental interactions during this time period (~40 BC to 420 AD). The results should feed into key debates involving climatic vs. human influences as factors for environmental change within the Mediterranean (e.g. Gratani and Amadori 1991). The thesis will also examine theories of deforestation, degradation and desertification due to the Roman interactions with their environment, as mentioned in the section on the Mediterranean landscape, and popularised by environmental historians such as Donald Hughes (e.g. 1975, 1983, 2001 and 2005). It will examine whether there is environmental evidence coinciding with the end of settlement ca. 420 AD.

The overall aim of this thesis is to examine the environmental changes that have occurred before, during and after the period of Roman settlement at Castelporziano.

Research questions:

1. Are dune slacks suitable archives for palaeoenvironmental reconstructions? As dune slacks represent the only available sinks for sediment and organic matter at the Castelporziano, it is important to establish their suitability as limited work has been done previously using them for palaeoenvironmental reconstructions.
2. Which palaeoenvironmental proxies can be used to reconstruct past changes in the dune slacks? If dune slacks can be used as a palaeoenvironmental archive, establishing which proxies can and cannot be used is important, as it cannot assume proxies from peatlands or lake sediments will be suitable or preserved. Furthermore, it will be important to understand the reasons for their presence or absence within the slacks, and what this says about the environment.
3. What environmental changes are apparent from the palaeoecological and chemical proxies? When did they occur and why? The environment may have remained unchanged for the last 2500 years, but it may also have changed, and the proxies

can give indication of these changes at a local and/or regional level. The proxies will all be constrained using radiocarbon dating, to give a chronology to any changes and then by combining the proxies together, it may possible to give an answer to why these changes were occurring.

4. To what extent were these changes anthropogenic and/or natural? Palaeoenvironmental reconstructions can be used to indicate in a quantitative way the extent to which the environment has changed. If changes have been noted in the palaeoenvironmental estate, the archaeological record can help establish what the known anthropogenic impacts were at set times. However, it is also important to consider the role of internal factors in the slack and the local environment, such as competition, disease, and non-anthropogenically induced fire.

5. What is the current vegetation of the area and how has it been affected by estate management practices over the last 50-100 years? Since access to the public was restricted for centuries, a large number of plant species typical of the Mediterranean area are still present to a great extent, however given the perceived 'naturalness' of much of the current vegetation in the coastal part of the Castelporziano Estate, alongside numerous afforestation schemes, the influence which these and other practises have had on the environment and vegetation will be considered.

6. What evidence is there of a legacy of past land use practices from Roman times onwards? Legacies of land-use activities continue to influence ecosystem structure and function for decades or centuries—or even longer—after those activities have ceased (Foster *et al.* 2003). Therefore, the Romans land use at Castelporziano may still influence the modern environment, and need to be considered alongside the modern anthropogenic impact.

The research questions and how they relate to the structure of thesis is highlighted in figure 10. The next section describes the content of each chapter.

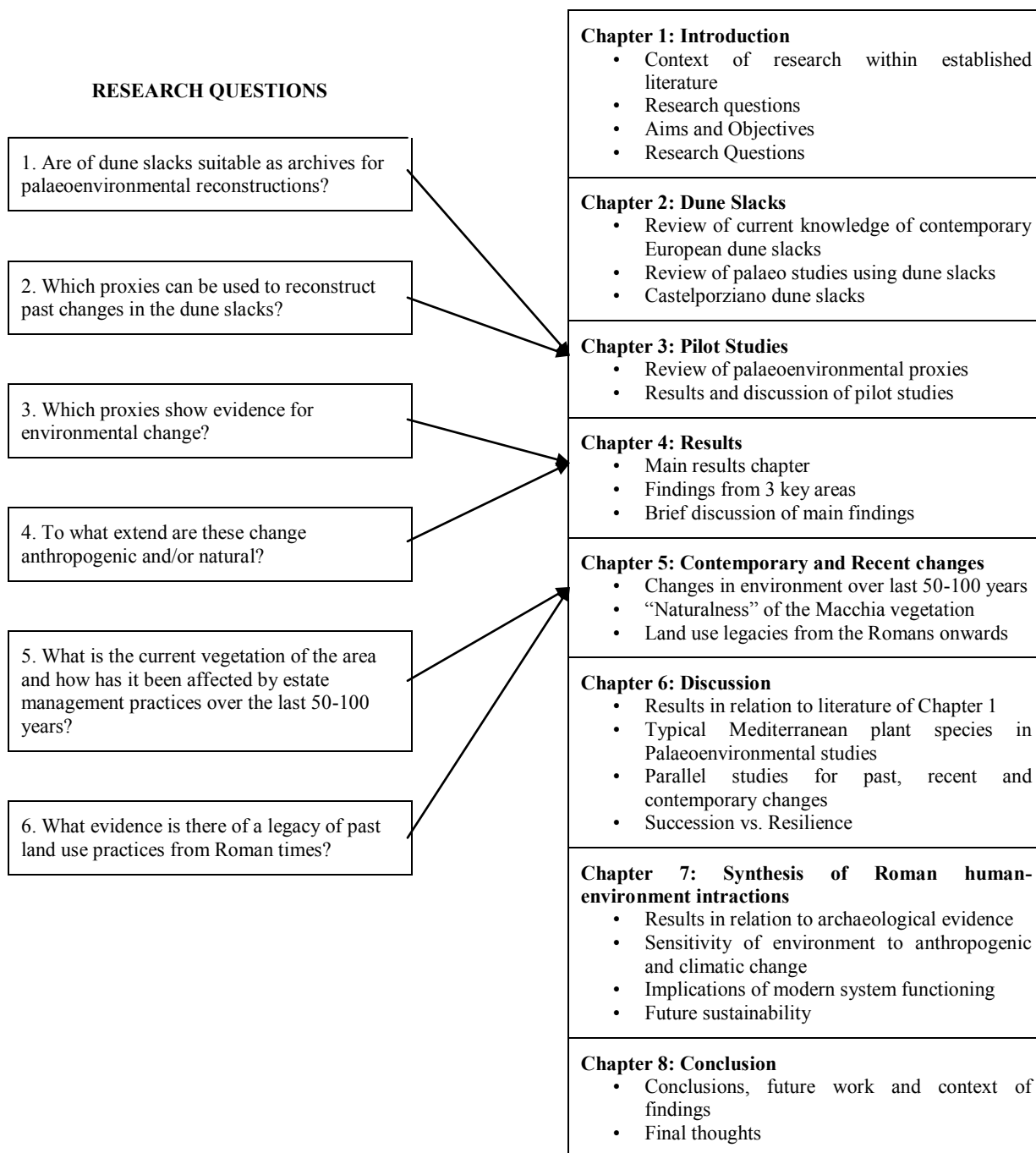


Figure 10 Thesis Structure

1.6.1 Structure of thesis

The second chapter begins with a review of the nature of dune slack ecosystems, drawing on the extensive work on Dutch and UK slacks, together with the much more limited literature on Mediterranean dune slacks. This chapter sets out the current knowledge of contemporary dune slacks from their formation and geomorphology, to issues of ecological succession, along with examples of natural and anthropogenic impacts. The applicability of Northern European analogues to a Mediterranean context is considered. The chapter ends with a review of the limited amount of palaeoenvironmental work from dune slacks, and an evaluation of the potential of using dune slacks as archives for palaeoenvironmental work.

The third chapter (Methodological approaches and development) begins with a summary of potential biological, physical and chemical proxies, and explains why a multi-proxy approach is important in this type of work. This information is then related back to dune slacks and what these proxies may be indicators of (e.g. temperature, precipitation, pH, salinity). Since a choice of proxies cannot be made without examining the actual dune slack material, pilot studies were carried out on some initial cores in order to establish the sampling strategy, methodologies and selection/rejection of proxies to be used for the rest of the thesis. The results of the various pilot studies are then evaluated.

The results of the palaeoenvironmental reconstruction work are presented in the fourth chapter (The palaeo record: A multiproxy palaeoenvironment reconstruction). In addition to the results, this chapter will examine how different parts of the environment can be reconstructed and whether the results from the different proxies are complementary. The chapter then examines spatial and temporal variability across the sampled area and discusses the results in terms of inferences about environmental change.

Chapter five (Recent and Contemporary Environmental change) presents a synthesis of the last 100-50 years of environmental change and estate management. The 'naturalness' of the macchia vegetation in the coastal strip is discussed in the context of past land use legacies, management strategies of the estate and natural succession.

Chapter six (Discussion) is divided into four sections and begins with an examination of the results for the last ~2500 years, within the context of the wider literature on

Late Holocene changes. The second section scrutinises the use of palaeoenvironmental reconstructions for typical Mediterranean species while the third section examines the importance of parallel studies for past, recent and contemporary change in the environment. The final section examines the issues of succession vs. resilience that are informed from the palaeoenvironmental reconstruction.

Chapter seven (Synthesis of Roman human-environment interactions) focuses on the interpretation of the environmental change results in the context of the archaeological evidence, the sensitivity of the Castelporziano Estate to climatic and anthropogenic drivers of change and the implications of the modern system functioning of the estate and future sustainability.

The eighth and final chapter (Conclusions) provides a summary of the work undertaken, conclusions in terms of the research questions, and sets out recommendations for further research.

Chapter 2: Dune Slacks

2.1 Introduction

This chapter reviews the nature of contemporary dune slacks in terms of their geomorphology, hydrology and ecology as well as anthropogenic and climatic impacts upon them. Although the majority of published work on dune slacks focuses on the Netherlands, a limited literature exists from the Mediterranean. The chapter then reviews the very limited literature on the use of dune slacks for palaeoenvironmental reconstructions, and concludes with a discussion of how the studies undertaken so far on dune slacks may be relevant to the Castelporziano example.

Dune systems along the European coast are characterized by pronounced geochemical and geomorphological gradients (for example in soil moisture and soil acidity), which favour high diversity of plants and animals (Grootjans *et al.* 1998). Figure 11 shows an idealised transect across a dune system with both high shell content and silica sand but the reality, as at Castelporziano, is often more complex.

Dune slacks are also known as swales (Shumway and Banks 2001) and interdunal wetlands (McAvoy and Clancy 1994). Figure 12 shows a dune slack from the Castelporziano estate. Ecologically they present some of the few examples of primary succession series with a high degree of facilitation between functionally distinct groups of plants and a strong impact of the inter-annual variation of the water table (Grootjans *et al.* 2002).

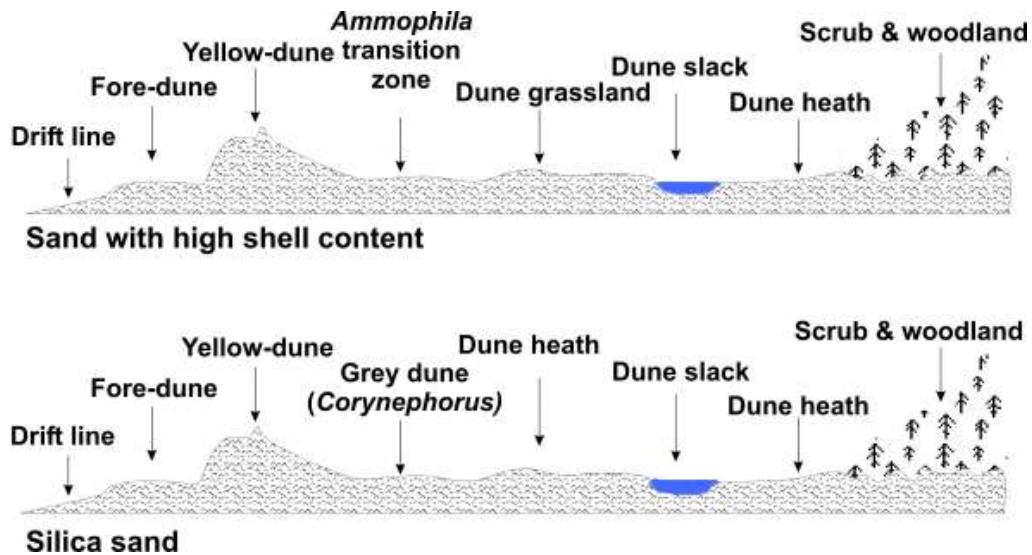


Figure 11 Idealised transect across a dune system for high shell content and silica sand (redrawn from Duffy 1968)

Dune slacks are defined as the low-lying area within the coastal dune systems where the water table is near the surface but subject to high seasonal fluctuation. They are a unique type of wetland ecosystem, highly ranked on the international conservation agenda because of the occurrence of many rare and endangered plant species and their associated fauna (Grootjans *et al.* 2004). There are a number of threats to the biodiversity in dune ecosystems including sea level changes, changes in temperature and precipitation and anthropogenic impacts, therefore studying the impacts of these in the past, may help with present and future conservation of these ecosystems.

Recent research on dune slacks has predominately centred on north-west European coasts (e.g. van Dijk and Grootjans 1993, Grootjans *et al.* 2004); comparatively little work has been undertaken along Mediterranean coasts (Dimopoulos *et al.* 2006), with the foci on biological and environmental processes within or around them counteracting the rapid loss of diversity owing to human impact. Very few studies have looked at longer term changes.



Figure 12 Dune slack at the Castelporziano estate (photograph taken April 2008)

The distribution of dune slacks within different areas of the Europe, by biogeographic unit and country (Table 1), show that within these areas there are 42 sites deemed to have “humid dune slacks” and these account for 27.7% of the total surface area in the coastal areas of the Mediterranean, and within Italy they account for 5.8% of the total coastal zone. They form an integral part of the extensive dune systems of the Atlantic and some Mediterranean biogeographical regions (Houston 2008) (figure 13).

Biogeographical Region	Number of Sites	Estimated surface in Natura 2000 (ha)	% of total surface in Natura 2000
Atlantic	124	13029	44.33
Mediterranean	42	8155	27.7
Continental	52	7113	24.2
Boreal	27	1113	3.8
Countries	Number of Sites	Estimated surface in Natura 2000 (ha)	% of total surface in Natura 2000
Denmark	33	7788	26.5
France	50	7003	23.6
Portugal	6	4109	14.0
Netherlands	15	1909	6.5
Italy	25	1705	5.8
Spain	8	1443	4.9
Poland	7	1412	4.8
United Kingdom	25	1254	4.3
Germany	19	643	2.2
Ireland	15	642	2.2
Estonia	8	522	1.8
Finland	7	367	1.2
Greece	8	300	1.05
Sweden	14	212	0.7
Latvia	3	49	0.2
Belgium	1	37	0.01
Lithuania	1	15	0.05
TOTAL	245	29410	100

Table 2 Biogeographic and Country distribution of Dune Slacks (Houston 2008)

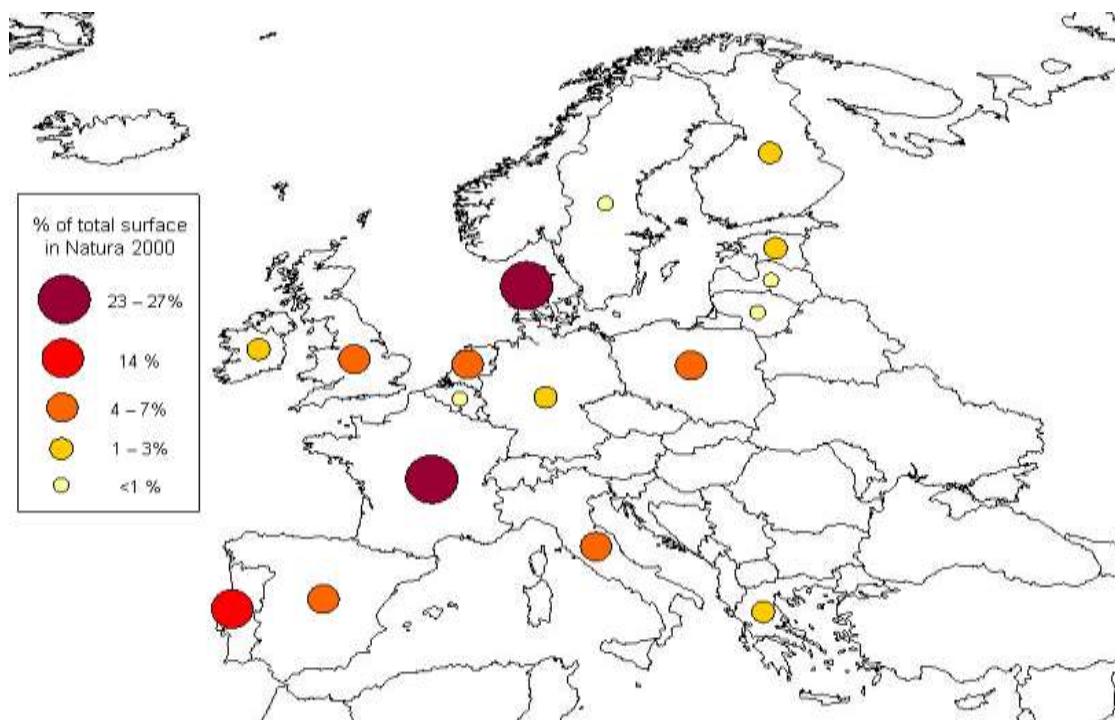


Figure 13 Percentage distribution of the total surface of humid dune slacks (Houston 2008)

2.2 Comparison of Castelporziano dune slacks with those within the established literature

At Castelporziano a range of different dune slack environments is encountered ranging from dry to seasonally- to perennially-wet. The contemporary wet dune slacks are now confined to the south-eastern portion of the estate (figure 14). The slacks at Muraccioli and Pozzo Napoliello and D5 all had the water table within 50 cm of the slack surface, whereas the centre of the D6 slack was perennially wet. The slacks sampled elsewhere were all dry. The whole of the coastal area of Castelporziano Estate is now forested.

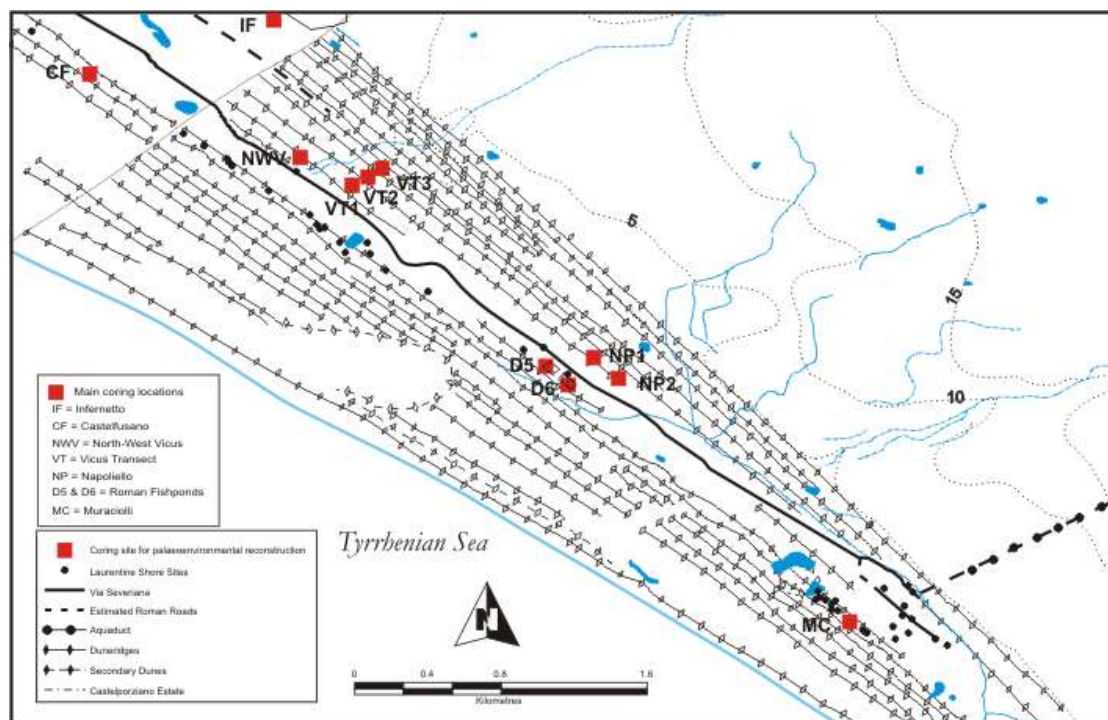


Figure 14 Location of dune ridges and slacks in the Castelporziano estate in 2009 (Adapted from Bicket 2010)

2.2.1 Rationale

There is a substantial body of work on modern dune slacks, with the most notable studies being undertaken in the Netherlands (especially the Wadden Islands), United Kingdom and Germany. By comparison the studies of dune slacks along the Mediterranean coastline are few in number. Nevertheless the Castelporziano dune slacks may be compared with other European slacks in terms of: the

geomorphological and physiographic setting; the composition of sediment; and, perhaps to a lesser extent, the (plant) community structure

2.2.2 Geomorphical and physiographic setting

Slacks are integral components of the dune systems in which they are found and therefore the geomorphological setting of a system is bound to influence the hydrological characteristics of its slacks. The dunes at Castelporziano are within 5 m of current sea level, and are arranged as a series of shore-parallel ridges. With the exception of the contemporary foredune ridge, all of the dunes are completely vegetated (Lupia-Palmieri and Tortora 1980). Rendell *et al.* (2007) dated the dune ridges and showed that they were mostly Holocene in ages with the oldest dating to 12810 ± 1485 years ago. A post-Roman dune dated to 1150 ± 100 years ago (AD 850 ± 100) lies ~50 m seaward of the line of Roman remains, while the contemporary foredune lies ~900 m from the *Vicus Augustanus*.

The Roman remains along the Laurentine Shore lie on the lower delta plain of the Tiber river (Bellotti *et al.* 1994). Inland from the *Via Severiana*, the dune ridge topography displays ridge heights (or amplitudes) of ~1 m, whereas between the Roman site and the modern beach, amplitudes increase to between 2 and 5 m. The dunes are currently stabilised by forest plantations utilising *Pinus pinaster*, *Quercus ilex* and *Pinus pinea* (De Lillis *et al.* 2004). There have been various phases of afforestation aimed at stabilising sand drift and retaining the integrity of pasture grazing, with planting recorded 180–150 years ago and 130–100 years ago and, most recently, 20 years ago (Rendell *et al.* 2007).

2.2.3 Composition of sediment

Coastal sand dunes are typically composed of quartz, other detrital mineral grains and shell fragments. The calcium carbonate concentration may be extremely variable between, and to an extent, within dune systems (Schwartz 2005). It can be derived from the erosion of calcareous rocks (e.g. chalk, limestone) but in many places it is derived from shell debris brought ashore by waves and onshore winds. Foredune sands usually have the highest amount of carbonate, as carbonate may be progressively dissolved in older dunes (Davy *et al.* 2006). Machairs are a distinctive type of coastal grassland found in the north and west of Scotland, and in western Ireland. They are associated with calcareous sand, blown inland by very strong

prevailing winds from beaches and mobile dunes. In its strict sense, '*machair*' refers to a relatively flat and low lying sand plain formed by dry and wet (seasonally waterlogged) short-turf grasslands above impermeable bedrock, a habitat termed 'machair grassland'. However, *machair* can also cover the beach zone, mobile and semi-fixed foredunes, dune slacks, fens, swamps, lochs (some of them brackish), saltmarsh, and sand blanketing adjacent hillslope (UK Biodiversity Group 1999)

The provenance of coastal sands in the Lazio region of central Italy is from the major rivers, predominantly the Tiber, with a small contribution from the Garigliano and the smaller rivers of Marta, Mignone, and Astura (Calmieri 1980). The mineralogy is therefore linked to the geology of the river catchments. The materials deposited on the coast north of the mouth of the Tiber are linked to volcanic outcrops – with a predominance of pyroxene and heavy minerals (Gottardi and Mittempergher 1955; Anselmi *et al.* 1976). To the south of the Tiber mouth, the beach sand shows an increase in the content of magnetite (Brondi *et al.* 1979) while, compared to the northern part of the delta, higher percentages of feldspar, quartz and calcite and limestone lithic fragments can be found (Calmieri 1980). A detailed study of the minerogenic components of the dune sands was carried out by Bicket (2010) as part of the larger AHRC project.

The dune slacks of the Castelporziano estate are characterized by hydromorphic⁴ soils, whose impermeability gives rise to permanent ponds. What makes the Castelporziano dune slacks unusual is that one of the slacks, at the D5/D6 sampling

⁴ Hydromorphic soils are a general term for soils that develop under conditions of poor drainage in marshes, swamps, seepage areas, or flats.

locations, appears to have been adapted for use as (two) large fish ponds or tanks. Parts of the dune slack were effectively enclosed and the hydrology of these areas was consequently altered.

2.2.4 Community Structure

Acosta *et al.* (2007) highlighted the structure, environmental features and most representative species for dunes within the Lazio area of central Italy. Two main communities were identified. The first of these is an herbaceous wet community of the dune slack; with the water table remaining near the surface during the summer drought. The community structure is typically *Schoenus nigricans* and *Erianthus avennae*, and therefore typical species should include *S. nigricans*, *E. ravennae*, *Juncus acutus*, and *Lysimachia nummularia*.

The second community comprises evergreen woodland, dominated by *Quercus ilex*. The community structure is typically *Quercus ilex* community and therefore typical species should include *Q. ilex*, *Viburnum tinus*, *Phillyearsea latifolia*, *Myearstus communis*, *Ruscus aculeatus*, *Hedera helix*, *Cyclamen repandum*.

The next few sections of this chapter will look more in depth on the current knowledge of dune slacks.

2.3 Geomorphology

The geomorphological history of dune slacks is very varied. Primary slacks originate from beaches, which have been partially or fully cut off from the influence of the sea as a result of dune development at the shoreface. Desalinization can occur within a few years, but a brackish character may be preserved by exceptional flooding during severe storms (Gares and Nordstrom 1988). Secondary slacks are the result of intense sand-blowing in dune complexes. Dune slack soils can be calcareous (alkaline) or relatively acidic, depending on the initial calcium carbonate content of the dune sand. The dune slacks associated with prograding beaches are usually formed as a result of wave erosion followed by aeolian accumulation (Gares and Nordstrom 1988; Jämbäck 1995), so that they should not be regarded as blowouts formed by deflation.

Young dune slacks are generally covered by sparse vegetation and have a simple structure; they do however show great variability with respect to species composition, which closely reflects the characteristics of the groundwater regime (Grootjans *et al.* 2002). The species assemblage in dune slacks has much in common with lowland marshes, mires and fens. Some species are restricted to the coastal area, sometimes because of the extinction of inland populations resulting from severe drainage and fertilization of their habitats (Grootjans *et al.* 2004). The plant species of dune slacks have to cope with a hydrologically dynamic environment, which impacts on the chemical form of nutrients, and an environment poor in the major nutrients - nitrogen (N) and phosphorus (P). Anoxia tolerance is one of the dominant factors responsible for a stable vegetation zonation between dune slack and dune top (Grootjans *et al.* 2002, 2004).

2.4 Ecological Succession

Natural succession in dune slacks starts with a pioneer phase in which small pioneer species establish on almost bare sediment. This wet sediment is usually covered with a thin layer of green algae and laminated microbial mats (Grootjans *et al.* 1997), and only a few phanerogamous (i.e. seed-producing) species are adapted to the low nutrient availability in this phase. Succession can evolve gradually from this bare sediment via pioneer and intermediate stages to a climax stage (Grootjans *et al.* 2004). However the assumptions of succession within coastal dunes have been criticised by Johnson and Miyanishi (2008) as far too simplistic, while within dune slacks alternative steady states have been found by (Adema *et al.* 2002), which cannot be accounted for by succession. The ideas of succession vs. resilience and adaptive cycles will be discussed further in chapter 6.

After the formation of the slack, a primary succession process is hypothesised during which the number of species in the slack increases as a result of colonization events. This increasing species pool in the slack can be considered as the potential species pool (i.e. gamma or regional diversity) for the local communities. If the number of species in the slack remains constant during succession, despite an increasing population of individual plants in the slack, this is evidence for a limitation on the number of species. This limitation can be caused by (1) habitat heterogeneity within the slack (2) dispersal limitations within the slack and/or (3) inter-specific biotic interactions resulting in competitive exclusion (Bossuyt *et al.* 2005).

Algal communities develop in the slack during the period of inundation. Some studies, particularly in the Netherlands, have shown that algae play an important role in dune stabilisation, namely in the fixation of soil, which allows rooting of other species (Van den Ancker *et al.* 1985; Pluis and De Winder 1990). The species that colonise these systems are mainly green algae and filamentous cyanobacteria with sheaths that adhere to sand grains. When the slack dries out, the algae die forming crusts; the sheaths remain adhered to the sand, acting as a cementing agent on the surface (Vázquez *et al.* 1998). The algae can form microbial mats, which are most abundant in tidal flats and salt marshes but also occur in other pioneer stages of ecosystems such as dune slacks. Recent research suggests that, in some freshwater dune slacks, microbial mats may assist in retarding the natural vegetation succession, thus extending the life span of pioneer stages (Grootjans *et al.* 2004) and result in poor growth of *Juncus* and *Calamagrostis* particularly in the presence of *Samolus valerandi* (Grootjans *et al.* 1997). However, it is not known in the literature how long this period is extended for, as research has focused on the growth of particular species and not on the time constraints limiting growth.

Grootjans *et al.* (2004) found that, in Dutch slacks, once species have colonized the slack and become part of the regional species pool, they will expand their population over the slack by seed dispersal and/or clonal propagation. However, when species are limited in their dispersal throughout the slack, populations only occur as one or more small local patches within the slack. The location of these patches will depend on the location of accidental arrival of seeds in the slack. Due to dispersal limitations, not all species in the regional species pool are, in reality, able to occur in all plots within the slack (i.e. dispersal limitation hypothesis), which means that the regional species pool is again overestimated (Kalamees and Zobel 1998). Dispersal limitation results in a correlation between distribution of the species over the slack and their dispersal capacity. Moreover, because the location of seed arrival and germination in the slack is stochastic, species composition in the plots will also be random (Bossuyt *et al.* 2005). This observation is important with regard to a palaeoenvironmental reconstruction using plant macrofossils, but macrofossil production depends on the reproductive strategies of particular species. Annual plants, which overwinter as seed, typically produce many times more seed per year than perennial species, and seed production may vary from year to year, depending on environmental conditions. The representation of macrofossils in other palaeoenvironmental archives, e.g. lake sediments, has been found not to be linearly or unimodally related to the variable (proportion of a species within the vegetation community) of interest. Furthermore

many factors affect the relationship between macrofossil assemblages and plant communities (Koff and Vandel 2008).

Young dune slack systems, which are flooded during the winter and most of the spring, form hot spots of botanical diversity. The poorly productive, basophilous⁵ plant communities in the first two pioneer stages in wet dune slacks in the Netherlands harbour many rare and endangered species (Grootjans *et al.* 1988; Lammerts *et al.* 1999). Many plant species in Northern European dune slacks have been placed on the Red List of the International Union for Conservation of Nature (IUCN)⁶ including *Liparis loeselii*, *Epipactis palustris*, *Schoenus nigricans*, *Eleocharis quinqueflora*, *Dactylorhiza incarnata* and *Linum catharticum* (Grootjans *et al.* 1995), which makes understanding how they have changed using palaeoenvironmental reconstruction potentially important for future conservation. As knowledge of Italian and therefore, Mediterranean dune slacks is poor, it is not known whether species found uniquely here should also be this list.

Species-rich basiphilous pioneer communities (*Junco baltici-Schoenetum nigricantis*; *Parnassio-Juncetum atricapilli*; *Samolo-Littorelletum*) can be characterized by the following abiotic properties: low soil acidity (pH > 6.0), nutrient-poor conditions and soil water logging for part of the winter (Ernst *et al.* 1996; Lammerts *et al.* 1995; Schaminée *et al.* 1995; Sival 1997). Basiphilous pioneer vegetation in primary and

⁵ Basophiles are plants of basic or alkaline habitats, such as limestone, sandstone, or dolomites.

⁶ The Red List was created in 1963, is the world's most comprehensive inventory of the global conservation status of plant and animal species.

secondary dune slacks in Dutch dune slacks have a maximum age of ca. 35 years (Lammerts *et al.* 1998). After 10-35 years many basiphilous species decline. However, some species, such as *S. nigricans*, will persist for many years, and if the vegetation is mown annually the species-rich vegetation can persist for over 100 years (Lammerts *et al.* 1998).

Primary succession can lead to important changes in community characteristics within a period of 50 years. Total plant cover and number of species increase as a result of the endogenous succession process, during which organic matter and nutrients accumulate. Therefore, competitive interactions shift from competition for nutrients to competition for light. This in turn leads local factors to determine at least part of the community composition in the slack, particularly in the first successional stages. However, differences in community composition with increasing age are smaller when the slack is more isolated, suggesting a slower succession rate and biomass accumulation. Together with a lower contribution of slow dispersing species in more isolated slacks, this indicates that species accumulation is dispersal-limited and thus influenced by regional factors. The stochastic variation resulting from this dispersal limited species accumulation causes a divergent successional pathway (Bossuyt and Hermy 2003).

2.4.1 Potential errors in the succession model

In 1714 Lancisi (1654-1720) published "*Physiologicae Animadversiones in Pliniam Villam Nuper in Laurentino detectam, in quibus tum de novis aggreSSIONibus circa Ostia Tiberis...dissertur*". This work was on the local vegetation of Castelporziano and surrounding area; the changes in vegetation are noted as dynamic processes and the concepts of succession and pioneer plants are first used (Pignatti and Savioa 1989). This work makes the site even more interesting from an ecological perspective raising the question as to whether the concepts of succession, climax, resilience, adaption and panarchy are suitable for describing changes in the environment, particularly with regard to anthropogenic impact.

"Ecological succession" is the observed process of change in the species structure of an ecological community over time (Johnson and Miyanishi 2008). Within any community some species may become less abundant over some time interval, or they may even disappear from the ecosystem altogether. Similarly, over some time interval, other species within the community may become more abundant, or new

species may even invade the community from adjacent ecosystems. In a coastal dune setting succession theory assumes that a simple linear relationship occurs from a bare beach climaxing to an oak forest (figure 15). This simple relationship is shown in most basic ecology textbooks. Within dune systems it assumes an aggrading system of successive dune ridges allowing a classic space-for-time substitution. However, as Johnson and Miyanishi (2008) have noted the underlying assumptions of these models, based on work done on the dunes of Lake Michigan, are flawed. They point out that *Cakile* is assumed to be a pioneer species on dunes prior to being replaced by perennial *Ammophila*, but this has been found not to be the case, as it is seasonal wave disturbance that reflects where this species maybe found. *Populus* trees are believed to dominate the second dune ridge behind the *Ammophila*-dominated fore dunes, which again has been shown to be false because this is due to particular historical moist germination beds close to the water table followed by subsequent sand deposition after the seedlings become more established. Vegetation found on a dune is due to the local topography and disturbance history, not necessarily succession (Johnson and Miyanishi, 2008).

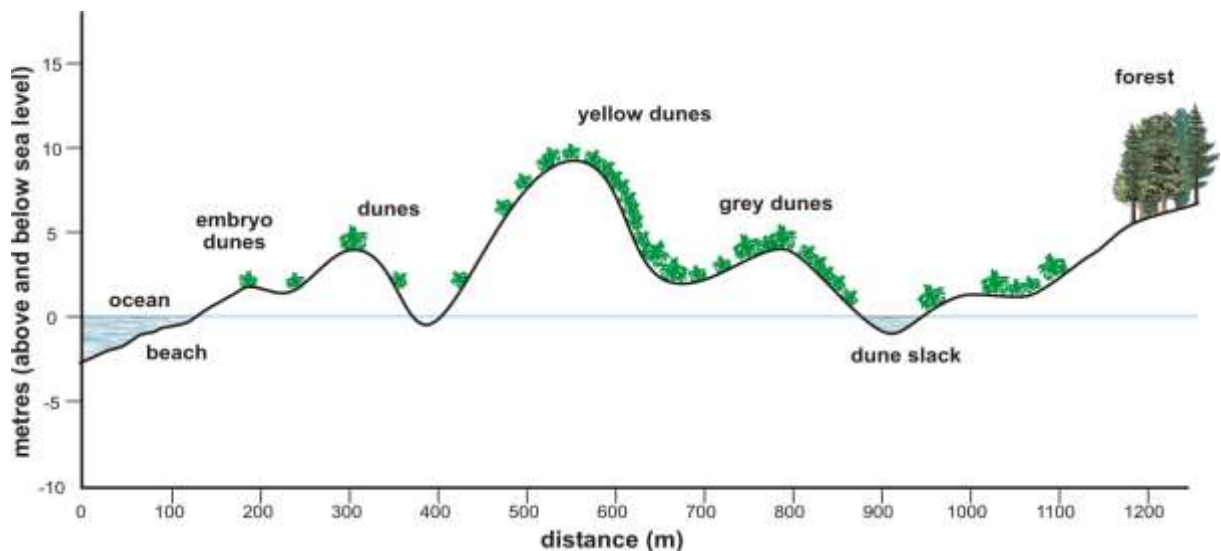


Figure 15 Simplistic view of dune succession

The applicability of the classic successional model to a Mediterranean environment such as Castelporziano may be overly simplistic because, it only allows for single pathway leading towards a climax forest, i.e. it is unidirectional. This does not account for disturbance events, such as fire, that are prevalent in this type of environment. At Castelporziano, after a fire in August 1982, *Quercus ilex*, *Phillyrea latifolia*, *Arbutus unedo*, *Erica arborea*, and *Pistacia lentiscus* all showed a rapid growth in the first

years after fire, and all the species survived the fire and reconstituted a community similar to that unburned in a relatively short time span (Gratani and Amadori 1991). Allen (2009) asserted that Mediterranean ecosystems do not need light as a primary driver for succession, whereas moisture is more likely to be a limiting factor. Furthermore, modern Mediterranean woodlands appear to show a built in resilience to the anthropogenic impact. Additionally, macchia is noted to represent intermediate stages in the course of evolution or degradation of vegetation (Paola and Peccenini 2003), which again is not accounted for in the succession model. When macchia grows in situations which limit its expansion, e.g., steep slopes, high contents of salt in the soil, or the continual drying capacity of winds means that woody plants cannot grow tall. These cases may be interpreted as permanent stages of vegetation, or “subclimax”.

2.5 Factors influencing dune slack development

Dune slacks may be maintained by the pattern of airflow across the dune system. Onshore winds are high over the dune ridges, but turbulence creates strong eddies within the dune slacks, preventing the accumulation of sand. It is only on the lee slope of dunes that the wind is light enough for sand accumulation (Reading and Collinson 1996). The height of the dunes is also restricted by the strength of the wind (figure 16).

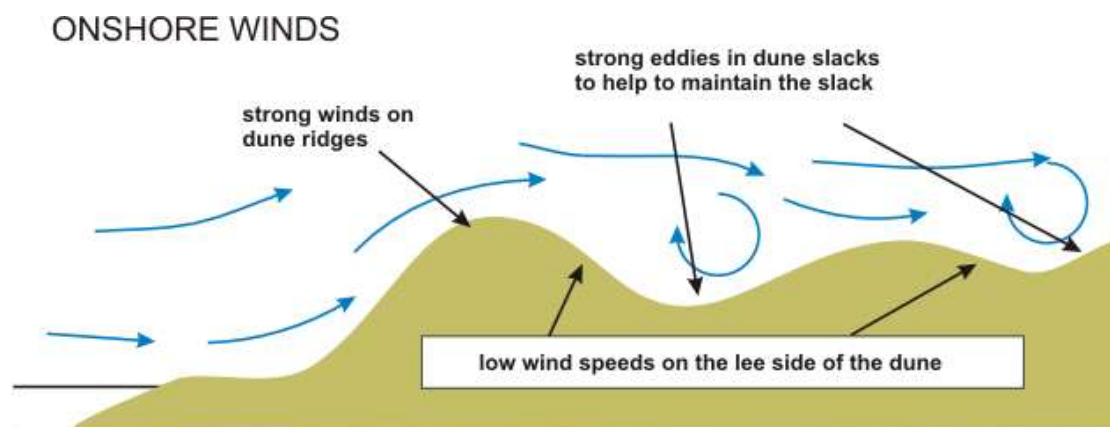


Figure 16 Wind and dune slack formation (Adapted from Reading and Collinson 1996)

If a unidirectional vegetation development occurs (figure 17) then the succession (C, D) does not coincide with increasing age of the landscape (A, B) and is unique at any point in time. Positive and negative feedback mechanisms operate at every moment in the development of the vegetation X from A to B. Through-flow of calcareous

groundwater, sand-blowing and grazing can each hamper biomass production and stimulate growth of rarer dune slack species in pioneer stages. Landscape processes in dune areas are also strongly influenced by unpredictable factors such as the outbreak of myxomatosis in rabbit populations in the Netherlands, or the activity of wild boar at the Castelporziano estate. All these changes may lead to stimulation of biomass production and a loss of biodiversity (Grootjans *et al.* 1998).

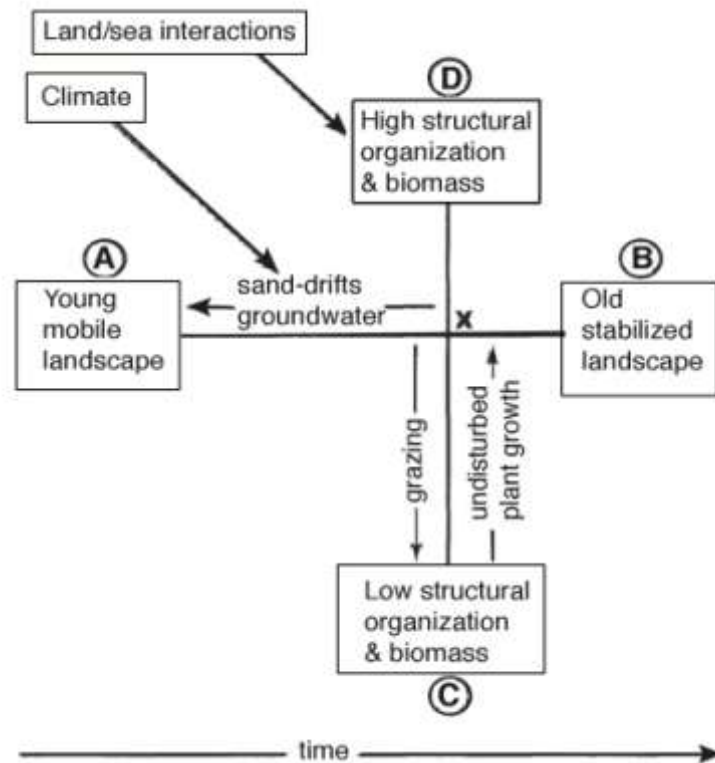


Figure 17 Factors influencing dune slack development (Redrawn from Grootjans *et al.* 1998).

2.5.1 Hydrology

Dune slacks are not just temporary dune ponds that fill with water during the wet season and dry out during the dry season (Grootjans *et al.* 2004). The hydrology leading to the formation of a humid dune slack can be seen as figure 18. The source of water that feeds them may be: inflow of precipitation water, surface water or groundwater (Grootjans *et al.* 2002). In many cases the maintenance of dune slack ecosystems depends on both the amount of precipitation and the groundwater discharge (Grootjans *et al.* 2004), see figure 19, which presents a hypothetical model of groundwater flow in dune slacks (figure 18 and 19). In an area such as Castelporziano where there are several series of dune slacks in close proximity,

slight differences in water level between slacks may initiate ground water flow from one slack to another (Kennoyer and Anderson 1989; Grootjans *et al.* 1996). Under such conditions calcareous groundwater from deeper layers can flow towards the up-gradient parts of the slack. The influx of calcareous groundwater stimulates mineralisation of organic matter and therefore, the accumulation of organic matter is hypothesised to be lower here than at the infiltration sites (Sival and Grootjans 1996).

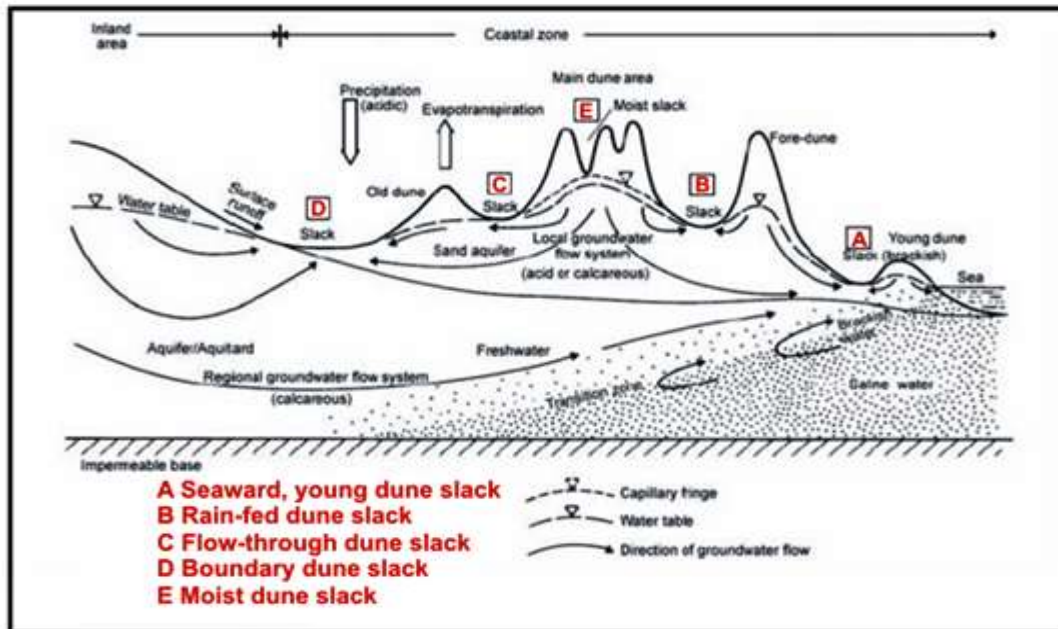


Figure 18 Hydrological controls on humid dune slack formation (redrawn from Coulet *et al* 2008)

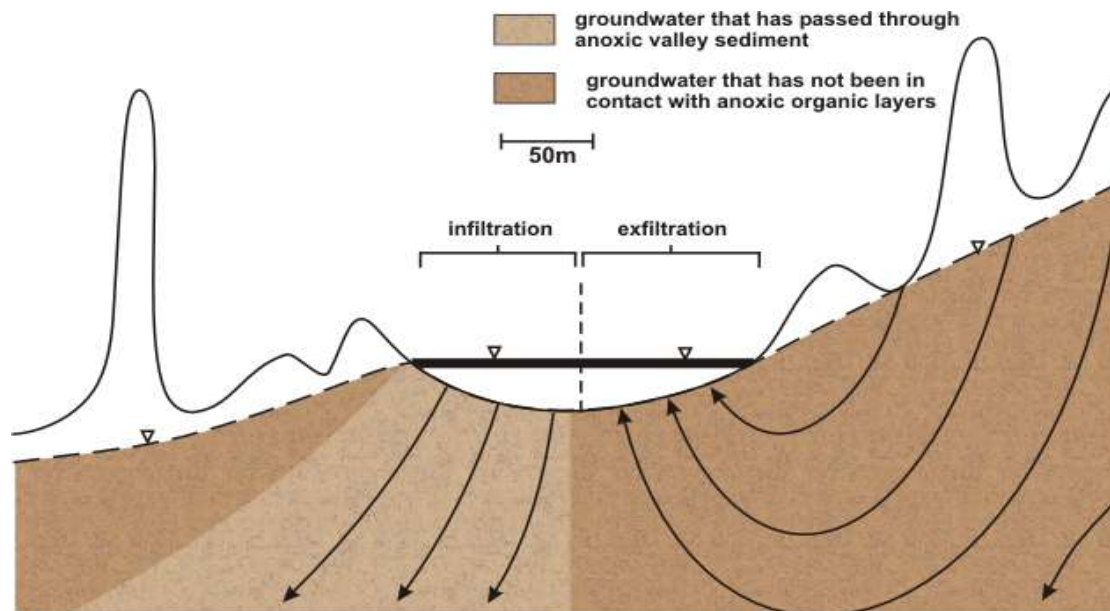


Figure 19 Model of groundwater flow in flow-through dune slacks
Adapted from Stuyfzand and Moberts (1987)

Dune slacks, as with other dune habitats, are generally nutrient-poor and therefore associated with low levels of nitrogen and phosphorus in the soil (Koerselman 1992, Lammerts and Grootjans 1997 and Lammerts *et al.* 1999). Eutrophication of sand dune habitats is of growing concern (Jones *et al.* 2002a) and can lead to increased above ground biomass (i.e. accumulation of leaves, living branches, dead branches, bark and wood) and a decline in species richness in dry dune grasslands (Jones *et al.* 2002b, 2004; van den Berg *et al.* 2005), similar to the effects observed in other eutrophic habitats (Bobbink *et al.* 1998; Jones *et al.* 2002a; Stevens *et al.* 2004) (figure 20).

If local circumstances allow complete blowing out of secondary slacks, assuming that there is no vegetation cover, deflation will carry on until the capillary zone of the (summer) water table has been reached. In unaffected dune areas the local climate introduces seasonal fluctuations of the water table as a result of the alternation of high evaporation during summer and low evaporation during winter, which results in negative effective precipitation during summer and a large precipitation surplus in winter. In the Mediterranean summer drought will only serve to enhance the drying out process. In the Netherlands, the water level is lowest in August or September and rises in winter to a maximum in January or February and the annual fluctuation of the water table is 0.3-0.7m (exceptionally even 1.1m); the pattern of fluctuation is mainly determined by the extent of open water and by the size of the surrounding water system. The result of the seasonal fluctuation pattern is that in summer there are

vast, recently-drained sites, whereas in winter, pools with a depth of half a metre appear. Should there be accretion of the coastal zone then locally the water level can increase strongly and these pools can achieve a more permanent lake-like character (van Dijk and Grootjans 1993).

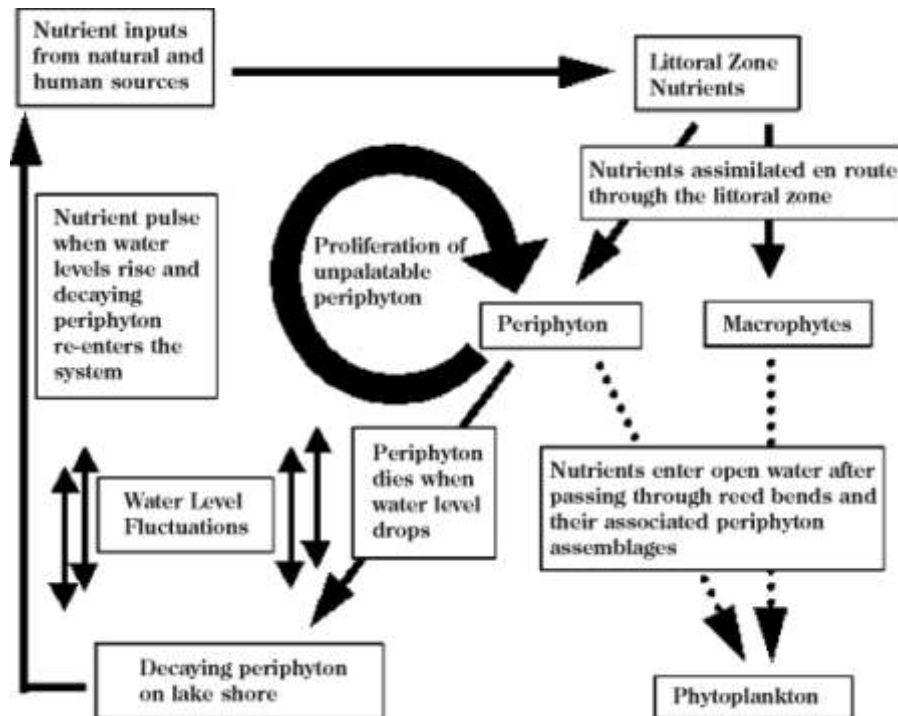


Figure 20 Conceptual Model of Nutrient Enrichment in Dune Slacks (Redrawn from Adema et al. 2004)

Secondary dune slacks may contain precipitation-fed and groundwater-fed pools. The first type is generally found in the central dune areas, near the top of the freshwater lens, where infiltration predominates. Precipitation-fed type pools are sometimes found near the borders of the dune area. In this case superficial impervious layers occur, which may stop the groundwater from entering the pool. Most water of the second (groundwater) type has a long residence time within the subsoil (Van Dijk and Meltzer 1981). In general precipitation-fed type pools are characterized by lower nutrient concentrations than the groundwater pools and they are usually more sensitive to acidification and desiccation (van Dijk and Grootjans 1993).

Water flows at or over the soil surface are ecologically important. Direct ecological effects, such as those of flooding, on the survival of plant species (Willis et al. 1959),

and indirect effects, e.g. the presence or absence of oxidised conditions on special plant characteristics (Van Beckhoven 1995), the presence of microbial mats (Grootjans *et al.* 1997) or mineralization processes (Berendse *et al.* 1998) are important. These phenomena underline the importance of refining the description of site-specific hydrological conditions.

The hydrochemistry of dune slacks, in particular the pH, is dependent on carbonate (shell) content. This affects the alkalinity of local and regional groundwater flow systems creating base-rich conditions; a flux of anoxic and Fe-rich water important for vegetation succession; regular supply of mineral-rich groundwater to develop microbial/algal mats and stabilise longevity of pioneer stages; and spatial and temporal variations in hydrochemical conditions in response to fluctuating water levels (Coulet *et al.* 2008).

Five different types of dune slacks types were proposed by Davy *et al.* (2006), which vary in terms of hydrology.

A. Seaward, young dune slack in reach of the transition zone between the circulation of fresh and saline ground-waters and so may be subject to brackish conditions.

B. Precipitation-fed slack situated in a dune hollow formed by a blow-out. Groundwater flow is directed towards the slack and water is lost by evapotranspiration.

C. Precipitation-fed flow-through slack. Groundwater flows into the up-gradient edge of the slack, flows through the slack and then exits the slack at the down-gradient edge before continuing to flow in the direction of the hydraulic gradient.

D. Slack at the boundary between the dune system and inland area. Slacks are fed by both the regional and local groundwater flow systems and may also receive some surface run-off.

E. Moist dune slack situated at a high elevation in the main dune area. Moisture in the capillary fringe above the water table keeps the base of the dune slack moist with only occasional flooding when the water table is high in wet years.

This typology has been prepared by a multi-national (United Kingdom, Netherlands, and Germany) research group but would benefit from further field testing in others areas, particularly within the Mediterranean region. The European Union classification of dune slacks was based on species rather than hydrology (Table 3), and does include areas of the Mediterranean.

2.5.2 Vegetation

Vegetation development is strongly associated with the average depth and seasonal fluctuation of the water table and the water-holding properties of the sand. Working in the UK, Ranwell (1972) found that sand is saturated for about 10-15 cm above the water table and that capillary action carried substantial amounts of water up to 45 cm above it. The water table has little influence on the moisture content of sand 1m above it. The depth and duration of winter flooding, and the severity of summer drought, are likely to be important determinants of slack community structure (Davy *et al.* 2006). Ranwell (1959) described slacks as either wet in which the free water table never fell below 1m of the ground level in any season, or dry, in which the free water table in summer was always 1-2m below ground level (Houston 2008).

The number of plant species in any slack may be correlated with the size of the slack (large slacks hold more species). Slacks, however, have few endemic species; many slack species are also found in calcareous fens and other wetlands. *Carex trinervis* (three-nerved sedge) is probably the only plant species which is largely confined to western European dune slacks (Foley 2005).

Although dune slacks have mineral soils, they have floristically much in common with mires, especially rich fens (Grootjans *et al.* 1996). In the moist to wet dune slacks, the vegetation may be very diverse. Many environmental gradients may be reflected in it (Vuyck, 1898; Bijhouwer, 1926; Londo, 1971; Van Zadelhoff, 1981; Westhoff, 1989). The constancy of the annual water table fluctuation, the relative shortage of nutrients in the soil and in the groundwater, and the scant development of dense undergrowth and forest under the influence of the coastal wind regime and anthropogenic activities e.g. use for grazing animals, have all been found to contribute to this diversity in the 'Young Dunes' (i.e. AD 1300 – 1600 AD, based on Klijin 1990) at the Wadden Sea (Grootjans *et al.* 2004).

The spontaneous development of shrubs and deciduous trees may in due course result in the complete disappearance of the open character of the vegetation, particularly in the (wet) dune slacks. This development is not entirely part of a transition towards the final stage of the vegetation succession. Often human influences have stimulated the process, such as in the Wadden Sea, over exploitation of the dunes, sod cutting and drinking water extraction (Adema *et al.* 2004).

The European Union's European Nature Information System (EUNIS) classified dune slacks according to their vegetation (Table 3), and is based on the whole of the European Union. EUNIS identified "Humid dune slacks" in the Mediterranean region (Table 3). In terms of vegetation, the Veneto region of Italy has species such as *Juncus articulatus* (jointed rush), *Cyperus flavescens* (yellow galingale), *Samolus valerandi* (brookweed), *Blackstonia perfoliata* (yellow-wort) and *Phragmites australis* (common reed) (Fiorentin 2006). Dune slacks are a rare and threatened habitat in Greece and are a priority for monitoring (Dimopoulos *et al.* 2006), but little is known about other areas within the Mediterranean.

EUNIS	B1.8	Corine Land Cover*	16.3	EU Interpretation Manual (Annex 1)**
Moist and wet dune slacks		Humid dune slacks		Humid dune slacks
Dune slack pools	B.181	Dune slack pools	16.31	Freshwater aquatic communities of permanent dune slack water bodies
Dune slack pioneer swards	B.182	Dune slack pioneer swards	16.32	Pioneer formations of humid sands and dune pool fringes, on soils with low salinity
Dune slack fens	B.183	Dune slack fens	16.33	Calcerous and, occasionally acidic fen communities often invaded by <i>Salix repens</i> occupying the wettest parts of dune slacks
Dune slack grassland and heaths	B.184	Dune slack Grasslands	16.34	Humid grasslands and rushbeds of dune slacks with creeping willows (<i>Salix rosmarinifolia</i> & <i>S. arenaria</i>)
Dune slack reedbeds, sedgebeds and canebeds	B.185	Dune slack reedbeds and sedgebeds	16.35	Reedbeds, tall-sedge communities and canebeds of dune Slacks
Wet dune slacks: dominated by shrubs or trees	B.186	No Category		

Table 3 Main sub-types of humid dune slacks identified in the EUNIS and Corine biotopes classifications (Houston 2008)

*Corine Land Cover (CLC) is a map of the European environmental landscape based on interpretation of satellite images.

** Annex I lists today 218 European natural habitat types, including 71 priority (i.e. habitat types in danger of disappearance and whose natural range mainly falls within the territory of the European Union)

2.6 Impacts on Dune Slacks

2.6.1 Drinking water

Dune slacks can be affected by artificial recharge of eutrophic river water in phreatic aquifers for the purpose of public water supply (Bakker 1981; Van der Meulen 1982) as is the case in the Netherlands. Through this recharge the trophic level, and in most cases, the range of the water table fluctuation is raised. This in turn has led to an excessive development of certain ruderal plant species (Londo 1975; Van der Meulen 1982), especially in the phreatic vegetation (Van Dijk 1984). Such species are nitrogen-indicating tall hemicryptophytes (classification after Mueller-Dombois and Ellenberg 1974; and Ellenberg 1979). As these plants can rapidly build up an above ground biomass, they can be classified as 'competitors' (Grime 1979), e.g.: *Urtica dioica*, *Epilobium hirsutum* and *Eupatorium cannabinum* (Van Dijk 1984). The dominance of these species suppresses the development of the floristic gradients which allowed for high species diversity in these areas before infiltration started (Londo 1966, 1971, 1975; Van der Werf 1974; Van der Laan 1979; Van der Meulen 1982). Van Dijk and Van Strien (1984) suggested that the development of such 'nitrophilous' phreatophytes is mainly caused by an increase of the nutrient load of the infiltration water penetrating the soil. This leads to the hypothesis that a considerable reduction of the main limiting macronutrient in the infiltration water could repel these species and possibly help to re-establish the original wet dune slack vegetation. The limiting macronutrients in the undisturbed dune environment are nitrogen, phosphate and potassium (Willis 1963; Olsson 1974), whereas either nitrates, or orthophosphate, prevail in infiltration water (Van Dijk 1985). Prepurification of the infiltration water can reduce the orthophosphate concentration to a level below the natural values. The nitrogen concentration can also be reduced considerably (Meltzer and van Dijk 1986).

2.6.2 Impacts of Sod-Cutting

Sod-cutting, a common management practice in European coastal dune slacks, naturally leads to a decrease in soil organic matter and nutrient stocks and an

increase in soil pH. It can also decrease the nutrient availability and biomass production. In addition, the ground level of the slack may be slightly lowered and this could stimulate the exfiltration of bicarbonate-rich water (Grootjans *et al.* 2004).

Re-establishment of wet dune-slack vegetation by sod cutting results in a slow vegetation succession and pedogenesis and a rapid succession and humus accumulation for the first twenty years after cutting. After this period a strong increase in biomass will suppress plant species from the pioneer stages, so that a cycle of sod-cutting every 20 to 30 years or mowing is possible as long as the water table does not rise to the soil surface in every winter and thus does not hamper the development of less flooding resistant species (Ernst *et al.* 1996).

2.6.3 Water abstraction and drainage

Houston (2008) highlights the fact that water abstraction and drainage are the principal threats to European dune slacks where the vegetation communities may be sensitive to relatively small fluctuations than the natural seasonal fluctuations. This is especially the case for the lower plants. As noted above, dune slacks may be fed by direct precipitation, surface water and groundwater. The dune slack types identified by Davy *et al.* (2006) are shown in Table 4, but with their relative sensitivities to water abstraction noted.

Abstraction of groundwater in the Doñana National Park in Spain (Muñoz-Reinoso 2001) caused an increase in the spread of scrub and trees (especially *Pinus pinea*) by reducing the frequency of flooding even in areas some distance from the main slacks. The impacts of abstraction have been particularly acute in the Netherlands. Over-abstraction led to the lowering of the dune water table (by an average of 2-3m) and to salt water infiltration under the dune aquifer. Many of the former slacks have dried out and lost their ecological value. The negative impacts of groundwater abstraction have been ameliorated since the 1950s by using 'infiltration water' drawn from the rivers Rhine and Meuse but wet slack habitats remain affected to some extent. At first this remedial action was equally damaging as the abstraction as it led to the flooding of slacks with nutrient-rich water, bringing problems of water quality and the growth of tall nitrophilous marginal vegetation. Plants such as *Parnassia palustris* (grass-of-Parnassus) disappeared, while the ecological problems surrounding these changes have been well documented (for example Koerselman 1992).

Type	Description	Hydrological conditions	Sensitivity to abstraction/drainage
A	Seaward, young dune slack	Potentially subject to brackish conditions	Low sensitivity since likely to be of an ephemeral nature
B	Precipitation-fed slack situated in a dune hollow formed by a blow-out	Groundwater flow directed to the slack with the water then lost by evapotranspiration	High sensitivity since affected by water table fluctuations in response to seasonal wet and dry conditions
C	Flow-through slack	Groundwater flow into the up-gradient edge of the slack, flows through the slack and then infiltrates at the down-gradient edge	High sensitivity as above
D	Slack at boundary between the dune system and inland area	Water levels buffered by regional and local groundwater flow systems	Moderate sensitivity since slack water levels are maintained by steady regional groundwater flow even during dry weather
E	Moist dune slack situated at a high elevation in the main area		Very high sensitivity since only in reach of moisture in the capillary zone with only occasional flooding

Table 4 Sensitivity to abstraction/drainage of the main slack types (Davy et al. 2006)

2.6.4 Afforestation

Afforestation may have a direct effect on dune slacks if they are targeted for planting (often linked to drainage activity) and an indirect effect by drawing down the overall ground water table in the vicinity of plantations. Detailed studies at Newborough Warren, Anglesey, have shown that the water interception and transpiration associated with forest is likely to have an adverse influence on groundwater recharge and levels (Betson *et al.* 2002, Bristow 2003). A groundwater model constructed for Newborough Warren showed that potentially removing forest in the topographically high area of the reserve would allow greater recharge that would benefit groundwater levels across the site and so help maintain dune slacks.

An important aspect to consider with afforestation of dunes is whether they need to fully stabilised, like at Castelporziano with the *Pinus pinea* plantations. Sand dunes are a natural and dynamic system in which there needs to be a certain degree of mobility in an equilibrium situation. If instability is suddenly increasing, this is a result of human overexploitation, mostly by overgrazing or sand extraction. Many examples of this are reported, particularly from Portugal and Turkey (van der Meulen and Salaman 1996). This is a worry at Castelporziano in the current environment as

evidence for overgrazing were noticeable by the presence of certain species, e.g. *Asphodelus* sp, in the vegetation surveys close to the afforested areas. To increase stability the answer should be to reduce exploitation, but as the estate is a nature reserve with the deer being of ecological importance it will have to be a balancing act.

A second issue that needs to be considered is that natural dune vegetations are not able to stabilise mobile dunes. Therefore, artificial stabilisation has often been carried out with exotic tree species, as noted above at Castelporziano this has been done with *P. pinea*. The estate notes this is a recent scheme of the last 50 years, however, it was noted in 1909 by Lanciani (p308-309) that there has been plantation of pines since the 17th century! Other areas have to chosen to use exotic trees to fix the dunes, this has happening and has happened all over the Mediterranean, particularly in Turkey. After the recent afforestation and destruction of the enormous Akyatan dune system in the tukurova Delta (near Adana), a 5000ha afforestation project threatened the adjacent dune system towards Yumurtalik, whilst a ban on grazing in itself would have been be sufficient (van der Meulen and Salaman 1996). This ban on grazing would also work at Castelporziano, or limiting the areas that the deer are allowed to graze.

2.6.5 Other anthropogenic impacts

Trampling of dunes can lead to blowouts. The removal of vegetation, particularly from the foredune can lead to sand migrating rapidly inland. In the case of relatively narrow sand dune systems this can remove a protective barrier, which leaves the land behind the dune vulnerable to flooding during winter storms.

Dune slacks are highly sensitive to human influences leading to increased acidification. Wet dune slacks with calciphilous pioneer vegetation, are especially vulnerable to disturbances and the rise and decline of the vegetation is controlled by soil processes that can both increase and decrease the pH (Lammerts *et al.* 1992).

Erosion of dunes, often through human activities, may result in build up of sand within the slack. The consequent change in height of the floor of the slack raises it further above the water table, with consequent loss of marsh species. This may pose conservation problems where rich slacks adjoin popular beach areas. However, smaller slacks nearer the sea may in any case be part of a cyclic alternation of

building and erosion phases, as demonstrated at Braunton Barrows, South West England, and Newborough Warren, Wales (figure 21; Note the erosion of the white dunes beyond the slack. Sand is likely to blow into the slack, bringing about a drying effect), where the alteration to the Marram (*Ammophila arenaria*) dunes and *Salix repens* slacks was estimated by Ranwell (1972) to follow an eighty year cycle.



Figure 21 A large dune slack with erosion of the white dunes beyond the slack; Looking seaward (English Nature 1967)

2.6.6 Climate change

Little work has been done explicitly with regard to dune slacks and climate, however, the literature on sand dunes and climate is immense and perhaps reflects the apparent fragility of these ecosystems, as they easily eroded by the sea and wind particularly if the vegetation cover is disturbed or removed (Doody 1985). Overall changes in climate will impact on dune slack hydrology and the seasonality of water table fluctuations and on dune vegetation. Increased storminess could result in dune slacks being overwhelmed by blown sand as coastal dune systems continue to develop (Houston 2008). However, given Mediterranean Sea is characterised by a small tidal range (0.3-1 m), i.e. a small difference in sea level between high and low water, and increased sea level will increase susceptibility of the foredunes to erosion. The release of material at the shoreline may allow construction of coastal dunes, to the point of progradation in some zones. The response of dune vegetation to a warmer, wetter climate is uncertain. Most of the main temperate dune species are C3

plants which given favourable conditions would respond positively to CO₂ enhancement. However local factors may offset such potential gains (Carter 1991).

A rising water table, in response to an increase in sea-level, may be expected to favour humid dune slack species and to encourage sand stabilisation in low-lying areas (Pye and Saye 2006) although saline water intrusion may cause brackish conditions to develop in slacks near the shore. Rising groundwater levels would, however, not lead to the rejuvenation of existing wet slacks (Noest 1991) as the humus layer which had already developed would need to be removed (hence the use of sod cutting to maintain slacks as nutrient-poor environments). Potential increases in summer rainfall may reduce the success of slack restoration projects if the slacks remain flooded in the summer (Grootjans *et al.* 2007).

2.7 Dune slacks as Palaeo archives

A limited number of studies have examined the palaeo record within dune slacks. Dickinson and Mark (1994) examined forest-wetland vegetation patterns associated with a Holocene dune-slack sequence in south-west New Zealand. The site had six alternating dune-slack features along a 2.3 km coastal strip, assuming that distance from shore was equivalent to the age of the slack. Information on the surface profile, vegetation pattern and associated environmental parameters were used to establish ecological processes with the slack. They found 110 different vascular species and 84 bryophytes, thus great species diversity. However, they did not core the slacks, and examine the changes within them, relying instead on a space-time substitution approach. Freund *et al.* (2004) used dune slacks when interpreting Holocene sea-level fluctuations along the southern North Sea coast, along with tidal flats, lagoonal deposits, and salt marshes. They used diatoms and plant macrofossils to distinguish between the slack and the saltmarsh environments from a 70 cm core. They found a high proportion of *Carex* species in the macrofossils, leading them to suggest that this was sedge peat. The diatom record gave good correlation with the salt marshes for the salinity change. Fontana (2005) used dune slacks as part of her PhD thesis examining the contemporary and Holocene environmental changes in Buenos Aires Province, Argentina. Her work used contemporary pollen from five vegetation zones defined on the basis of species composition and their quantitative variation: back shore, mobile dunes, dune slacks, semi-fixed and fixed dunes. The pollen assemblages from back shore, mobile dunes and slacks were clearly differentiated from semi-fixed and fixed dunes, due to their dominance of *Poaceae* and

Cyperaceae pollen (Fontana 2005). The pollen-vegetation comparison in the palaeo samples revealed that pollen assemblages differed considerably from the associated vegetation. Some of the major discrepancies were caused by large differences between pollen and vegetation proportion of *Hyalis argentea* and *Discaria Americana*. In addition, she recently noted: “*Pollen analysis on dune slack sediments is sometimes tedious, depending on the preservation of the pollen*” (Fontana pers. comm. 2008), and that ostracods are “*good indicators of changing salinity and coast line fluctuations*” (Fontana pers. comm. 2008).

The key attribute of dune slacks is their potential to act as sinks or traps for sediment/organic matter, thus preserving material which can then be used in environmental reconstruction.

2.8 Conclusions

Dune slacks occur as naturally fragmented biotopes in dune landscapes. Many factors influence their formation, plant growth and succession and, of these factors, the water table level fluctuations, driven by both natural processes and human impact, appear to be the most influential. Although much of the published work on contemporary dune slacks relates to Northern European examples this work is of relevance to the Mediterranean in terms of both the geomorphological and the sedimentological aspects of dune systems. The extent to which these examples provide appropriate plant community analogues for the Mediterranean dune slacks is more open to debate. A limited number of studies highlight the potential of dune slacks as archives of change, with plant macrofossils, ostracods diatoms, and pollen all potential proxies. The present research builds on this existing work, where relevant, and the next chapter will examine the nature of proxies in more detail together with the choice of proxies for this study.

Chapter 3: Methodological approaches and development

3.1 Introduction

This chapter begins with a review of the nature of proxies for use in palaeoenvironmental reconstructions, highlighting their potential application to dune slacks within a Mediterranean context. The potential advantages and disadvantages of particular proxies will be noted, with particular reference to sensitivities to variables such as pH or “wetness” of the slacks. This information will then be used in a series of pilot studies that were carried out to answer the first two research questions: (1) Can dune slacks be used as a palaeo archives; and (2) What proxies would be suitable for palaeoenvironmental reconstruction? These pilot studies are used to narrow down the range of potential proxies using, as a starting point, proxies developed in studies of lake sediments, peat bogs and wetlands. The chapter concludes with a discussion of the results of the pilot studies with regard to the appropriateness of the proxies for application to the Castelporziano case study.

3.2 The nature of proxy data

Evidence for past environmental change, in terms of instrumental records, is limited to the last 300 years for Italy and therefore proxy records are required in order to reconstruct the late Holocene environment. Ingram *et al.* (1981) defined a proxy as any line of evidence that provides an indirect measure of former climates or environments. Each proxy varies according to its spatial coverage, the period to which it belongs and its ability to resolve events accurately with respect to time (Bradley 1985). Proxies can provide quantitative data or semi-quantitative data or qualitative data. All proxy data are indirect measurements of change, climatic and/or environmental, and vary considerably in their reliability as indicators of long-term change (Jones and Mann 2004). The choice of proxy depends upon the type of environment being investigated, and therefore some proxies used in ombrotrophic peat bogs, e.g. peat humification, may not be directly applicable to a dune slack environment. In reconstructing the past, it is worth remembering that although each proxy is considered individually, in reality they would have interacted, as components within an ecosystem (Lowe and Walker 1997). Dearing *et al.* (2006) made the case for distinguishing between proxies which are used for climatic reconstructions (e.g. oxygen isotopes) and those that are used to reconstruct the response of ecosystems to the interacting influences, be they climatic and/or anthropogenic. Changing

terrestrial ecosystems can also have significant impacts upon the climate at regional or even global scale, through mechanisms such as forest fires, biomass burning and methane production (Langenfields *et al.* 2002). However, organisms and plants have adapted to and interacted with their environment and, in the Mediterranean, they have responded to changes in variables such as temperature, precipitation and pH. Combining proxies allows simultaneous correlations of different aspects of the environment, which no single proxy can do alone. However, such an approach can also bring out the weaknesses of each proxy, such as gaps in knowledge of that proxy's contemporary relationship to environmental factors, or the lack studies of taphonomy of the fossil remains.

There are many traditional archives for palaeoenvironmental work, with the most common being lake sediments, and peatlands. As the previous chapter showed, little palaeoenvironmental work has been done using dune slacks, adding to the novelty of the work undertaken for this thesis.

3.3 Dune slacks as a 'palaeo archive'

Dune slacks possess several potential advantages for palaeoenvironmental reconstructions: their coastal location makes them generally accessible; they are highly sensitive to human disturbances; their accumulation of organic material is initiated diachronically. However, they also possess a number of potential disadvantages for palaeoenvironmental reconstructions: their seasonal wetness may lead to poor preservation and degradation of particular proxies; their pH depends on the carbonate concentrations within dune sands and ground waters, and an alkaline environment may again effect the preservation of proxies. However, dune slacks provide potential wetland environments in the, otherwise seasonally dry, Mediterranean and within the Castelporziano Estate the dune slacks represent the only available sinks for sediment and organic matter.

3.4 Biological proxies

Biological proxies are used on the premise they conform to uniformitarian principles. The key assumption is that an understanding of the factors influencing the abundance and distribution of contemporary organisms allows inferences to be made about how these environmental factors have varied in the past as a result of studying floral and faunal remains (Rymer 1978). A number of other factors that should be

considered include: the quality of the preservation and whether it has affected taxa differentially; what level of taxonomic precision can be achieved; and what processes led to the deposition of the proxies and whether they are autogenically deposited (i.e. in the place where they lived) or allogenuically deposited (i.e. away from the place where they lived) (Charman 2002). The classification of biological proxies is based on size. Macrofossils, e.g. molluscs, wood, seeds, can be seen by the naked eye, although identification and more detailed study requires a microscope, whereas microfossils can only be detected and studied using a microscope, e.g. pollen, ostracods or diatoms.

3.4.1 Molluscs

Terrestrial molluscs are good proxies for local environments as they are particularly sensitive to the amount of vegetation and nature of ground cover (Evans 1972; Preece 2001). They can be used as indicators of climatic conditions, due to their particular sensitivity to moisture and temperature and are useful for reconstructing past environments (Mayer 2005). Species identification together with knowledge of present-day habitats and climatic zones allows for interpretation of the environment in which they lived (Mienis 1992, Evans 1972). Terrestrial and freshwater molluscs have been found in sediments rich in CaCO₃; including aeolian sediments and buried soils, whereas under acidic conditions their shells are rapidly dissolved (Lowe and Walker 1997). Therefore, the alkaline conditions within dune slacks, which are a contemporary habitat for molluscs, should make them a suitable proxy. Marine molluscs have been found in beach gravels and estuarine sediments, as well as within midden dumps, giving information on past environments of contemporary shorelines. Terrestrial (freshwater) snails have relatively thin shells compared with those of marine molluscs and therefore the interpretation of mollusc assemblages from the palaeo record is compounded by taphonomic problems. Within dune slacks, the mollusc assemblage may derive from terrestrial, freshwater or near shore marine habitats.

3.4.2 Plant Macroremains

The analysis of subfossil seed and plant macroremains (henceforth “*plant macrofossils*”) can provide useful complementary data to pollen analysis, often capturing a different landscape scale or taxonomic resolution. Plant macrofossils can generally be identified to a higher taxonomic resolution than pollen (Grosse-

Brauckmann 1986). They are generally not transported long distances from their source and this is both an advantage and a disadvantage. On the one hand, they only provide a record of local vegetation, and this record may not be compatible with the regional picture obtained from pollen. Alternatively, the presence of macrofossils provides definite evidence of the local presence of a particular plant (Birks and Birks 2003). Therefore, within dune slacks plant macrofossils may be used to determine the vegetation make up in and around the slack. Moreover, the previous chapter highlighted some concerns about seed banks within dune slacks, however, fruits and seeds are relatively resistant against decomposition, and may prove to be suitable proxies.

3.4.3 Charcoal

The presence of charcoal or charred particles in sediment sequences provides evidence of the occurrence of fires, and changes in the abundance of charcoal through time have been interpreted as evidence of millennial-scale changes in fire regimes at a regional to continental scale in lakes (Haberle and Ledru, 2001; Carcaillet *et al.* 2001). There are two types of charcoal used in palaeoenvironmental reconstructions, macrocharcoal (ca >100–200 μm length) and microcharcoal (typically less than 40 μm). Macrocharcoal, because of its relatively restricted dispersal, has greater potential to provide detailed information on fire regimes from defined areas, vegetation types, and specific plant types. Unlike microcharcoal it is also not subjected to the same potential problem of breakage and consequent distortion of the fire signal during chemical preparation (Lynch *et al.* 2007). Although macroscopic charcoal remains are generally thought to reflect fires within a catchment, changes in the abundance of microscopic charcoal can also provide at least a qualitative measure of changes in the background level of fire (e.g. Tolonen 1986; Whitlock *et al.* 2003; Whitlock and Bartlein 2004).

The direct comparison between microcharcoals and pollen data from the same sediment record have made it possible to study how fire regimes responded to major changes in vegetation and climate in the Mediterranean environment (Sadori and Giardini 2007). One unanswered question is whether drastic reductions in arboreal pollen concentrations could have been determined by fires, by climate changes or by human action, or by a synergy of two or three of these factors. The possibility that forest clearance, natural- or human-induced, could favour fires should also be taken

into account. Rackham (1986) and Rackham and Grove (2001) refute the suggestion that the Mediterranean landscape could have been completely deforested at some time in the past. However, the relationship between the vegetation type and the fire regime has not been fully investigated in palaeo-records of the Mediterranean Basin, in a region which today experiences a number of large fires every year (Alexandrian *et al.* 1999 and Le Houerou 1987). Moreover the role of fire in maintaining and favouring Mediterranean-type vegetation is a basic concept in ecology (Odum 1988). As noted in chapter 1, in the Mediterranean region the difficulty exists of disentangling climate and anthropogenic activity in shaping the landscape, as humans have been present since the Palaeolithic Age, and their impact on the environment is likely to have become stronger and stronger through the millennia (Sadori and Giardini 2007).

In contrast to microcharcoal, macrocharcoal particles are usually not transported far from fires, and are likely suitable for reconstructing local fire events (Clark 1988; Clark and Royall 1995; Carcaillet *et al.* 2001; and Whitlock and Larsen, 2001). Thus, within the Castelporziano dune slacks any concentrations of macrocharcoal may represent an influx from local fires, and thus feed into arguments concerning deforestation during the period of Roman settlement.

3.4.4 Ostracods

Ostracods are microscopic bivalved crustaceans, which are found in moist aquatic environments that include lakes, ponds, rivers, estuaries and oceans. Additionally, some are semi-terrestrial (Griffiths and Holmes 2000). Within their environment ostracods are highly sensitive to temperature, salinity, anion composition and nutrients, alongside other habitat variables such as within the waterbody depth, size, permanence, substrate type, aquatic macrophyte cover and energy level (e.g. Holmes 2001; Danis *et al.* 2003; Frenzel *et al.* 2005). Additionally, the ostracod's shell can be analysed for isotopes or trace elements, to provide a geochemical record of the local environment, similar to that of mollusc shells. However, as a proxy they have been underused due to several perceived problems. The first problem is the identification to species level, however they are no more difficult than any other microfossil proxy to identify, further aided with the publication of a key by Griffiths and Holmes in 2000. However, it should be noted that this key is based predominately on British species with the more general European picture largely ignored. The second problem is that non-marine ostracods are regarded by some of little value (Griffiths and

Holmes 2000), but as more studies are undertaken this view may change. Finally, as with many proxies, the limited knowledge of contemporary ecology of many species hampers palaeoecological work but this issue is beginning to be addressed with biologists working on improving taxonomy. Therefore, within dune slacks they hold the potential for understanding the local hydrology, which as noted in chapter 2 may vary from slack to slack in terms of salinity. The use of ostracods within dune slacks was highlighted by the work of Sonya Fontana in Argentina (Fontana 2005), who suggested that their presence within slacks was a good proxy for salinity, marine vs. freshwater inputs into the slack.

A promising method within the literature is that of the Mutual Temperature Record (MTR) for ostracods (Horne 2007), comparable with that of the Mutual Climate Range developed for beetles as a result of pioneering work by Russell Coope (Huppert and Solow 2004), and thus can be used to infer palaeo air temperature for January and July.

3.4.5 Testate Amoebae

Testate amoebae are common inhabitants of moist soils, wetland, and lacustrine habitats (Booth 2001). They are a group of free-living protozoans, which have an organic shell (testa). Some taxa from this group are covered with exogenous mineral material (xenosomes), plant detritus, or endogenous material (idiosomes), such as silica or, rarely, calcium phosphate plates (Bobrov *et al.* 2004).

Testate amoebae are sensitive indicators of hydrological conditions in peatlands, primarily the depth of the water table and can be used to decipher past climatic conditions (Woodland *et al.* 1998). Their well-defined ecological preferences and the relatively good preservation of fossil shells in peats, lake sediments, and buried soils form the basis for the development of rhizopod analysis as a method for reconstruction of climate and environmental changes (Bobrov *et al.* 2004). Therefore, within dune slacks, where the water table fluctuates seasonally, they may be able to show how this has varied with time.

3.4.6 Diatoms

Diatoms are a major group of eukaryotic algae, and are one of the most common types of phytoplankton (Round *et al.* 1990; Battarbee *et al.* 2001). They are a

widespread group and can be found in the oceans, freshwater, soils and on damp surfaces. Most live pelagically in open water, although some live as surface films at the water-sediment interface (benthic), or even under damp atmospheric conditions. Unlike many other algal groups, diatoms are readily identifiable to species level (Round 1991), which has made them particularly useful in palaeoenvironmental and palaeoclimatological studies (Battarbee *et al.* 2001). They are sensitive ecological indicators and have been widely used to quantify past changes in pH (Battarbee and Renberg 1990), salinity (Fritz 1989) and nutrients (e.g. total phosphorus (Bennion 1994)), and transfer functions have been established for several regions (Battarbee 2000). Within dune slacks they hold the potential to understand the local hydrology and chemistry.

3.4.7 Bryozoan statoblasts

Bryozoan statoblasts are common subfossils in lacustrine sediments, relatively easy to identify to species level and often found alongside plant macrofossils. *Plumatella repens* was found to be sensitive to the effects of logging activity (Francis, 1997). Additionally, bryozoan statoblasts have been found to be sensitive to increased inputs of organic matter and may prove to be useful for ascertaining evidence for eutrophication of a dune slack, which can lead to anoxia and, as noted in chapter 2, this is one of the dominant factors that leads to stable vegetation zonation between a dune slack and the dune top.

3.4.8 Stoneworts

Stoneworts (or charophytes) are a common type of algae within contemporary dune slacks. Most genera and species have partly known ecological requirements for optimal growth such as pH, water depth, temperature and clarity, and nutrient regimes (Hallett *et al.* 2003). Changes in these conditions can impact charophyte growth in lakes if sensitive taxa are present. Changes in charophyte distribution or abundance within an assemblage may be used to infer past conditions in a lake (Haas 1994; 1999). Dune slacks are an important habitat for charophytes, particularly where the sand is calcareous (Grootjans *et al.* 2004). In some studies they been found to be absent when the influx of charcoal is high and therefore they may prove to be another proxy for the use of fire within the local environment.

3.4.9 Branchiopod Crustaceans

These are aquatic crustaceans typically having a carapace and many pairs of leaf like appendages used for swimming as well as respiration and feeding (Korhola and Rautio 2001). The mostly commonly found remains in palaeoenvironmental reconstructions are those of *Daphnia magna* ephippia in lakes, which are freshwater, no marine species are known, they are sensitive to changes in pH (the optimum range is 7.2-8.5, although 6.5-9.5 is acceptable) and temperature 18-22°C, for *D. magna* (Belgrano *et al.* 2005). Therefore their presence or absence within dune slacks may relate to changes in temperature or pH within the slack.

3.4.10 Pollen

The majority of palaeoenvironmental investigations reconstructing Holocene vegetation history have tended to focus on regional interpretations of vegetation change using pollen. This has partly been a factor of availability of suitable sites and partly a consequence of the predominant application of palynology in aiding the interpretation of geomorphological and archaeological contexts. Pollen analysis is effectively a remote sensing tool (Prentice 1988) enabling investigation of past landscapes and long-term ecosystem dynamics. As with any remote sensing technique, better understanding of the spatial resolution possible under different conditions will lead to improved use of the method (Bunting *et al.* 2004). Pollen is best preserved in acidic conditions (i.e. pH < 7.0) whereas most dune slacks have an alkaline (pH i.e. pH > 7.0) due to their calcareous groundwater. However, even a small pollen count can be meaningful, as has been demonstrated for cave sediments where pollen counts are often less than 100 per slide. In the interpretation of fossil pollen assemblages, much use has been made of information derived from the study of modern pollen rain produced by various types of vegetation (Hall 1989). Studies carried out by Andersen (1970) on forests, and by Vuorela (1973) on the extent to which agriculture is reflected in pollen rain, have done much to increase the understanding of the many processes affecting the production, transport and deposition of pollen. Since pollen accumulation values can be calculated for single moss samples of known surface area, it is possible get a rough estimate of the time span of pollen deposition by comparing the results with the accumulation values of an adjacent pollen trap. This method assumes that mosses and pollen traps are equally efficient in trapping pollen (but see Faegri and Iversen, 1989, pp. 19–20). Few studies have been made comparing the pollen accumulation in pollen traps and

mosses (Räsänen *et al.* 2004). For the present study, both pollen traps and mosses were used as they enabled further study of the contemporary vegetation

3.4.10.1 Collection of modern pollen

A Cundill pollen trap (figure 22) consists of a plastic flower pot (7.5 cm diameter) in which acetate wool (cellulose acetate) is placed. Finally, a metal wire mesh on top of the construction keeps the acetate wool in place, and traps are then left for a flowering season. Cundill pollen traps are said to represent the modern pollen rain data from one year, whereas the moss cushions represent the pollen rain of several years.

Moss polsters or cushions (figure 23) are those that have no permanent attachment to a substrate and therefore are moved about by wind, water, or other agents, have been described as associated with glaciers, forest soils, sand dunes, and lakes. Typically these polsters assume a spheroidal form because of nearly equal growth in all directions made possible by the frequent change in orientation of the polsters (Shacklette 1966).

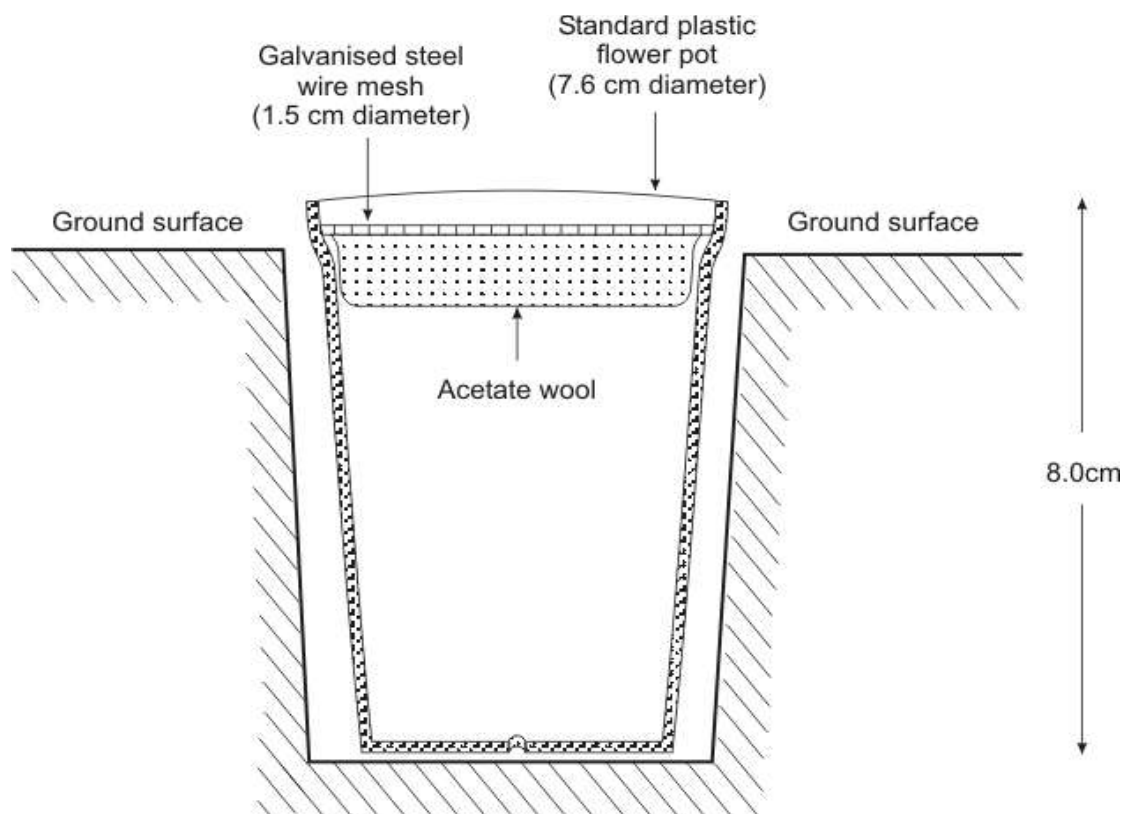


Figure 22 Cundill Pollen Trap



Figure 23 A Moss Polster

3.5 Physical and chemical proxies

3.5.1 Loss on Ignition

The percentage loss-on-ignition (LOI %) is one of the most widely used and physical proxies in palaeoenvironmental reconstructions (Birks and Birks 2006). It reflects the proportion of organic matter, organic carbon, carbonate, water content, and minerogenic residue in the sediment (Dean 1974; Boyle 2004), but can have problems in clay rich sediments. Fares *et al.* (2009) noted the total content of soil organic carbon at Castelporziano is in the range of 3.1 g(C) kg^{-1} soil, with high rates of microbial activity which also favoured a high mineralization rate (Trinchera *et al.*, 1998; Pinzari *et al.* 1999). Within a dune slacks the organic matter accumulation relates to the local hydrological regime, and during succession, as organic matter accumulates, soil enrichment and acidification increase. Therefore, as a proxy indicator it will give an indication of succession within the slack, and the local hydrology, i.e. groundwater levels.

3.5.2 Geochemistry

Geochemistry has been used in palaeoenvironmental reconstructions to establish the link between sediment composition and the environment particularly in peatlands and lakes. Within peat bogs geochemical analysis has been used to establish records of atmospheric heavy metal deposition, atmospheric fluxes of dust and to identify long-term weathering trends (e.g. Shotyk 1996, Martinez-Cortizas *et al.* 2000). Sediment can be blown in or washed into dune slacks from surrounding areas, which is likely to

reflect the mineralogy of the slack. The presence of some elements (e.g. phosphorous, nickel or selenium) may relate to changes in the environment or to anthropogenic activity.

3.5.3 Stable isotopes

The stable isotope composition of carbonates, organic carbon etc. provides valuable evidence of changing environmental and climatic conditions during the Holocene (Swart *et al.* 1993). Studies have concentrated mainly on ratios of stable isotopes of carbon ($\delta^{13}\text{C}$) and oxygen ($\delta^{18}\text{O}$). The materials studied range from organic matter of various forms (e.g. wood, soil organics, sediments), to biogenic minerals such as calcium carbonate (mollusc shells) and calcium phosphate (bone), and to inorganic carbonate precipitates e.g. speleothems, soil nodules, vein calcites, lake carbonates (Goodfriend 1999).

3.5.4 Particle size analysis

Grain-size analysis, also known as particle-size analysis or granulometric analysis is perhaps the most basic sedimentological technique to characterize and interpret sediments. A consequence of differential erosion, transportation and deposition, sediments are laid down in different depositional environments, which may have distinctive particle size distributions. By determining these particle size distributions it is, therefore, possible to hypothesise about the environment of deposition (Lario *et al.* 2001). Sandy layers interlayered in muddy sequences of middle shelf environment are normally regarded as a proxy for past storminess (Budillon *et al.* 2005). The Guadalquivir marshlands (southern Spain) were characterised by the input of coarse material and shell fragments as evidence for storms and tsunamis. De Jong *et al.* (2006, 2007) used aeolian sediment influx (ASI) and maximum grain-size within ombrotrophic mire as a proxies for winter storminess (Bjorck and Clemmensen 2004), although especially ASI values are affected by source area characteristics and sample resolution variations. Due to the shoreline position of the Castelporziano slacks during the Roman period, episodes with high-energy conditions may perhaps be confirmed by the input of coarse sediments into the slacks although material could also be washed into the slacks and active inputs would imply the presence of adjacent unvegetated dune surfaces.

3.6 Pilot Studies

3.6.1 Rationale

To answer the first two research questions concerning the suitability of dune slacks as archives for palaeoenvironmental reconstructions, and owing to the array of potential proxies noted in the previous sections of this chapter, a series of pilot studies were carried out on three cores from two locations on the site.

The initial choice of proxies was based on visual inspection of the cores onsite and in the laboratory, a literature review on peatlands, lakes, and wetlands, together with the limited literature on dune slacks as palaeo-archives. The proxies explored were plant macrofossils, molluscs, LOI, geochemistry, testate amoebae, diatoms and macrocharcoal. Other potential proxies, found during the pilot studies, were also evaluated. All of the results were constrained by AMS ¹⁴C dates.

3.6.2. Materials and methods

Three cores from two dune slacks were analysed (figure 24): Cores 1 and 3 from dune slack D6 and Core 6 from D5 (figure 25). Cores 1 and 6 were sampled at 5cm intervals and each proxy (apart from geochemistry and LOI) was identified, counted and recorded with depth. Detailed methodologies can be found in Appendix 2 for each proxy used during this research, and therefore what follows in the next section is a synopsis of the techniques used and the results obtained.

Core descriptions

Figure 26 shows a visual description of cores 1 and 6 stratigraphy, with a key to the symbols is figure 25. Core 3 was briefly used for the pilot studies, but used for finer sampling after the pilot studies so it is described in chapter 4, along with details of the coring locations.

Core 1 and core 6 show marked differences in stratigraphy (figure 26), with core 1 being peat throughout its length, whereas core 6 was only peat to 86 cm, before a gradational contact with underlying organic-rich sand until its base at 150cm. Both cores showed the visible presence of molluscs within the peat.

Core diagrams were drawn using Adobe Illustrator, and all results were drawn from C2 from exported files from Microsoft Excel or Excel plots, unless otherwise stated.

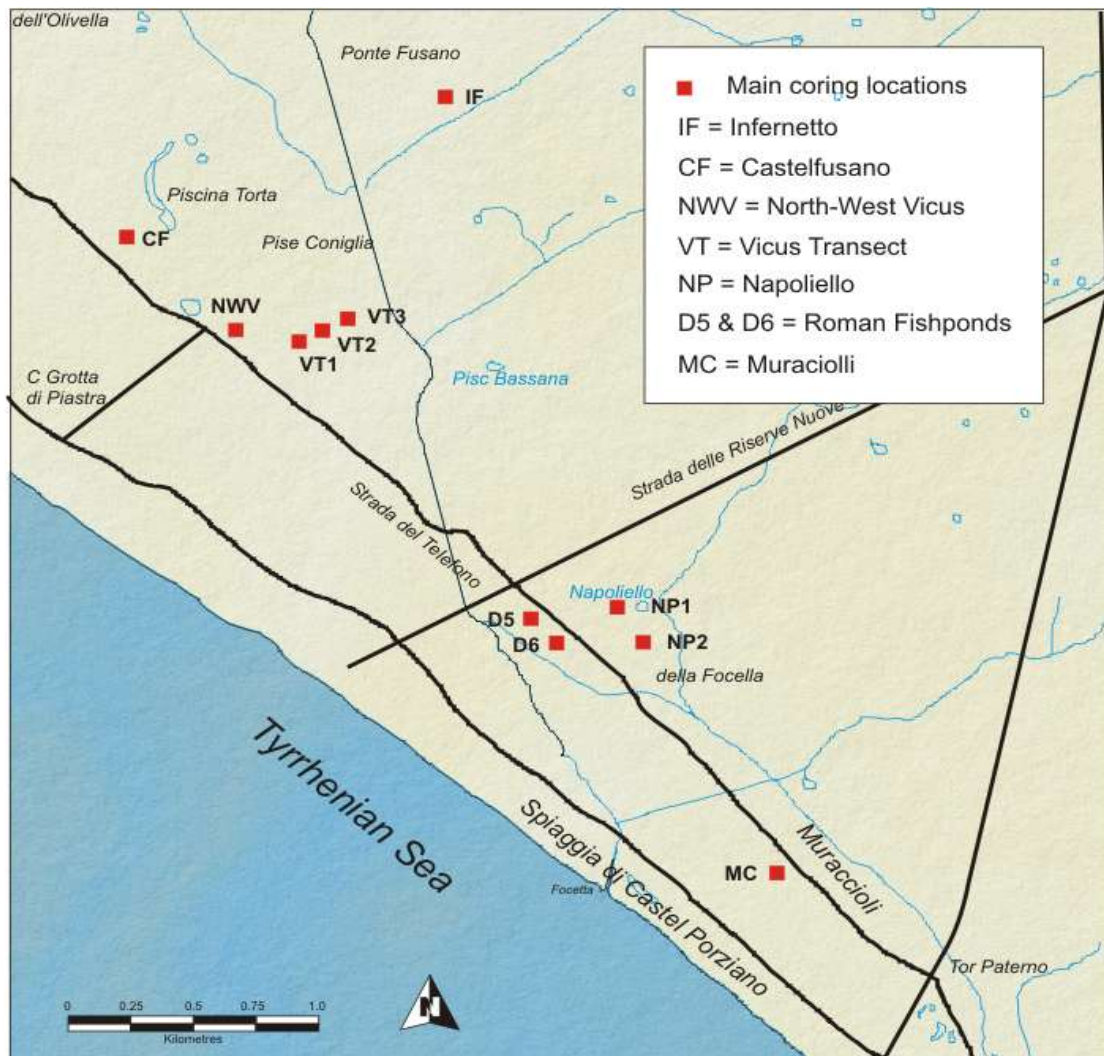


Figure 24 Locations cored and locations used in pilot studies (D5 and D6)

Core site descriptions (figure 24)

D5 and D6 are dune slacks but are unusual in comparison to other dune slacks sampled within the Castelporziano Estate as this portion of the interdune slack appears to have been enclosed for a specific use during the Roman period. The two sites are near rectangles sitting next to each other now some 500m from the sea, whereas in Roman times their location would have been immediately behind the foredune.

The contemporary vegetation of both coring sites is macchia with *Quercus ilex* which also contains *Fraxinus angustifolia subsp. oxycarpa*, *Arbutus unedo*, *Erica arborea* and *Pistacia lentiscus*. The boundary of D6 is marked by the presence of ferns with other hygrophilous vegetation and is still wet in the centre, which contrasts with D5 which is now completely dry and has less plant diversity.

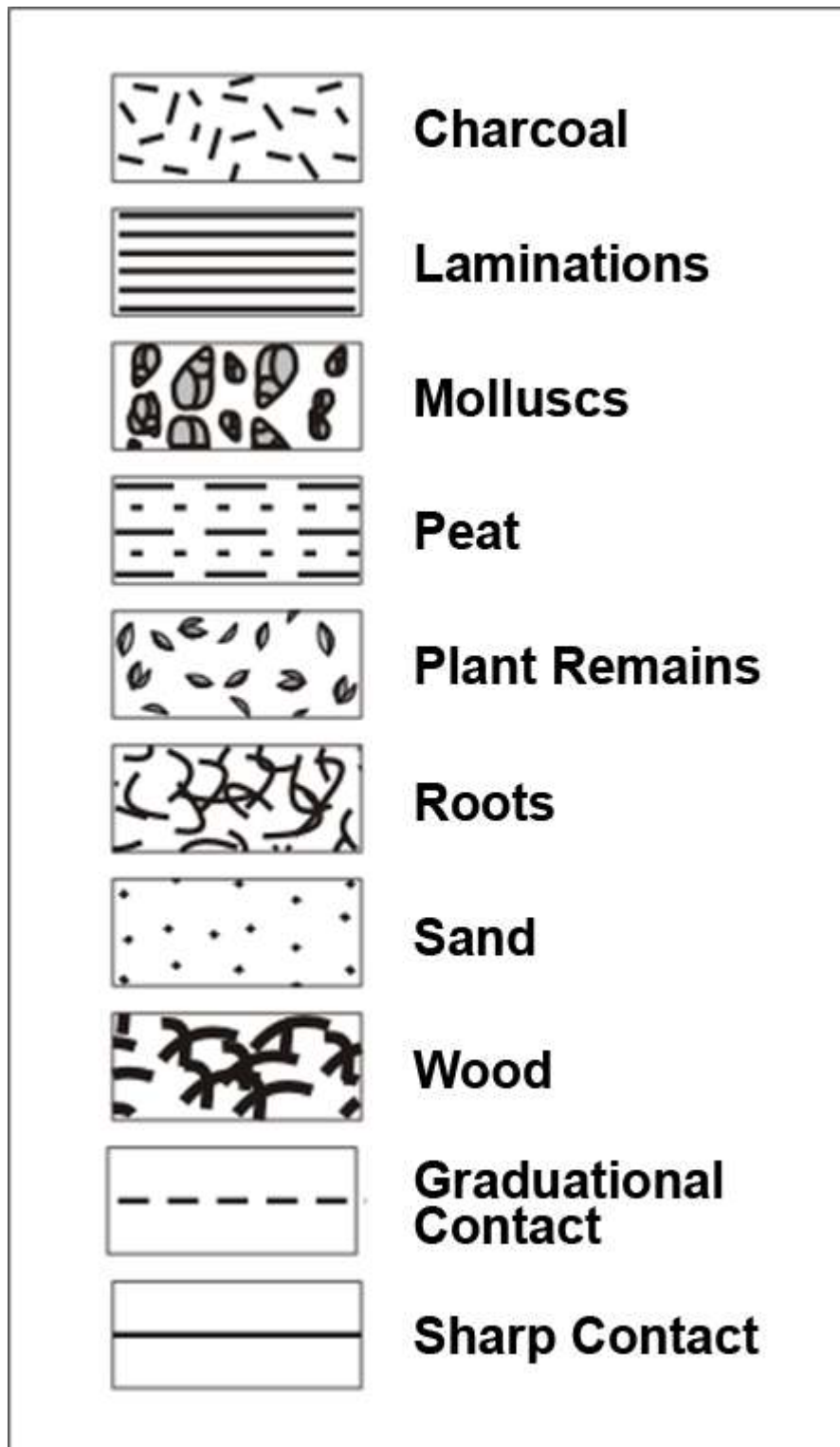


Figure 25 Key for Core Stratigraphy and descriptions

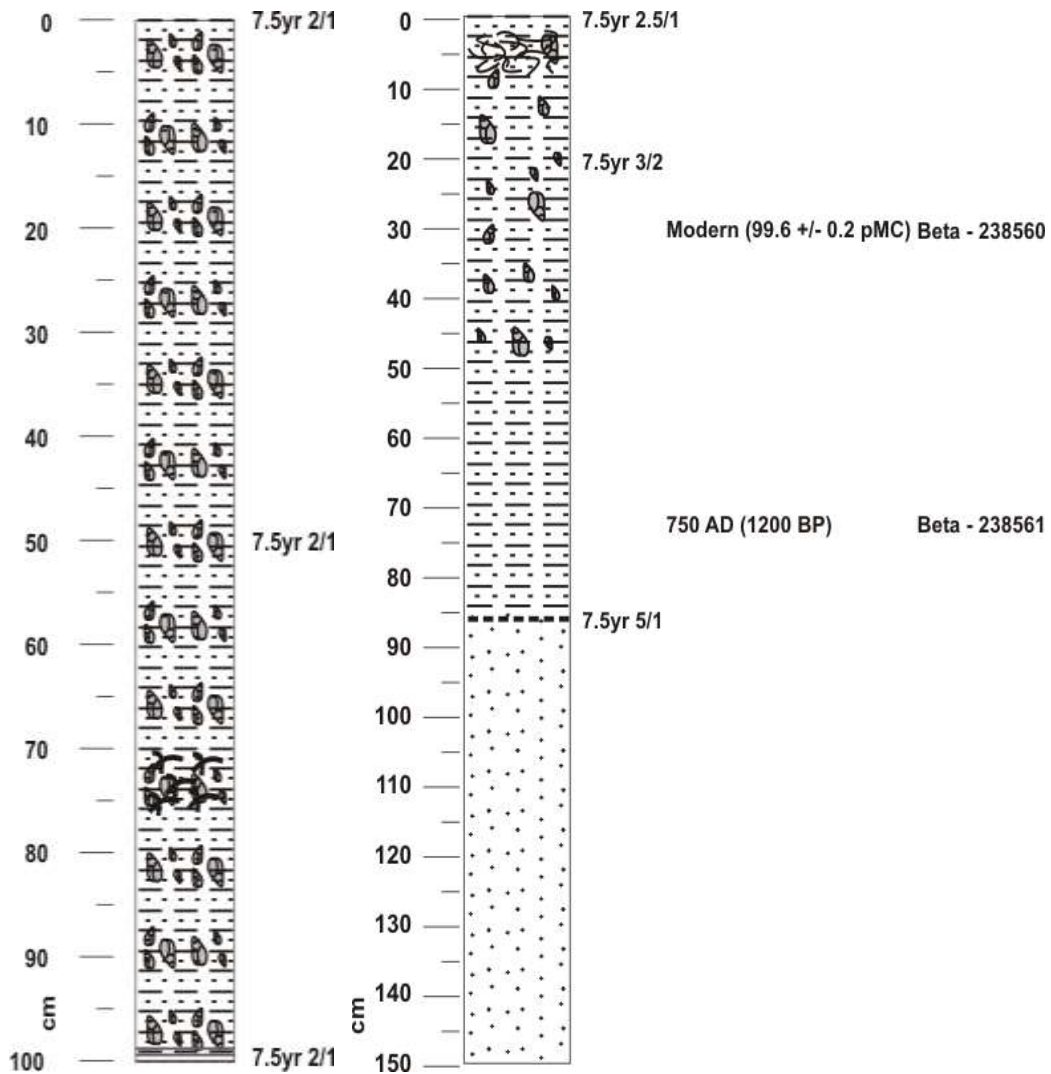


Figure 26 Stratigraphy for cores 1 and 6

3.6.2.1 Summary methodologies

Detailed methodologies for the pilot studies can be found in appendix 2. Counts were based on presence or absence because this is convention for the proxies used and can also help explain fluctuations in plant and animal life within the slacks, and thus changes in the environment.

The mollusc analysis used 10g wet sediment (w/v) which was cut from the core at the 5 cm intervals prior to analysis. Identification was aided by: Evans (1972), Cameron and Refern (1976), Kerney (1999) and Cameron and Riley (2008). All counts were based on a presence or absence of that particular species. Based on the species found, they were divided into habitats, aiding the reconstruction of the local environment

The extraction of plant macrofossils, stonewort oospores, bryozoan statoblasts and branchiopod crustaceans was done using the same methodology, as per Birks (2007). For all samples, 10g wet sediment (w/v), were cut from the core at the 5 cm intervals prior to analysis. For the bulk sediments the same mass was taken. All plant macrofossil identification was aided by: Berggren (1969; 1981), Birks (2007), Blamey and Grey-Wilson (2004), Cappers *et al.* (2006), Fletcher (2007), Touring Club Italia (1958) and University College London (Archaeology) seed collection. The stonewort oospores, bryozoan statoblasts and branchiopod crustaceans were identified from Francis (2001), Korhola and Rautio (2001), Birks (2007), and Wood and Okamura (2008) respectively. All plant macrofossil counts were based on a presence or absence of that particular species, and classified according to their habitat as arboreal, aquatic, herbaceous etc. The stonewort oospores, bryozoan statoblasts and branchiopod crustaceans' counts were based on presence or absence and then identified to species, following the recommendations set out by Francis (2001), and Korhola and Rautio (2001).

Initial charcoal analysis was done using macroscopic sieving, as per Whitlock and Larsen (2001). Counts were based on the criteria macrocharcoal content ($>125 \mu\text{m}$), which is a distinct marker of local fire productivity (Clark 1988; Macdonald *et al.* 1991).

For the testate amoebae, 2 cm^3 samples were removed from the core every 5 cm using the protocol set out for the Accrotelm project (2007) initially, however was superseded by use of a diatom preparation procedure. Identification was aided using Charman *et al.* (2000), and enumerated on the basis of presence and absence.

For the diatoms, 0.1g was removed from the core every cm and analysed using a modified version of the University College London preparation from Ryves and Mills (Ryves pers. comm. 2008). Samples also contained Chrysophytes, grass cuticles, phytoliths, and testate amoebae, which were then added to the proxies considered as part of the pilot studies. The presence or absence of diatoms was noted as well as species variation.

For LOI, approximately 1.5g of sediment was taken from the core every 1 cm for analysis. Values were converted to percentage organic carbon by use of a conversion of the organic matter values, multiplication by a factor of 1.724 (Schumacher 2002).

The geochemistry was carried out using X-Ray Fluorescence (XRF); approximately 10-12g wet sediment was taken every 5 cm, and dried in an oven for 24 hours to drive off excess moisture, so that 8.5g could be then used for analysis. All samples taken were of organic sediment, which were prepared at Wolverhampton University, prior to analysis by David Thompsett. All results were converted from percentage to parts per million.

3.6.2.2 Results: Cores 1 and 6 (D6 and D5)

Molluscs: Core 1

The most common molluscs species found in core 1 (figure) were: Hippeutis complanatus > Vitrea contracta > Vitrea crystallina > Bathyomphalus contortus > Unio pictorium. Plotting the abundance of each species did not give any information on the local environment beyond the species present. They were therefore classified using a series of habitat studies to determine the local environment. As the species were already known and counted, they were then sorted into ecological groups that best reflected the species associations of their analogues (as per Miller and Tevesz 2001).

The molluscs were first classified according to whether they were freshwater, brackish or marine; all species were found to be freshwater, but some could tolerate brackish conditions. Secondly some of the species identified had a preference for slow moving water whereas others did not. Thirdly study they were classified as open and closed ground species i.e. was the local area wooded or open (figure 27), which showed for the core depth range 85-50 cm much of the local environment was open ground, with the upper 45 cm showing a marked increase in woodland. The molluscs were then re-classified according to whether they were pond, fen or other (dune) (figure 28). The results showed the majority of the molluscs that were found in woodlands were also found in the fens, and the open species were found in ponds. Therefore, the local environment appears to have been an open pond, with a wet woodland (fen) around it, which increased in dominance with time.

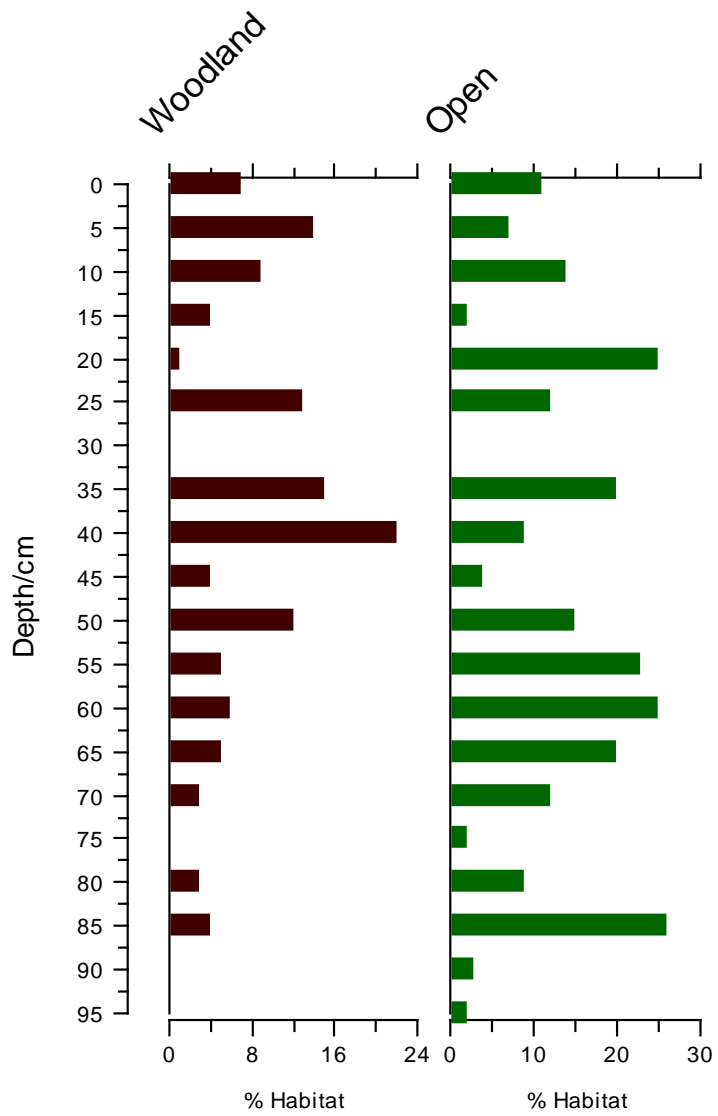


Figure 27 % Molluscs species core 1: Woodland vs. Open environment

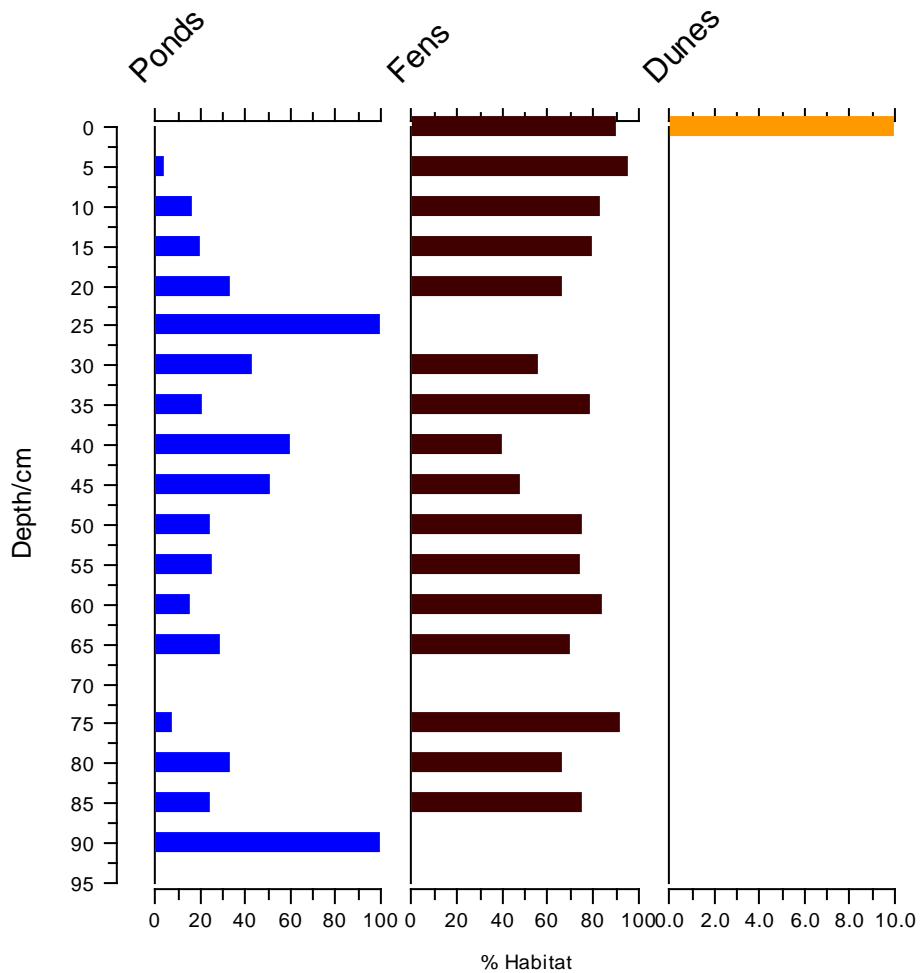


Figure 28 % Molluscs species core 1: Pond vs. Fen vs. Dune environment

Molluscs: Core 6

The results from core 6 show the presence of molluscs throughout the 0-80 cm part of the core (figure 29), the (lower) sand-rich section of the core contained no mollusc remains. The three species identified (*Zonitoides nitidus*, *Vitrea crystallina*, and *Vertigo antivertigo*) are all typical wetland species, particularly associated with marshes or fens, and all three species were also found in core 1 (D6).

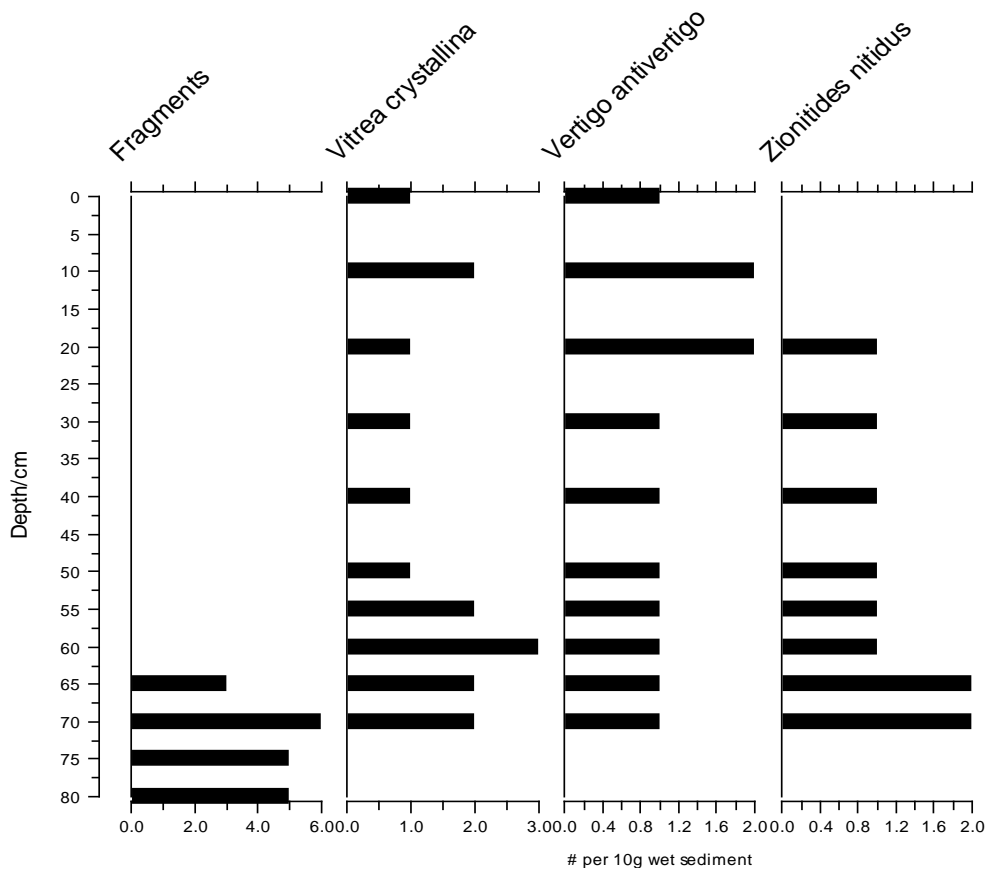


Figure 29 Core 6/D5 Molluscs

Plant macrofossils

Core 1 (figure 30) shows the presence of *Carex sp.*, *Betula pendula* and *Potamogeton obtusifolia* seeds, which would indicate the same local environment as the mollusc remains i.e. the presence of a wet woodland or fen carr. Results from core 6 (figure 31), showed a complete absence of plant macrofossils below 80 cm depth. *Poaceae*, *Carex sp.* and *Alnus glutinosa* were identified and can be interpreted as indicative of a fen carr environment.

Using the plant macrofossil preparation technique, other potential proxies were found in the core material in both core 1 and 6, namely, stonewort oospores, bryozoan statoblasts and *Daphnia ehippia*. The stonewort oospores of *Chara* were found, and were identified as those of *Chara tomentosa*. This species of stonewort and its oospores can be found in lakes from Sweden and the Baltic coast to the Mediterranean Basin (Krause 1997). *C. tomentosa*, like most *Chara* species is indicative of alkaline habitats (Hutorowicz 2008). In core 6 these were only present in

the 80-20 cm section of the core, and were absent in the upper 0 to 20 cm. Whereas core 1 (figure 32) showed Chara oospores present at 65-90 cm and at the core top. The centre of the D6 area is perennially wet under current climate conditions.

Statoblasts of *Plumatella repens* were found in core 1 (figure 32), that were further evidence for freshwater habitats. Their absence below 70 cm depth suggests that macrophyte abundance was low, which in turn may reflect a change in the littoral zone development or a change in water-level. *Daphnia ephippia* is also absent below 70 cm down the core (figure 32).

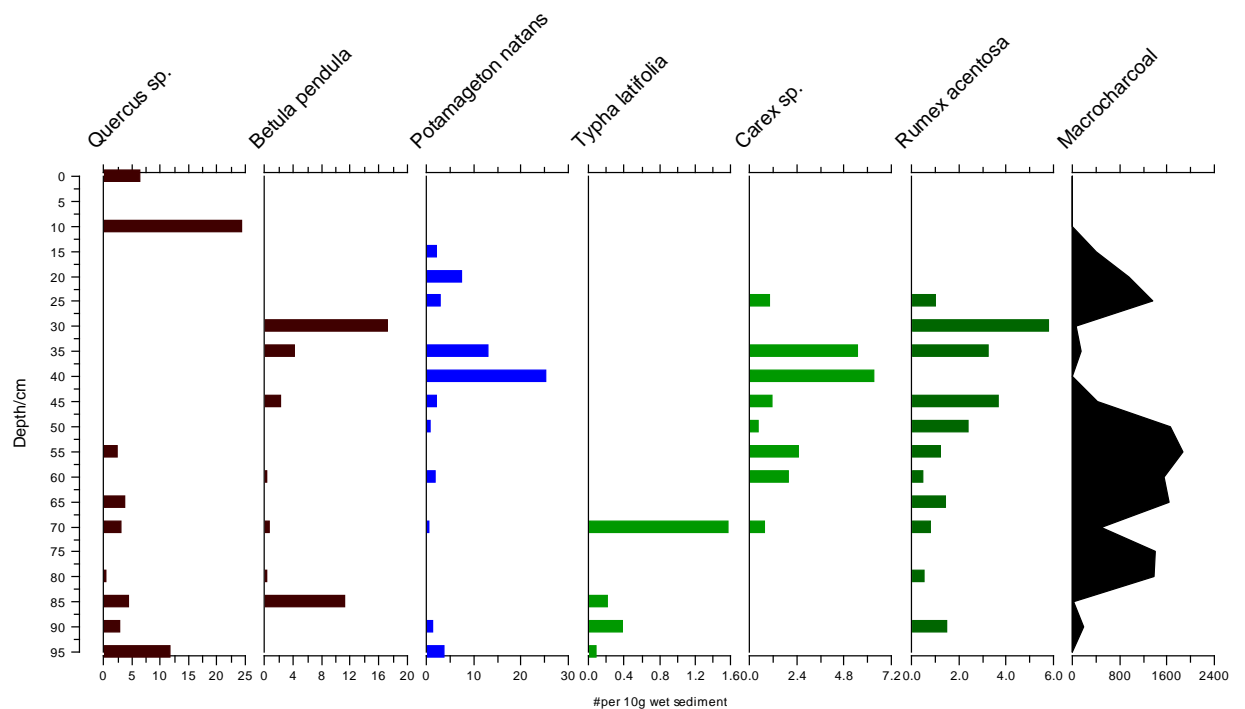


Figure 30 Main plant macrofossil species and macrocharcoal Core 1

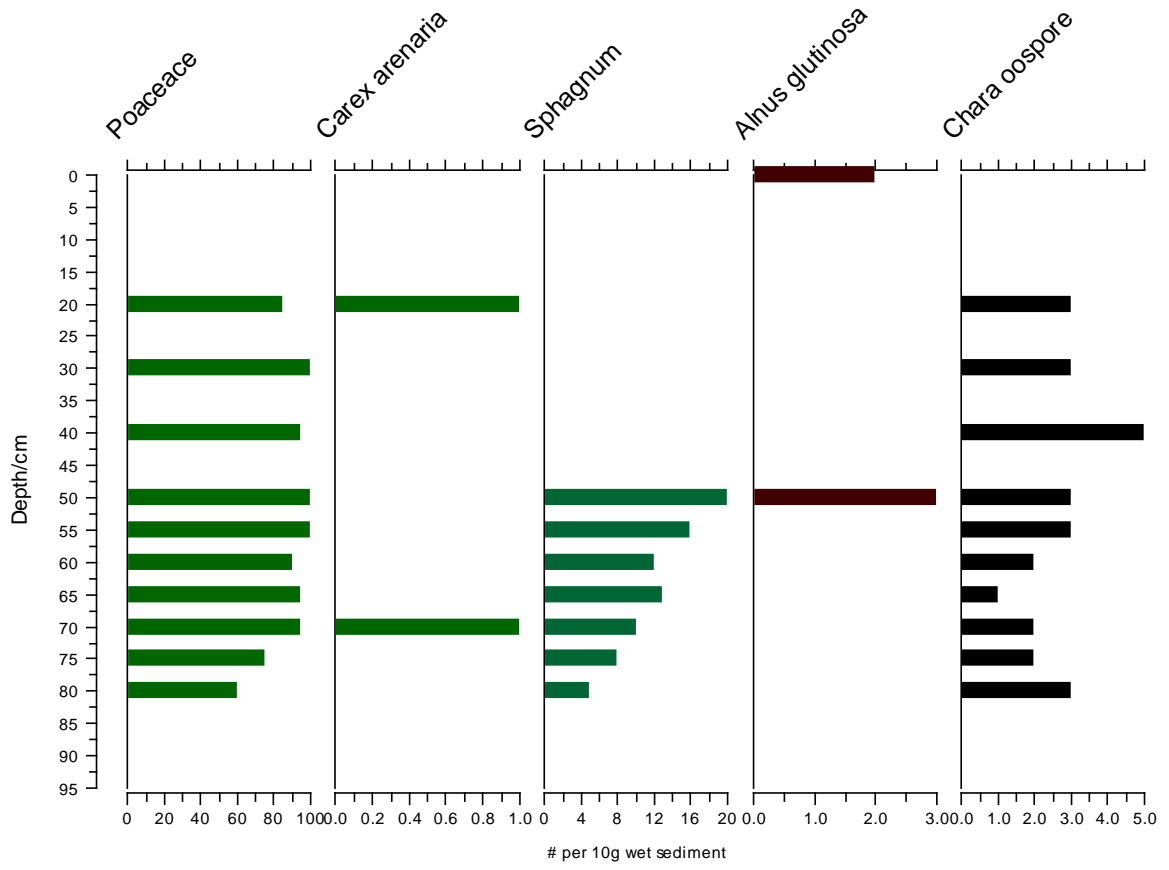


Figure 31 Plant macrofossils Core 6

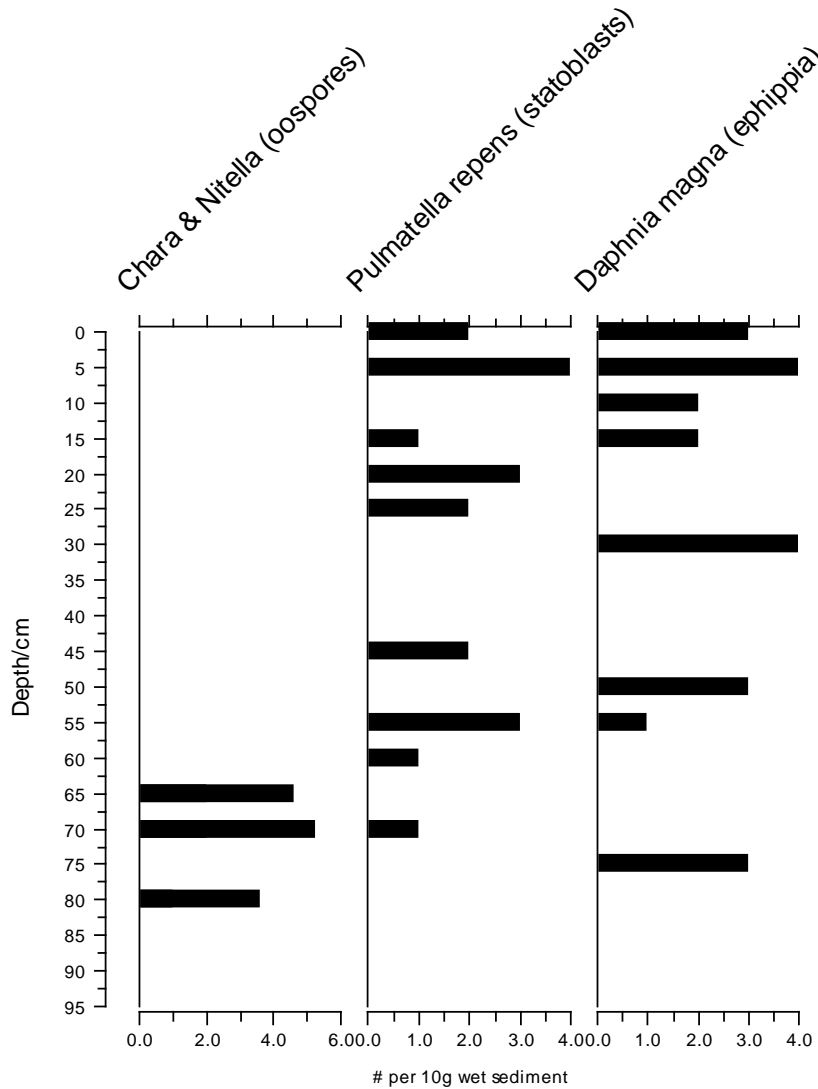


Figure 32 Stonewort oospores, *Daphnia ephippia* and *Plumatella repens* statoblasts (Core 1)

Macrocharcoal

The pilot study raised issues involving distinguishing macrocharcoal and haematite, due to both having the same colour and particle size, leading possible over counting of charcoal. This led on to further pilot studies to evaluate other possible methodologies for assessing the macrocharcoal component and these developments are discussed further in Chapter 4.

Testate amoebae

Testate amoebae were initially prepared for core 1, using the methodology of Charman *et al.* (2000), which proved unsatisfactory the slides proved to be too sticky, and thick to see anything under a microscope, even a repeat trying different sizes of sieves did solve these issues. A different sample preparation protocol was used, that of diatom preparation (Ryves pers. comm. 2008), and evaluated using a second core from D6 (core 3). The results showed presence of *Trigonopyxis arcula*, *Diffflugia bacillariarum* and *Nebela tinctoria* (figure 33) from 80-100 cm, confirming an alkaline wet environment.

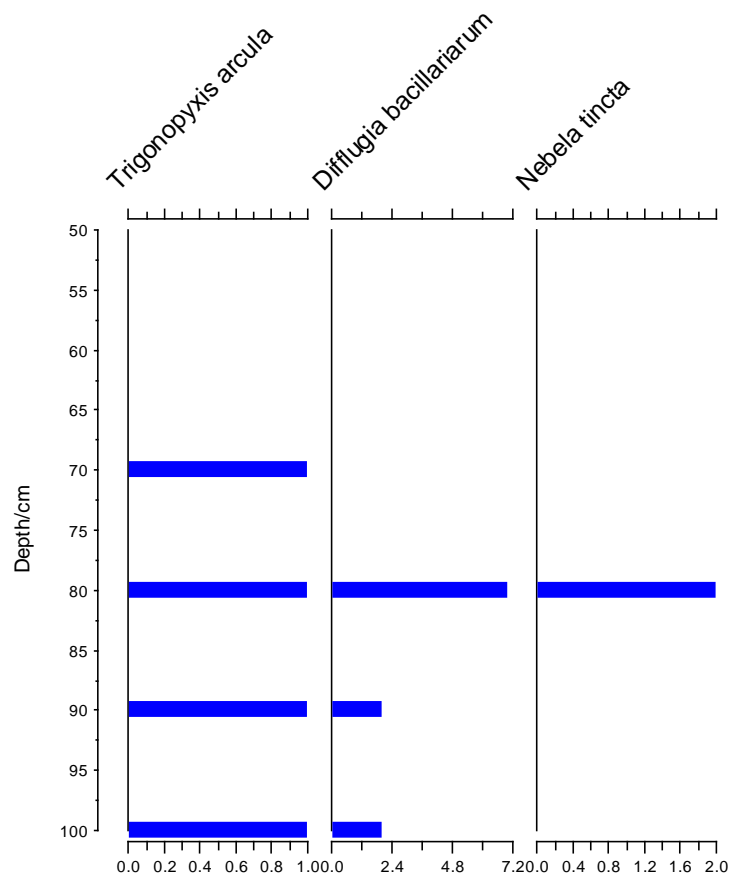


Figure 33 Testate amoebae D6

Core 6 showed a complete absence of testate amoebae throughout the core length.

Diatoms

The diatoms were evaluated for a second core from D6, core 3, (a 2-m core containing 3 distinct transitions in stratigraphy: from peat to marsh to beach sand). Slides were prepared from samples at core depths of 50, 80, 90 and 100 cm to evaluate the use of diatoms as a possible proxy, (figure 34). These were evaluated on the basis of presence/absence, species and worthiness for further study. Within Core 3 it was noted that the species were not changing with depth to 130 cm, but that the numbers of each species varied. The main species identified were: *Epithemia adnata*, *Rhopalodia sp.*, *Navicula vulpine*, *Cocconeis placentula* and *Nitzschia sp.*, which indicate the local pH is circum-neutral to alkaline and which attach to macrophytes.

The pilot studies for diatoms were also undertaken with cores 6, 7 and 9 (from D5, Pozzo Napoliello and Muraccioli, respectively) to ascertain their potential as a proxy for using on natural dune slacks that had not be made into fish ponds by the Romans c.f. those that were. The results showed that there was virtually a complete absence of diatoms, which was also found by and Beadle (1932) and Jenkin (1936) for alkaline, saline lakes. This led to them not being continued beyond the pilot stage (see chapter 4). The reason for the absence is likely to be due to the carbonate content in those 3 areas, as per Flowers (1993) who found that drying carbonate rich sediment lead to breakages in diatoms. Hecky (1973) found that the solubility of diatoms in natural waters and sediment was not a simple function of pH and that the organic matter incorporated in the sediments can allow diatoms to act as an efficient sink for silica in alkaline lakes.

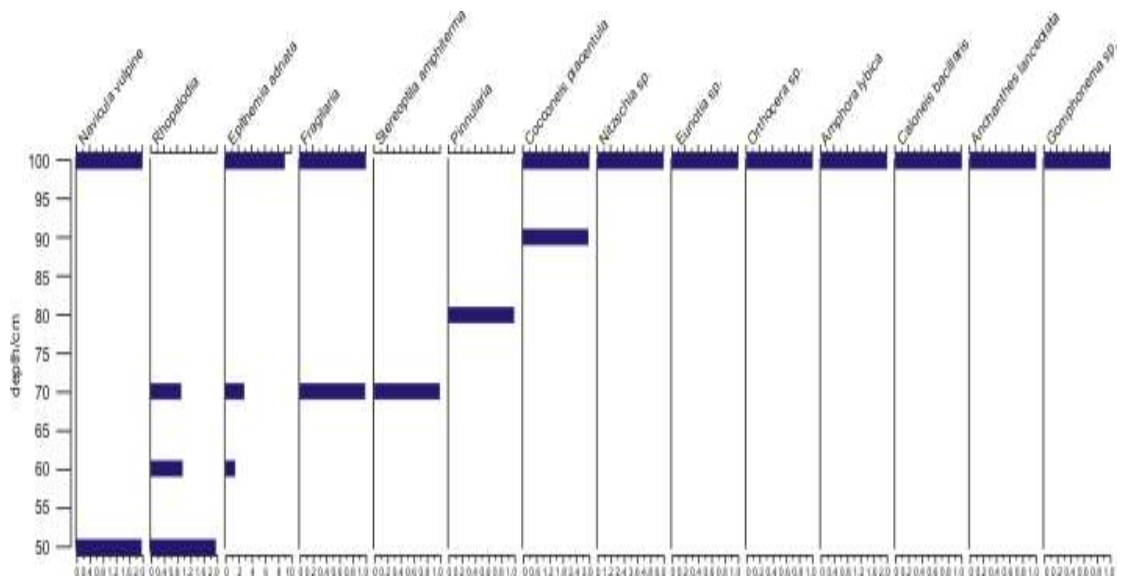


Figure 34 Diatoms from Core 3, D6

Loss on Ignition

This was carried out on core 6 initially, and eventually carried out on cores from all areas investigated (see chapter 4). The results show low organic matter throughout the core length (figure 35), but increasing in the top 20 cm. The low organic matter may reflect the limited macrofossil remains found, as well as the differences in stratigraphy c.f. core 1. Another reason for the low organic matter in the lower 60 cm, which may be due to differences in the mineralisation of organic matter, which may in turn be due to differences in local hydrology and groundwater regime within the slack.

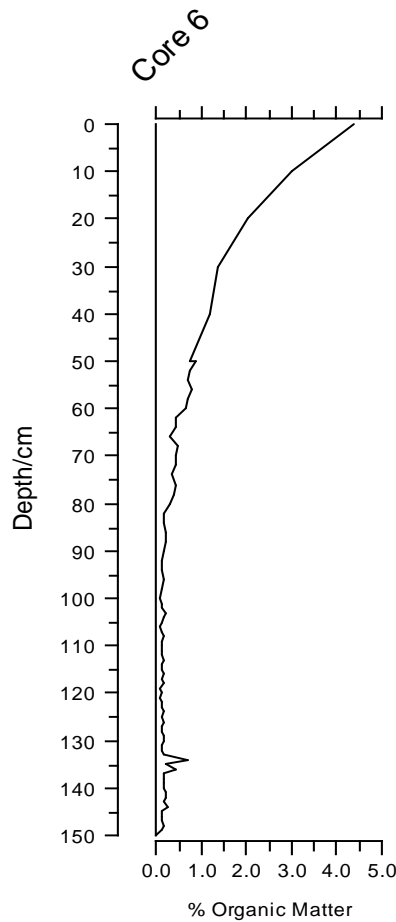


Figure 35 Loss on Ignition Core 6

Geochemistry

The geochemistry results (figure 36) proved more complex, due to the minerogenic nature of the cores. Owing to the large sample mass required for analysis, this work was only undertaken on core 1, as it was immediately clear that if this technique was to be used further it would limit other proxies that could be used, and that a finer resolution would not be possible. The results of the elemental analysis, in terms of geochemistry and potential proxies, are discussed below.

The calcium levels throughout the length of the core were high (ranging from 6.23% at 25 cm to 2.17% at 30 cm) relating to the calcareous remains in the core from molluscs and gastropods, the calcareous nature of the underlying dune slack, the levels of the mineral gypsum in the dune, its calcium carbonate groundwater, and the seasonal variations in the level of that ground water. The magnesium levels range with depth from 0.48% at 5 cm to 0.16% at 15 cm. Willis *et al.* (1959) found decreasing magnesium with increasing wetness within the slack itself, so the

changing levels could reflect this. A correlation between magnesium, iron and silicon was found, and may well be related to the presence of olivine within the dune sand. Phosphorus levels were found to gradually decline with depth from 95-75 cm before and then peaking at various intervals throughout the length, e.g. 45 cm and 25 cm, which may relate to anthropogenic impact. Phosphorous showed strong correlations with silicon, calcium, potassium and aluminium ($r = 0.79, 0.78, 0.77$ and 0.67 respectively). Silicon has been associated with the biological availability of phosphorus (Williams 1978), when added to soils it increased the uptake of phosphate by plants (Exley *et al.* 1993). In neutral and calcareous soils such as those found at D6, inorganic phosphorous in the soil water precipitates as calcium phosphate, which may explain the high correlation found between them. The high iron levels found may be due to an iron pipe running found during the archaeological excavation near the coring site. The iron also shows a strong correlation with manganese. Manganese varies from 401ppm at 50 cm, to 157ppm at 15 cm. Soil that has been waterlogged increased in iron and manganese; therefore it is accumulation of these ions in the soil which may influence the distribution of dune and dune slack plants (Singer and Havill 1985). Sulphur notably decreases with decreasing depth, from 21950ppm at 95cm to 8735ppm at 5cm, and Chloride also significantly decreases with decreasing depth from 3263ppm at 95cm to 773ppm at 5cm. The decreasing influence of the sea may be reflected by a reduction in chloride, which can be also noted in the sodium record. There is a moderate correlation between sulphur and potassium levels, which may be due to the weathering of potassium feldspar. The feldspars are alkaline aluminosilicates, which can be seen in the moderate correlation between aluminium and silicon ($r = 0.46$) levels. The silicon levels are a reflection of the local dune environment, and thus the high levels throughout the core length. However, the increased silicon levels from 95-85 cm could be related to increased quartz input and this pattern is repeated further up the core with peaks at 45, 25 and 5 cm. The increased quartz input could be related to storms, as highlighted by de Jong (2006. 2007) and this aspect is investigated further in Chapter 4.

Mercury levels generally decrease down the core from 4.9ppm at 95 cm to 2.3ppm at 0 cm, with peaks at 35 and 25 cm of 7.5 and 7.2ppm respectively. An assessment of mercury levels in rocks, soils and sediments of the Western United States indicates normal levels to be within the range of 50-200 ppb (Garcia and Kidd 1979). Standiford *et al.* (1973) reported mercury levels of 4-53 ppb in Lake Powell sediments (Arizona-Utah) which is believed to be free of artificial mercury contamination, with the lowest levels falling within those found in the sediment of D6.

A wide range of factors control mercury emissions from geological sources such as soils and water bodies, and the apparent variability of volcanic outputs, has made the quantity of mercury released naturally from geological sources difficult to quantify. Therefore, attempts to determine the natural and anthropogenic fractions of the current atmospheric and surface oceanic mercury pools involve considerable error (Nriagu 1989); although some research on peat bogs and lake sediments (e.g. Roos-Barraclough *et al.* 2002) has attempted to overcome this.

Titanium levels vary from 114ppm at 15cm to 530ppm at 5 cm. Titanium and aluminium show a strong correlation, which has been argued that for marine sediments the Ti/Al ratio reflects the average grain size of silicate minerals, with variations caused either by a change in aeolian source area, strength of wind transport, or both (Boyle 1983). However, at Castelporziano this ratio is more likely to be due to the composition of sediment and the effects of sedimentary process (Lopez-Buendya *et al.* 1999). The levels of selenium are highest at the base of the core, 38ppm, and are generally constant throughout the depth at 16-18ppm, except at 85 cm and 35 cm where it falls to 7ppm. According to Rosenfeld and Beath (1964), the concentration of selenium in most normal soils is estimated to be <2mg/kg, thus the levels in the cores are comparatively high. Mosher and Duce (1987), Nriagu (1989) and Nriagu and Pacyna (1988) suggest that the natural sources include crustal weathering (wind blown soil dust), volcanoes, sea salt, and the continental and marine biospheres, while the anthropogenic sources mainly comprise combustion (coal, oil, wood, biomass, incineration, etc.), nonferrous metal melting, manufacturing and utilization of agriculture products.

The geochemistry results were also compared with those found by Lopez-Buendía *et al.* (1999) for a Spanish coastal peatland, which contain lagoonal organic-rich depositional systems (back-barrier marshes). Comparison was made with the elements: sodium, magnesium, aluminium, sulphur, potassium, calcium, iron, nickel, copper, zinc, strontium, bromine, yttrium and lead levels.

Variations in the nature of the groundwater can be used to establish the relative influence of the seawater on the deposits. However, these simple generalised associations do not take into account the affinities of these elements with the different peat fractions (organic matter or minerals). These chemical affinities are investigated using the Pearson's correlation coefficients (Table 5). The organic matter was based on the LOI results for core 3. The results show, the organic matter has strong negative correlations with sodium, calcium, potassium, and copper, as

well as a positive correlation with zinc. Organic matter is oxidised using strong oxidising agents such as sodium, calcium and potassium, which is indicated by the negative correlations between these elements and organic matter. The correlation between zinc and organic matter are linked to the bioavailability of zinc, which in plants is generally low in organic soils. Elements with a high organic affinity give more geochemical information about the original palaeoenvironment if: (1) plants that grow in situ selectively fix the chemical elements; (2) the proportion of elements selected for the plant are assimilated in direct proportion to their respective concentration; (3) there are only small differences in elemental affinity between plant types and the substratum in which they grow (Casagrande and Erchull 1977).

	OM	Fe	K	Na	Al
Na	-0.68	0.77	0.14	1.00	0.23
Mg	-0.11	0.83	0.49	0.68	0.61
Al	-0.26	0.43	0.95	0.23	1.00
S	0.30	0.56	-0.39	0.61	-0.24
K	-0.39	0.30	1.00	0.14	0.95
Ca	-0.45	0.54	0.67	0.56	0.67
Fe	0.33	1.00	0.30	0.77	0.43
Ni	-0.27	-0.39	-0.08	-0.46	-0.14
Cu	-0.35	0.28	0.47	0.12	0.54
Zn	0.33	0.20	-0.36	0.34	-0.26
Sr	-0.27	0.49	0.68	0.34	0.64
Br	-0.06	-0.17	0.62	-0.30	0.48
Y	-0.10	-0.25	0.04	-0.16	0.08
Pb	0.04	0.15	0.66	0.04	0.53

Table 5 Parametric correlation coefficient (r) between chemical element concentration and organic matter (OM), iron, potassium, sodium and aluminium contents for the (n=20), to 95% of confidence limits

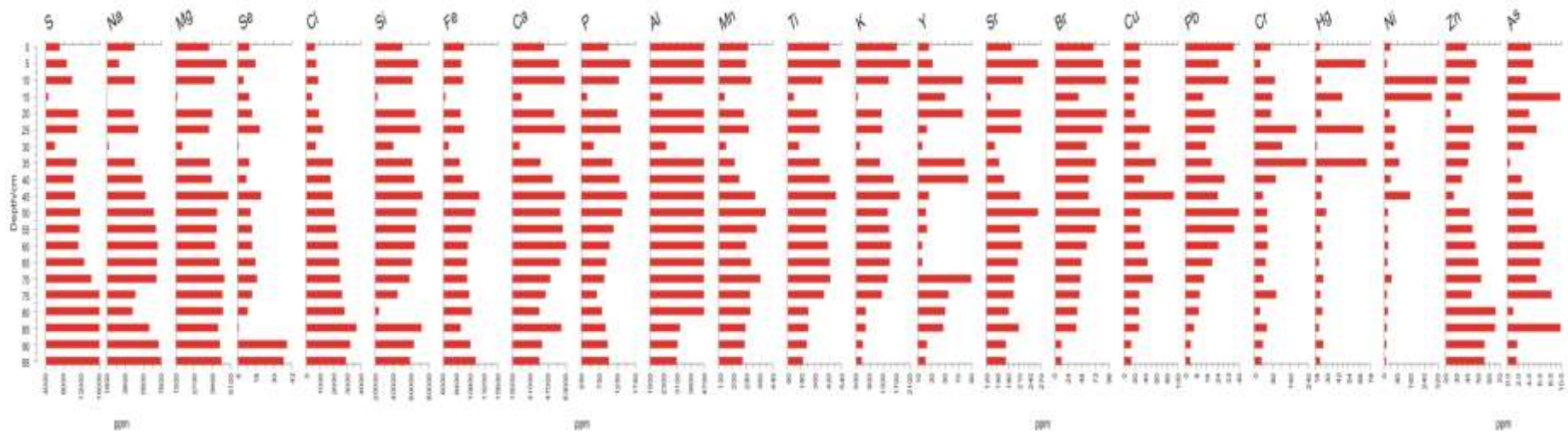


Figure 36 Geochemistry Core 1

3.7 Discussion of proxy results

The molluscs from core 1 indicated the presence of local wet woodland within an open pond, whereas the molluscs from core 6 suggested a fen carr, although the same molluscs species were found in both cores, core 6 showed less diversity. The molluscs also indicate alkaline conditions $\text{pH} \geq 7$ for most of the core length. Molluscs were present throughout the peat-rich material of cores 1 and 6, but absent in the sandier (lower) part of core 6. However, as the results from core 1 showed they were a potential proxy for the local environment in terms of open vs. closed canopy, and pond vs. fen.

The plant macrofossil results generally showed the presence of wet woodland species in core 1, whereas core 6 was more indicative of wet grassland dominated with Poaceae leaves. As plants produce far fewer macrofossils than pollen grains, the low numbers present with depth was not an issue. As with lakes and peat bogs, the slack record showed changes in the local vegetation. Although, initially hampered by lack of a specific Mediterranean seed atlas, the existing European atlases enabled identification to species level (Berggren 1969; 1981). With further understanding of the ecology of the species within a Mediterranean context, the genus (if remaining in doubt after using the seed atlas), could be confirmed. Therefore, as a proxy for local vegetation and environmental changes, plant macrofossils were carried on with no alterations to the methodology. Additionally, the bryozoan statoblasts, daphnia ephippia and stonewort oospores share the same preparation methodology as the plant macrofossils, and were readily identifiable.

The initial testate amoebae preparation was found to be unsuitable for the core samples, as the sieving still left a high minerogenic portion with remains of silica and haematite in the samples. Even with the adapted protocol, i.e. the same as for diatoms, the testate amoebae were few in number. As a proxy for wetness, the stoneworts oospores also provided this evidence without the need for using a different protocol. Even though they showed promise from the literature for reconstruction of the water table or sea-level, when using the diatom preparation the numbers counted were so low it was decided this would not be a representative count, and therefore excluded from further work.

Although present in D6 cores, diatoms were absent from cores through undisturbed dune slacks, which may be due to the coarseness of the sediment and carbonate

levels in these areas. Therefore, diatoms were also rejected at the pilot stage, they were however briefly revisited by Andy Bicket (2010) to aid the identification of Roman sea-level, based on the minerogenic basal portion of core 14 (D6) that showed a transition from beach sand to freshwater marsh to peat.

The geochemistry results were more difficult to interpret in relation to environmental change at Castelporziano. They simply reflected the fact that the minerogenic component of the dune slacks was not unsurprisingly dominated by silica and silicate minerals and associated trace elements. Additionally, the minimum sample weight requirement of 8.5g dry weight minimum, as previously noted, restricted the number of proxies that could be done, as well as making finer resolution harder to achieve given the core diameters and the weight of material required. Therefore, this proxy was rejected at the pilot stage.

Other proxies not considered during the pilot studies but which were used in the rest of the research included pollen and ostracods, both used previously for palaeoenvironmental work within dunes. The use of ostracods were not considered for testing in the pilot studies as the work by Fontana (2005) only came to light during the evaluation of the results, therefore they were tested and evaluated during the detailed studies. As for pollen, this was not tested during the pilot studies but it is a fundamental proxy it was decided to use it during the detailed study.

The selection of sample size depended on the richness and abundance of macroremains in the sample, something that was difficult to judge until some processing had been done. For cores, depending on the sediment accumulation rate, it was often important to restrict sampling to narrow core intervals (e.g., 1 cm slices) so that each sample only spanned a small time interval. The volume of material available from slices varied greatly depending on the type of corer used, and its barrel or collecting chamber diameter, varying from 5 and 7 cm respectively.

3.8 Conclusion

In conclusion, there are many palaeoenvironmental proxies that can be used to reconstruct past environments, each reflecting a different aspect of the environment. Combining these proxies, may improve the quality of the environmental reconstruction. However some proxies can only be applied to certain types of environment, e.g. peat humification, while others relate to specific environmental

variables Pilot studies have shown that the Castelporziano dune slacks can be used as a palaeoenvironmental archives with a wide range of proxies (table 6).

The proxies chosen for the rest of the research after the pilot studies (table 6) were as follows:

<i>Proxy</i>	<i>What is it a proxy of?</i>	<i>Used in pilot studies ? (Y/N)</i>	<i>Problems</i>	<i>Used for rest of thesis? (Y/N)</i>
Molluscs	Changes in climate/local environment/vegetation	Y	N/A	Y
Plant Macrofossils	Changes in climate/local environment/vegetation	Y	None in sandy parts of cores	Y
Charcoal	Fire	Y	Haemetite vs. Macrocharcoal	Y
Ostracods	Temperature/salinity	N	N/A	Y
Testate amoebae	Hydrological conditions	Y	Slide preparation issues, but methodology changed	N
Diatoms	pH/Salinity	Y	Variable preservation out with D6.	N
Bryozoan statoblasts	Logging/Eutrophication/Anoxia	Y	Indicators of what & contemporary comparisons.	Y
Stoneworts	pH/temperature/water depth/fires?	Y	Indicators of what & contemporary comparisons	Y
Branchiopod Crustaceans	pH/temperature	Y	Indicators of what & contemporary comparisons	Y
Pollen	Changes in climate/temperature/vegetation	N	N/A	Y
Loss on ignition	Organic matter/carbon	Y	Low organic matter, preservation of remains.	Y
Geochemistry	metal deposition/atmospheric fluxes of dust/pollution	Y	Minerogenic nature reflected	N
Isotopes	Environmental & Climatic changes	N	Y	N
Particle size analysis	erosion, transportation & deposition of sediments	N	N	N*

* Used later in a pilot study for examining storminess

Table 6 A review of proxies considered for the thesis

Chapter 4: Results of the multi-proxy palaeoenvironmental reconstruction

4.1 Introduction

In chapter one the first two research questions of this thesis were set out as, to test the suitability of dune slacks as a palaeoenvironmental archive and to determine which proxies were suitable in this context. These questions were addressed in the previous chapter via a series of pilot studies, showing that some proxies such as plant macrofossils were suitable proxies, whereas others were not applicable to all of the dune slack material. This chapter presents the main results of the palaeoenvironmental reconstruction based on a more detailed examination of the core material, particularly from D6 (the Roman fish pond). This chapter will address the third and fourth research questions, i.e. what environmental changes are apparent from the palaeoecological and chemical proxies? And to what extent were these changes anthropogenic and/or natural?

From chapter 3, the proxies chosen on the basis of the pilot studies, and associated literature reviews, for the detailed reconstruction were:

- Pollen - reconstruction of local and regional environment and vegetation;
- Plant Macrofossils - reconstruction of local environment and vegetation;
- Molluscs- aid the plant macrofossil record in reconstructing the local environment;
- Loss on Ignition - indicator of organic matter, and thus organic carbon content, linking cores from same location and standard correlation tool;
- Macrocharcoal - reconstruction of the fire history;
- Charophyte oospores - the state of the dune slack (i.e. pH/temperature/water depth), its calcareous nature;
- Bryozoan statoblasts - the state of the dune slack, and possible links with deforestation;
- Branchiopod Crustaceans - the state of the dune slack (i.e. pH and hydrology);
- Ostracods - salinity/hydrology (marine vs. freshwater), and possible temperature gauge.

The detailed reconstruction was undertaken using a series of cores, from dune slacks within the Castelporziano Estate (D5, D6, Pozzo Napoliello and Muraccioli)

and two low lying areas immediately outside the estate boundary (Castelfusano and Infernetto) using the above proxies.

4.2 Overview of coring

During April and May 2007, 13 cores were taken within the Castelporziano Estate from 7 different locations. These locations included D6 and D5 (thought to have been adapted as Roman fishponds), Pozzo Napoliello (referred by Ashby in 1900s with regards to a new pine plantation nearby), and Muraccioli aka the “Ruins” (remains of the imperial villa) (pers. comm. Claridge 2008). In May 2008 D5 and D6 were re-cored, in light of the findings from the pilot studies (chapter 3) and two areas outside the estate were added from the publicly-accessible park at Castelfusano (the estate between Castelporziano and Ostia Antica) and from Infernetto (a former marsh inland from Castelfusano) the locations of these sites are shown on figure 38. The cores were extracted using either a Cobra percussion corer with 1 m gouge attachment or a Livingstone (Russian peat) corer, depending on the nature of the sediments. The percussion corer had a core catcher sampler with a synthetic sampling tube (figure 37), which allowed for taking sediment samples in areas where hand coring using the peat corer was not possible. Livingstone cores were extruded into plastic drainpipe and wrapped in plastic film for storage. Multiple cores were extracted wherever possible and cores were logged in the field before packaging for transport back to the laboratory.



Figure 37 Core catcher sampler with core in sleeve

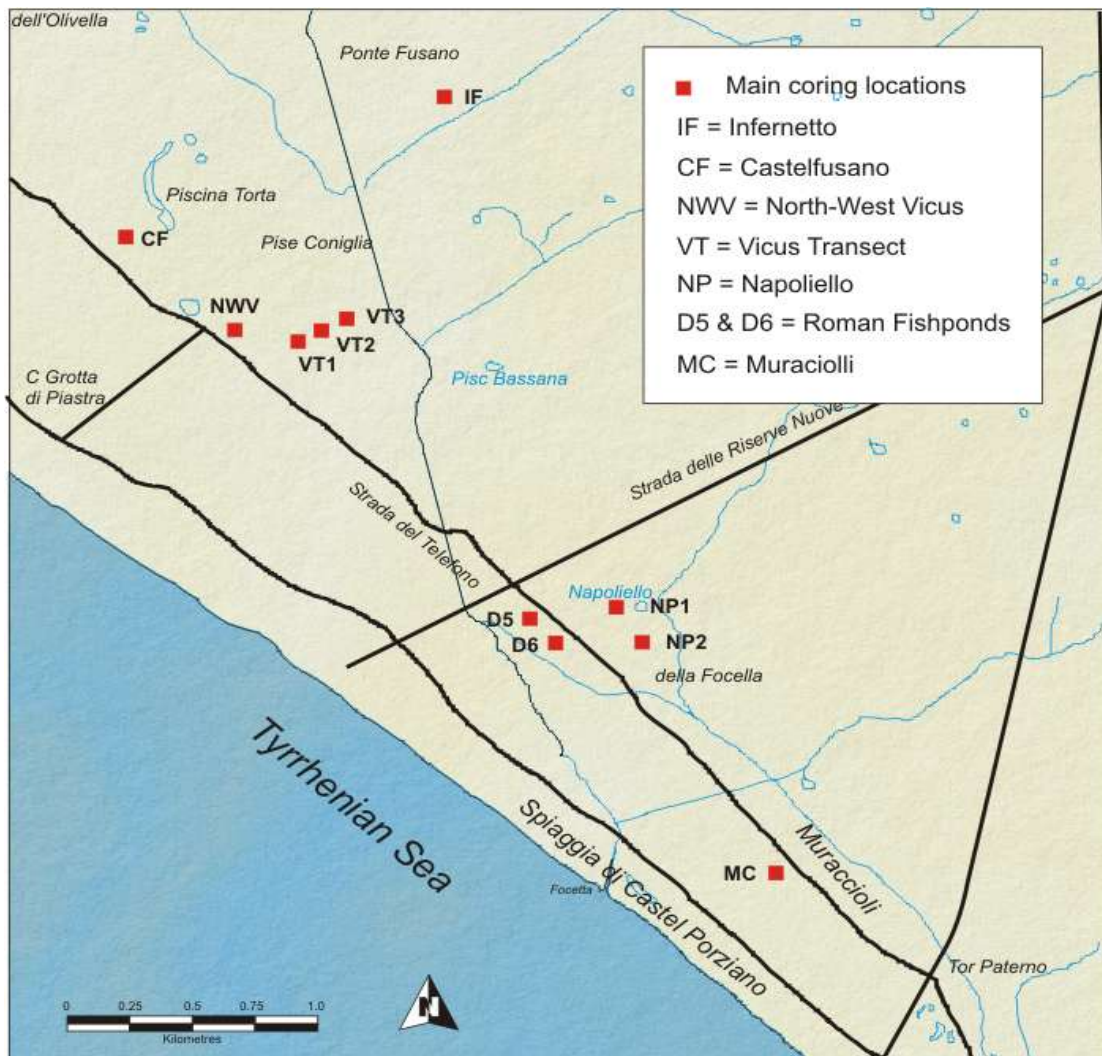


Figure 38 Coring locations for palaeoenvironmental work

4.3 Site descriptions, Core stratigraphy and Radiocarbon dating

This section describes the coring locations, the cores and the results of AMS ^{14}C dating of core material. The core diagrams and maps were drawn using Adobe Illustrator and age depth models drawn using Microsoft Excel.

4.3.1 D6: Fishpond 1 (Figure 39)

The D6/D5 area of dune slack is unusual in comparison to other dune slacks sampled within the Castelporziano Estate as this portion appears to have been enclosed for a specific use during the Roman period. The D6 structure was the subject of archaeological excavations during the period of research for this thesis as part of the larger AHRC project. It is thought that the rectangular enclosure, with dimensions of 60m by 80m, is a Roman fish pond (Claridge, pers. comm). It is

bounded on two sides by dune ridges. The current environment environment is a marshy ephemeral-perennial pond with a mixed sclerophyllous forest.

In April 2007, three long cores were taken from the centre and sides of this structure within the pond. In April 2008, a further three cores were taken from the centre. All cores from the central part of the dune slack showed the same stratigraphic sequence. Of the six cores taken, three were subsequently analysed, and are described below.



Figure 39 D6 in May 2008

Core 1: Taken at the centre of D6 (used in pilot studies in chapter 3, see page 67 for the core stratigraphy and description).

Core 3: Taken at the centre of D6 (figure 40). Identical in top 100 cm to core one, and transition at 175 cm was noted in core 14 at 172 cm. It was described in terms of stratigraphy ¹⁴C dating and general features.

Core 14: Taken in centre of D6 (figure 41) was treated the same way as core 3.

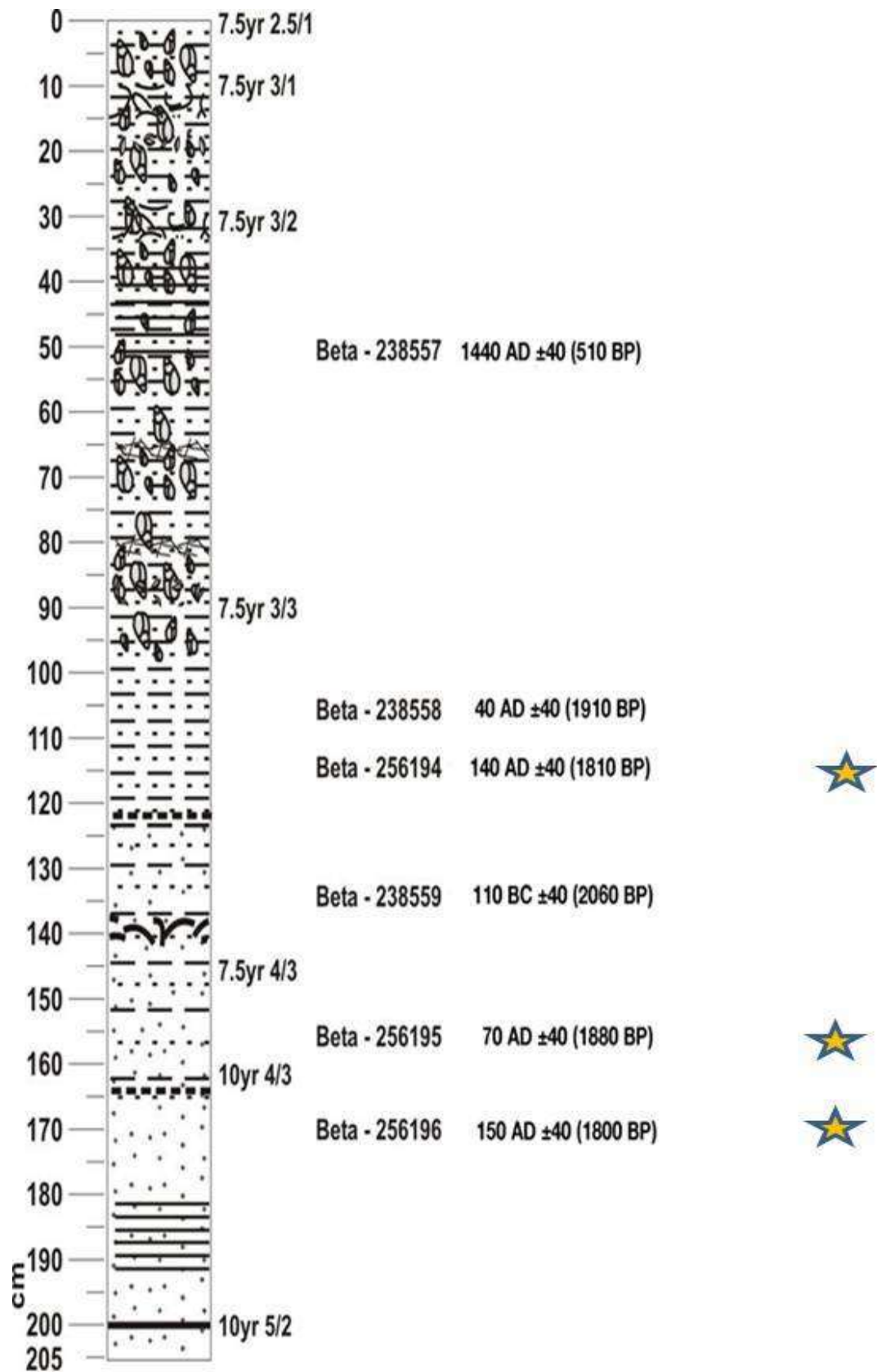


Figure 40 Core 3 Stratigraphy and description (Taken at the centre of D6)
Plant Macrofossil date

Number	Depth (cm)	Source material	Radiocarbon dates (BP) ± 40 BP	Bayesian calibrated dates (BP)	13C/12C Ratio/ o/oo
Beta – 238557	50	Peat	470	470	-27.2
Beta – 238558	105	Peat	1860	1900	-28.1
Beta – 256194	114	Seeds	1760	-	-27.9
Beta – 238559	134	Peat	2020	2050	-27.7
Beta – 256195	156	Wood	1840	-	-27.4
Beta – 256196	170	Wood	1770	-	-26.7

Table 7 Radiocarbon results Core 3 from D6

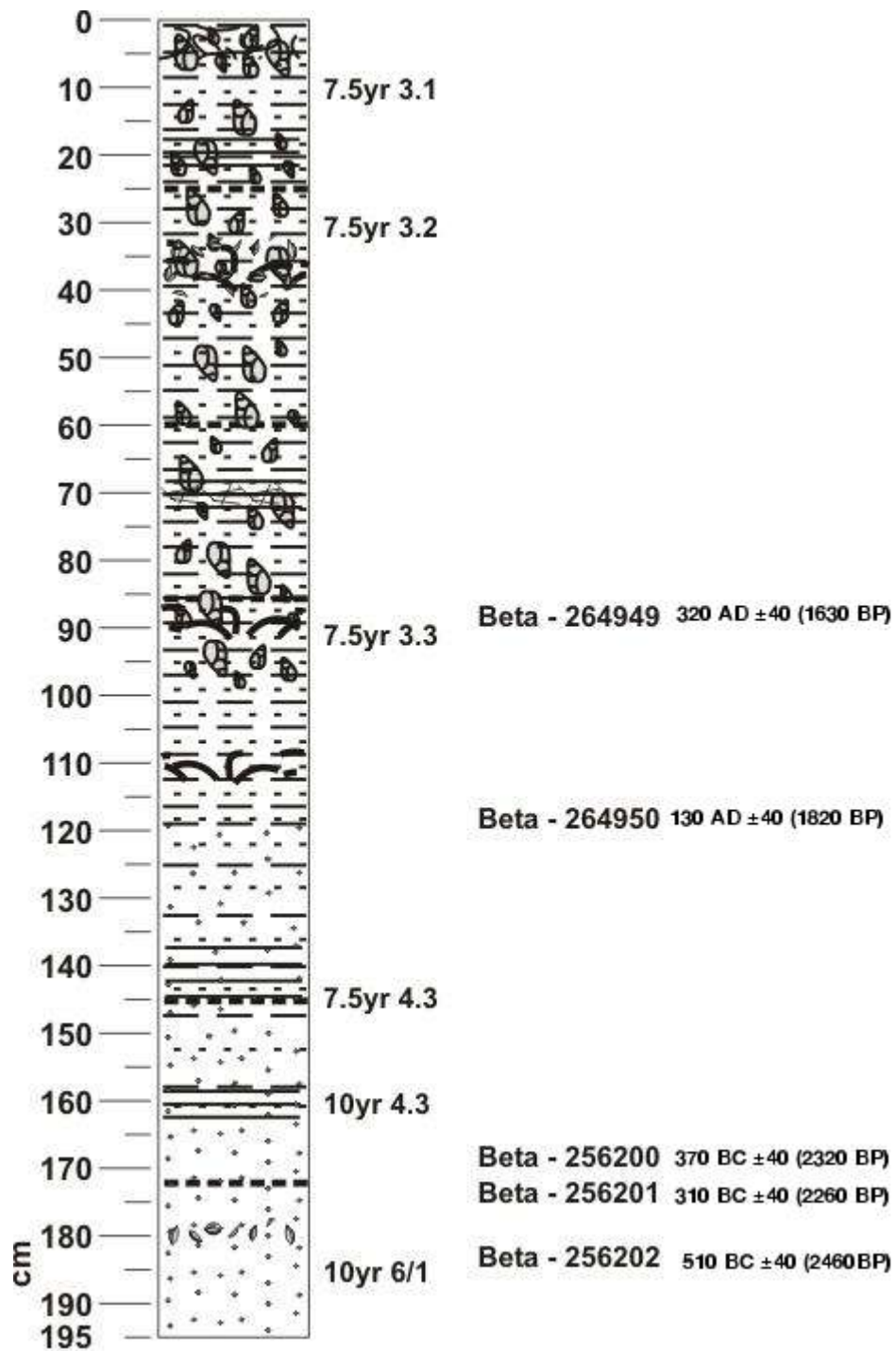


Figure 41 Core 14 Stratigraphy and description (Taken at the centre of D6)

Number	Depth (cm) (Core 14b)	Source material	Radiocarbon Dates (BP) ± 40 BP	Bayesian calibrated dates (BP)	13C/12C Ratio/ o/oo
Beta – 264949	88	Plant material	1580	-	-28.3
Beta – 264950	117	Plant material	1830	-	-24.2
Beta – 256194	167	Organic sediment	2370	-	-22.2
Beta – 238558	172	Organic sediment	2270	-	-24.3
Beta – 256194	182	Organic sediment	2390	-	-29.2

Table 8 Radiocarbon results core 14 from D6

4.3.2 D5: Fishpond 2 (Figure 42)

This is the other structure that the archaeological excavations proved to be a Roman fish pond, with dimensions of 60 m by 70 m, and more trapezoidal than D6. The current environment is a mixed sclerophyllous forest, and, unlike D6, it is completely dry today.

In April 2007 a 1.5m core was taken from the left of the centre of this structure using the percussion corer and a second 1.2 m long core was taken in April 2008, with the top 20 cm being dug out by spade.



Figure 42 D5 the “other” fish pond

Core 6: Taken near centre of structure (used in the pilot studies, see page 79 for stratigraphy and description).

Number	Depth (cm)	Source material	Radiocarbon dates (BP) ± 40 BP	Bayesian calibrated dates (BP)	13C/12C Ratio/o/oo
Beta - 238560	30	Organic sediment	Modern	Modern	-27.6
Beta - 238561	72	Peat	1910	1150	-27.9

Table 9 Radiocarbon results core 6 from D5

4.3.3 Pozzo Napoliello (Figure 43)

This area has an unknown archaeological record, although it is close to the original pre-Roman settlement. It is one of a series of elongated dune slacks further inland from the D5/D6/Muraccioli dune slack. The current environment is a mixed sclerophyllous forest, but unlike D6, the water table is close to, but not at the ground surface.

In April 2007 two 1.5 m cores were taken from the interdune depression using a percussion corer (core 7), with an additional core (core 8) taken close by, both of these were analysed for the palaeoenvironmental reconstruction. The cores are described in terms of stratigraphy, ¹⁴C dating and general features in figures 44 and 45.



Figure 43 Pozzo Napoliello

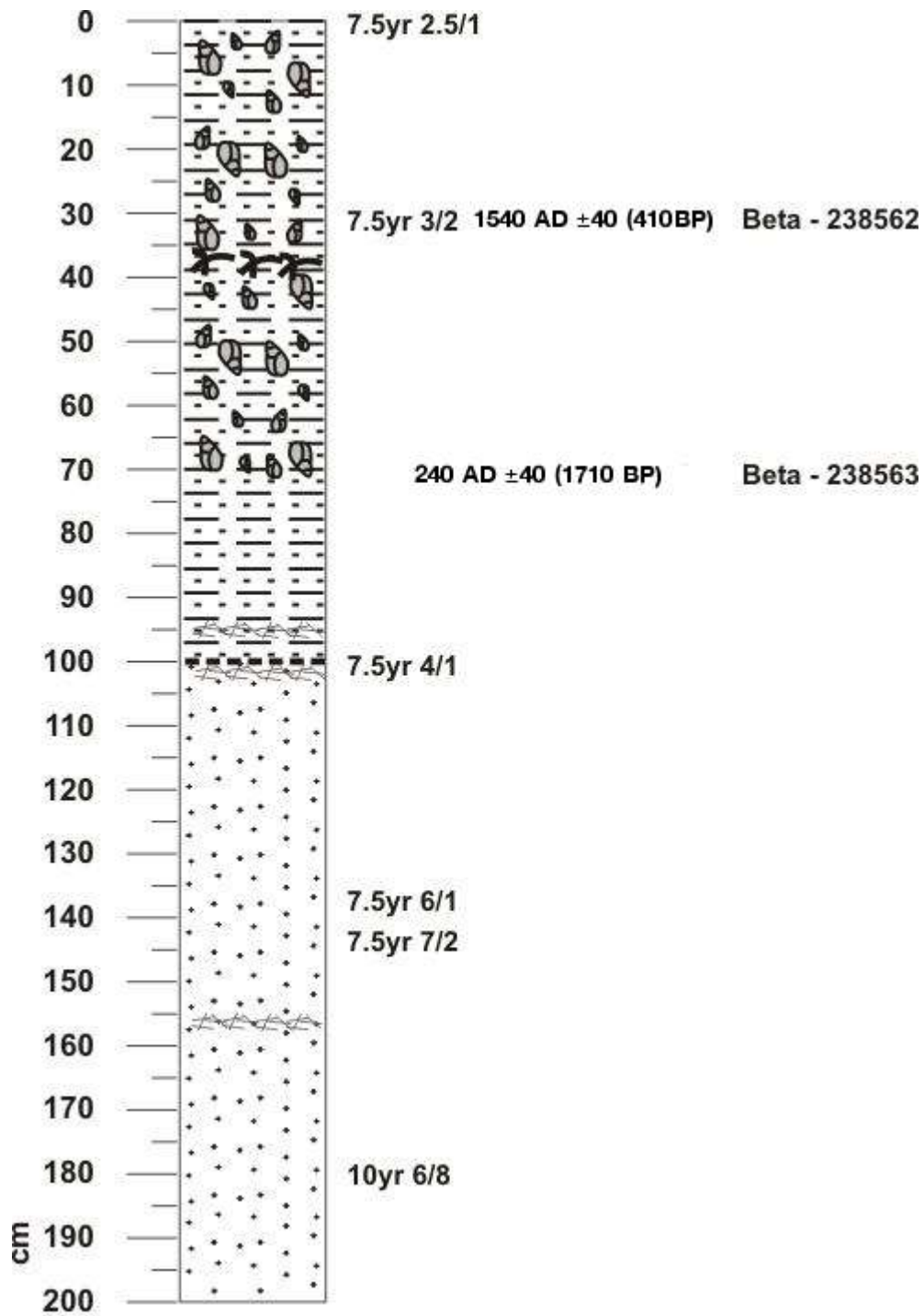


Figure 44 Core 7 Stratigraphy and description

Number	Depth (cm)	Source material	Radiocarbon dates (BP) ± 40 BP	Bayesian calibrated dates (BP)	13C/12C Ratio/ o/oo
Beta – 238562	30	Peat	370	-	-27.4
Beta - 238563	70	Peat	1680	-	-27.0

Table 10 Radiocarbon results from Core 7 at Pozzo Napoliello

Number	Depth (cm)	Source material	Radiocarbon dates (BP) ± 40 BP	Bayesian calibrated dates (BP)	13C/12C Ratio/ o/oo
Beta – 238562	83	Wood	Modern	-	-25.2
Beta - 238563	104	Organic sediment	1020	-	-27.4

Table 11 Radiocarbon results from Core 8 near Pozzo Napoliello

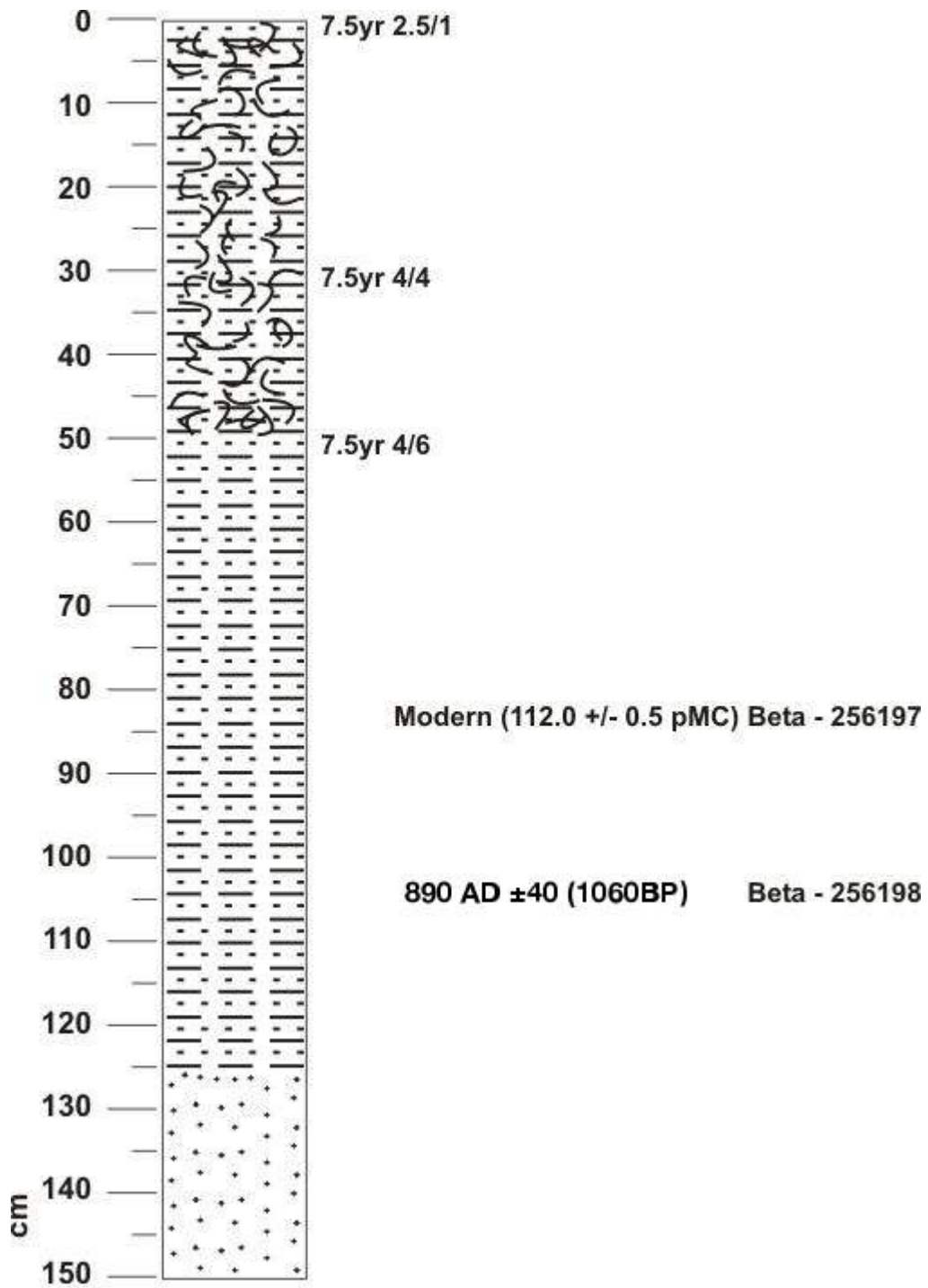


Figure 45 Core 8 Stratigraphy and description

4.3.4 Muraccioli (figure 46)

The Muraccioli area lies along the same line of dune slacks as D5 and D6. The current vegetation is mostly macchia in association with Holm oak, although some hygrophilous vegetation is noticeable.



Figure 46 Muraccioli coring site

In April 2007 two cores were taken from Muraccili (cores 9 and 10) using a percussion corer, of these, core 9 was used for the palaeoenvironmental reconstruction, figure 47 shows its stratigraphy and the ^{14}C dating results.

Number	Depth (cm)	Source Material	Radiocarbon dates (BP) \pm 40 BP	Bayesian calibrated dates (BP)
Beta – 238564	30	Peat	340	-
Beta - 238565	100	Peat	1420	-

Table 12 Radiocarbon results Core 9 from Muraciolli

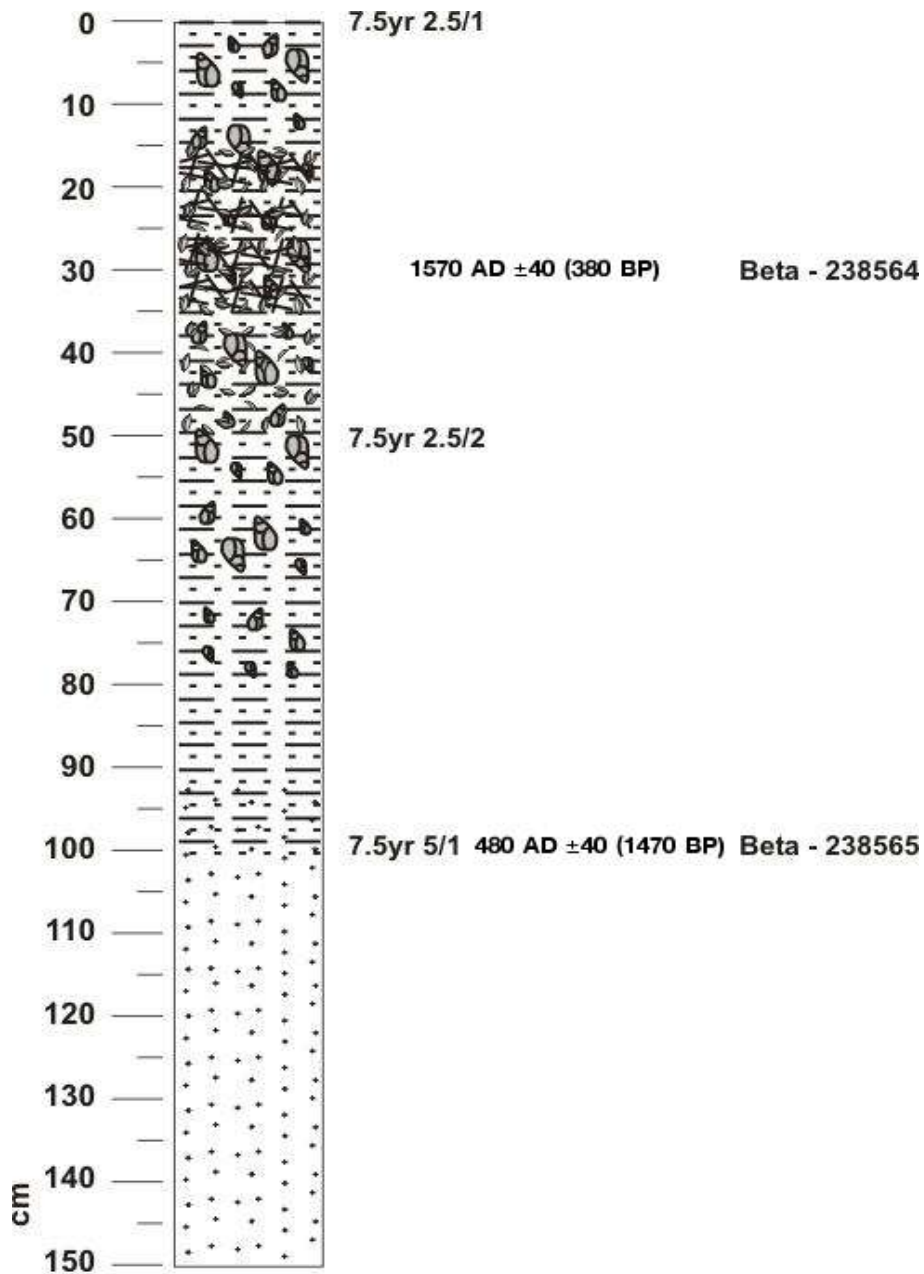


Figure 47 Core 9 Stratigraphy and description

4.3.5 Castelfusano (figure 48)

This area was chosen for comparison with the results from the Castelporziano Estate, and was marked on the 1:25 000 topographic map as an ephemeral pond ('Piscina Torta') within the dunes ridges of the Castelfusano Estate. The current vegetation is a mix of *Pinus pinaster* (not planted), mixed sclerophyllous forest, wet woodland, and grasses.

In April 2008 a 70 cm core was taken in the Piscina Torta depression. The core was of organic-rich sand, with no evidence of any molluscs. The material was not ^{14}C dated but is described in terms of stratigraphy and general features (figure 49).



Figure 48 Castelfusano coring site

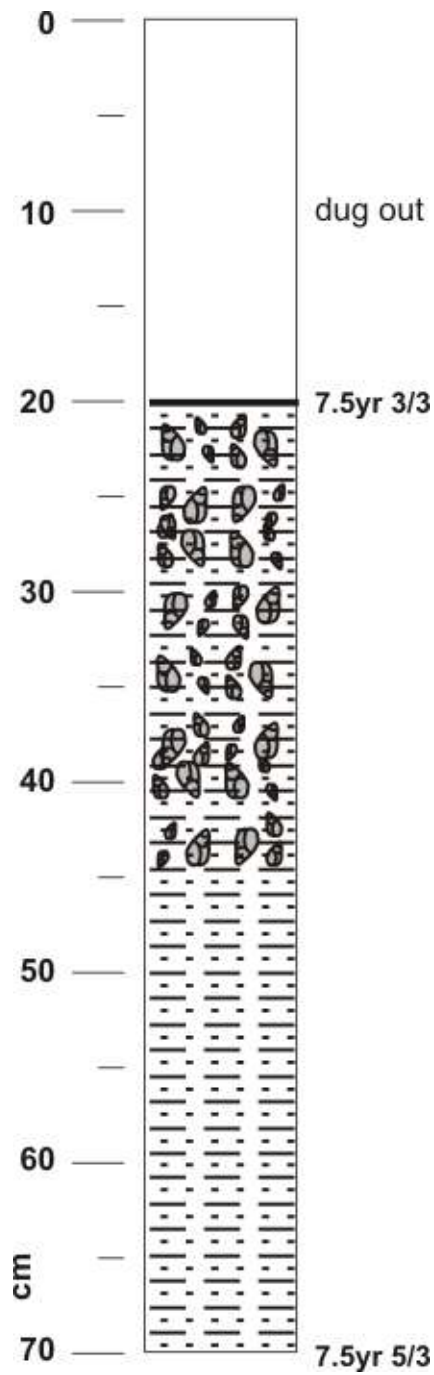


Figure 49 Core 16 Stratigraphy and description
 (Natural depression 'Piscina Torta' within wooded area of Castelfusano)

4.3.7 Infernetto (figure 50)

This area literally translates as “little hell” was chosen to compare with the results within the Castelporziano estate, and increase the regional picture of the study. The area is believed to may have been associated with a small harbour, where the animals were unloaded, near a swamp (Archaeoweb 2006).

The current vegetation is poor grasses, and marshy. In April 2008 a 70 cm core was taken extracted from the central part of this area. This core was ¹⁴C dated, and described in terms of stratigraphy and general features (figure 51).



Figure 50 Infernetto coring site

Number	Depth (cm)	Source material	Radiocarbon dates (BP) ± 40 BP	Bayesian calibrated dates (BP)	13C/12C Ratio/ o/oo
Beta – 256199	52	Peat	2490	-	-24.8

Table 13 Radiocarbon results Core 17 from Infernetto

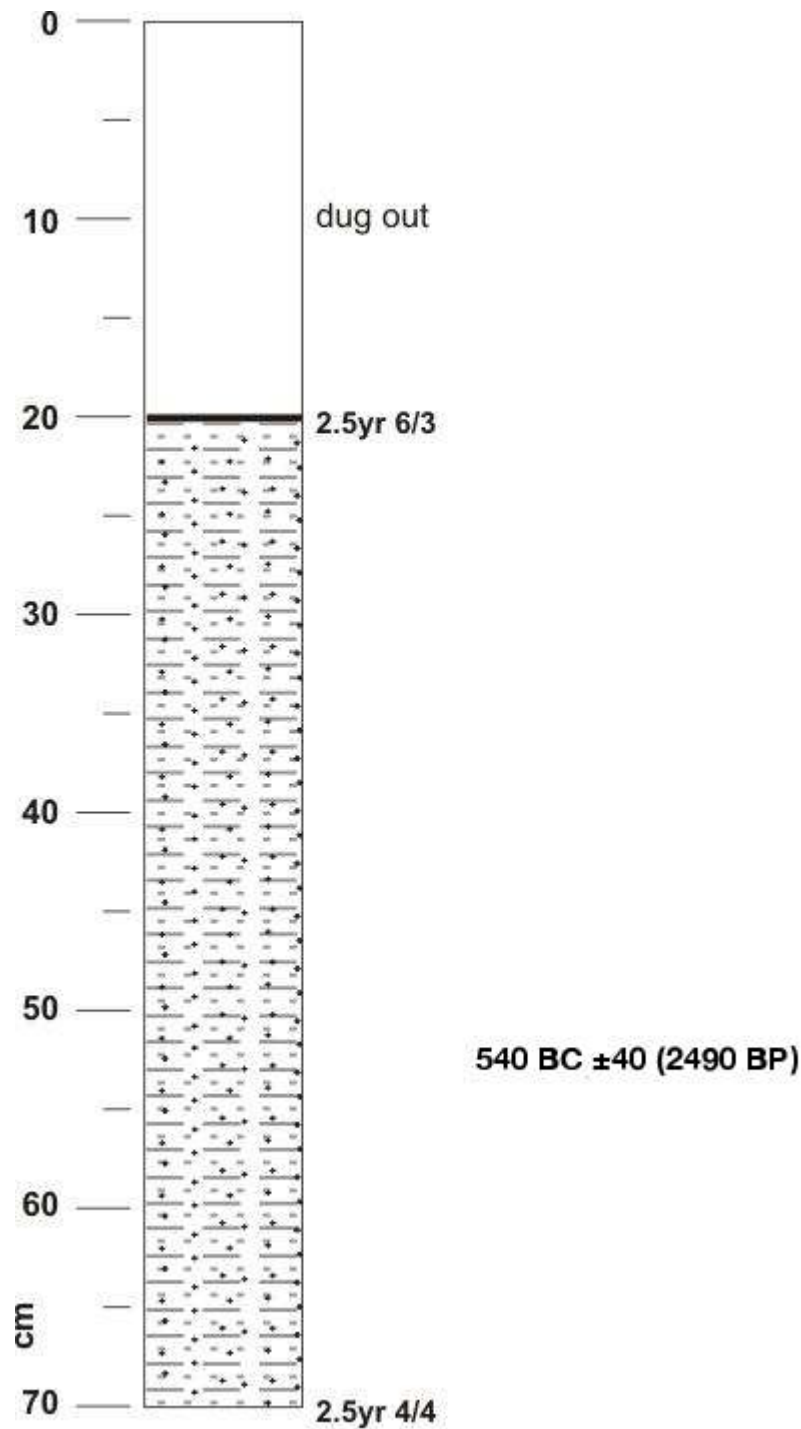


Figure 51 Stratigraphy and description Core 17

4.4. Discussion of radiocarbon dating results

Studies of Holocene sediments often rely on radiocarbon dating to provide a time frame for their deposition. Both absolute ages and rates of accumulation are relevant for the interpretation of minerogenic or biogenic sequences and their comparison with independently dated records. Ages and accumulation rates are described by a time-

depth relation, which is usually constructed in two successive steps (Killian *et al.* 2000). First, a series of ^{14}C dates is calibrated (van der Plicht 1993), i.e. converted to calendar ages individually with the ^{14}C calibration curve. Then a function is calculated to describe ages throughout the sequence. The resulting time-depth relations for sediments, including bogs, are often nonlinear (Bennett 1994; Clymo 1984; Middeldorp 1982). This may result either from real accumulation rate changes, from compaction, or from inaccuracies in the dating and curve fitting procedures (Killian *et al.* 2000). There are also cases where reported synchronicity between archives could have been caused by age-model errors, mistaken interpretations of proxy data, or even by wishful matching (e.g., tuning of records, subjectively selecting age-models, neglecting non-responsive sites, or drawing suggestive event-connecting lines: Bond *et al.* 2001; Neff *et al.* 2001; cf. Baillie, 1991; Wunsch, 2006).

Most of the cores for this thesis were dated from a bulk sample, rather than using plant macrofossils or wood as these were largely absent from the deeper parts of some of the cores. Contamination of samples, either in the laboratory, or by intruding roots or as a result of the uptake of older carbon (reservoir effect: Stuiver and Pollach 1977) are assumed to be absent. There is some evidence that bulk peat samples may contain fractions differing by centuries or millennia in age (Olsson 1986; Killian *et al.* 1995; Shore *et al.* 1995). Careful sampling and pre-treatment can eliminate some problems. Interpretation of ^{14}C dates is also made more difficult by the nonlinearity of the ^{14}C tree ring curve. Past atmospheric ^{14}C concentrations fluctuated mainly due to varying solar activity (Killian *et al.* 2000), the resulting century-scale atmospheric ^{14}C 'age' variations, wiggles, transform single gauss-distributed BP ages into complex calendar age probability distributions. These ages are generally simplified to support a fitted curve (Bennett 1994), but errors in individual data points and the time-depth relation as such are difficult to evaluate.

Four major sources of ^{14}C variation for mire deposits, such as those at Castelporziano, compared to tree rings were found by Killian *et al.* (2000), which are (1) dating error, due to sample composition. This includes a reservoir effect demonstrated for many bulk peat samples; (2) hiatuses, causing a sudden change in peat ^{14}C age; (3) changing accumulation rates, apparent from a break in the slope of the peat ^{14}C ages; (4) sampling error. The application of one single curve to complex mire sequences however, involves the highly unlikely assumption that both (past) productivity and decay are constant from top to bottom, i.e. "vegetation is unchanged" (Clymo 1984, p. 615). This assumption ignores the systematic changes in

stratigraphy as much as the impact of species on productivity and decay (Kilian *et al.* 2000). The stratigraphic changes are not explained by selective decay changing the macrofossil composition (Clymo 1984), but rather by environmental changes expressed as successive species producing different net accumulation rates.

Tornqvist *et al.* (1992) note that it has long been recognized that the use of macrofossils for ^{14}C dating can considerably improve results, since they are relatively unlikely to record disturbances, as they potentially avoid problems associated with dating mixtures of contemporaneous and older organic matter in bulk sediment. When both techniques are applied to the same stratigraphic record, ages for AMS-dated plant macrofossils are often found to be hundreds or even thousands of years younger than ages for bulk sediment from the same core depth (e.g. Cwynar and Watts 1989; Tornqvist *et al.* 1992; Bigelow and Edwards 2001).

Why the “young dates” in Cores 3 and 8?

A cyperaceous sample of *Eleocharis palustris* was selected for ^{14}C dating from core 3, to tie down an event noted in the palaeo record. *E. palustris* is an opportunistic species, which prefers dry hummocks, but is also able to resist prolonged wetting because of its aerenchymatic roots (Barber 1981). During growth, *Eleocharis*, transports carbon to its stems and roots, thus may explain apparently young ^{14}C age of the sample from 114 cm within Core 3. Natural contaminants to wood are those introduced in the post-depositional environment like humic and fulvic acids in soil. These are acids produced by the microbial degradation of plant and animal tissues. Humic and fulvic acids may attach to surfaces of wood and exchange carbon in a process called adsorption. This occurrence can make the sample's radiocarbon age too young or too old depending on the age of the organism that produced the organic acids. Penetration of roots into the wood samples also introduces modern carbon into them. These result from various kinds of post-depositional processes, especially bio-turbation and vertical cracks in the sediment. All of which may have led to the apparently young dates at 156 and 170 cm in core 3 and 83 cm in core 8. Another source of error could be due to calcium carbonate within the sediment on the wood samples were taken. However, no carbonate minerals or silica were visible within or clinging to the wood when the sample was collected, stored, extracted by Beta Analytic and then dated. In any case, such minerals would have been removed from the wood, even from within it, by the demineralising treatment carried out by Beta Analytic.

4.5 Age/Depth Models

Net carbon accumulation or loss from peat soils reflects the balance between plant productivity at the surface and decomposition throughout the peat profile. This balance is affected by environmental parameters (water table depth, oxygen availability, pH, and soil temperature) that moderate biological processes such as productivity, root dynamics, and decomposition. Given the same environmental conditions, individual peatland litters differ in their susceptibility to decay, reflecting differences in organic matter composition and nutrient content (Bauer 2002).

No age-depth models were made for cores 6 or core 17, this was because they only have a single dated point or contains a modern date, which if used to translate core depths would result in false estimates of calendar ages, resulting in line-graphs, which falsely suggest that the timing of changes is known exactly.

4.5.1 Cores 3 & 14: D6 Fish Pond

The results of the radiocarbon dating show different accumulation rates with depth in core 3 (figure 52), it is clear that the results are not linear, with the fastest accumulation rates occurring in the period 500 to 1800 Cal yr BP.

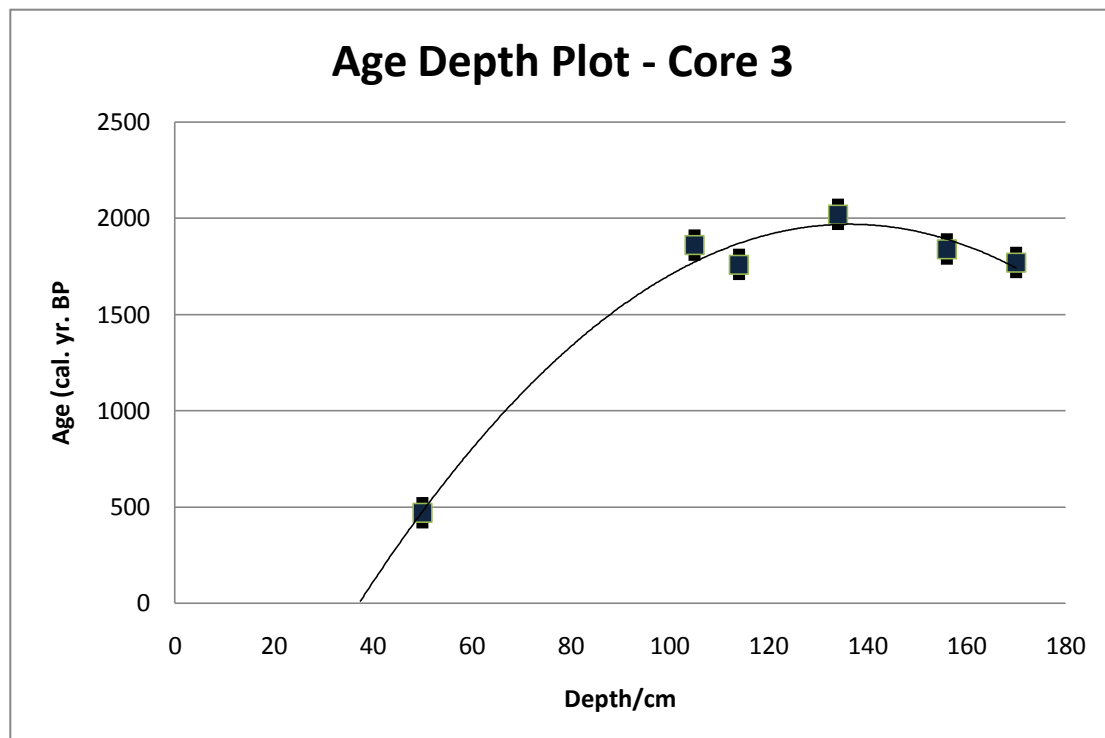


Figure 52 Age depth model for Core 3

The correlation between cores 3 and 14 established stratigraphically based on a distinctive transition from minerogenic silts to organic rich material at 172 cm depth in core 3 and 175 cm depth in Core 14 (figure 53). A composite profile incorporating dates from each core improves the age depth model. The age profiles raise issues of both accumulation rate and compaction. The dates for finely-divided organic carbon are (1) consistent with the stratigraphy (2) internally consistent and (3) show increasing age with depth.

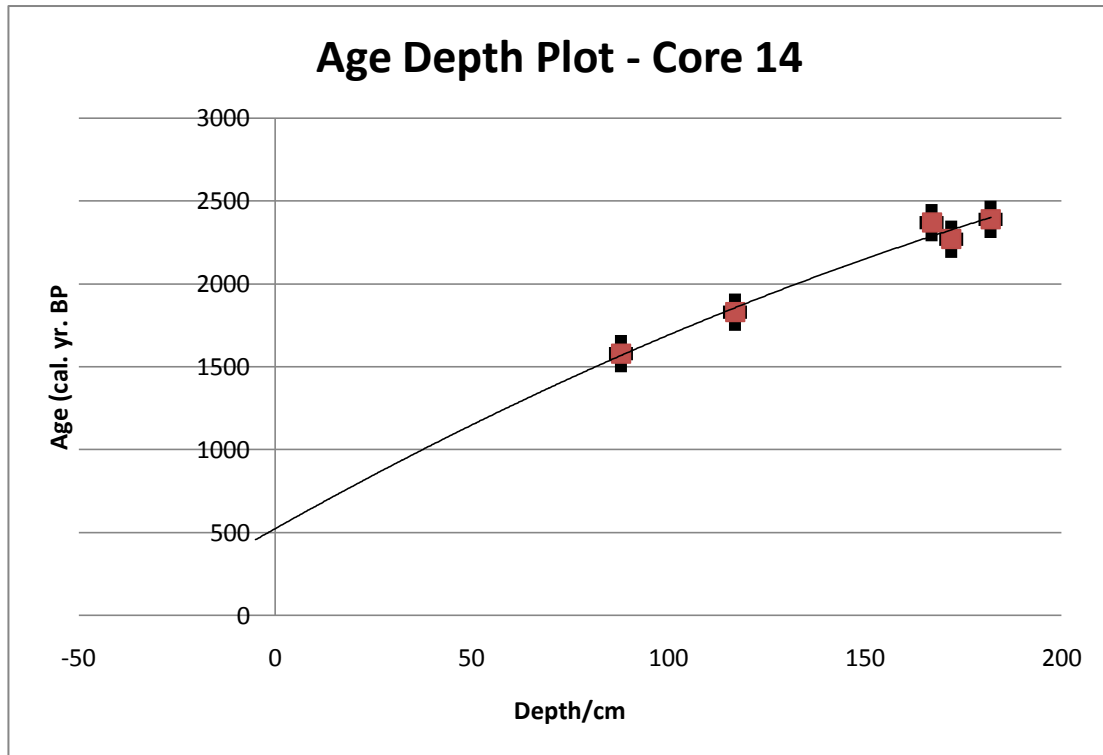


Figure 53 Age depth model for Core 14 (Based on finely divided organic carbon)

The accumulation rate of raised peat bogs throughout the Holocene has been found to be relatively constant (Clymo 1991; Barber *et al.* 1994; Kilian *et al.* 2000), suggesting that for the majority of bog systems the best age/depth model will be obtained from a linear or near-linear polynomial trendline plotted through the calibrated age ranges against depth.

For both cores 3 and 14, the age depth model uses the corrected and calibrated ages to produce a second-order polynomial trendline ($R^2 = 0.9842$ for core 3, and 0.9794 for core 14).

For core 3: Calibrated age (years BP) = $-0.2004x^2 + 54.64x$ (depth (cm)) - 1755.2

For core 14: Calibrated age (years BP) = $0.0166x^2 + 13.34x + 523.48$

4.5.2 Core 7 Pozzo Napoliello and Core 9 Muraccioli

An age/depth model can be used to estimate the age of undated material extracted at a known depth in the core. For cores 7 and 9 it was not done because only two dates were known for each core, and the lower parts of both cores were predominantly sandy, thus the magnitude of the error in the estimated age of the extracted material would be prone to greater error. No other age/depth models were created with one of the two dates being modern in the case of cores 6 and 8 as these would be subject to substantial uncertainty.

4.6 Methodologies for palaeoenvironmental proxies

The summary methodologies for most proxies are given in chapter 3, with more detailed procedures listed in the appendix 2. As the D6 core material (Cores 1, 3 and 14) was known to have good preservation from the pilot studies, most proxies were sampled at 1 cm intervals, unless otherwise stated. Where the preservation of the various proxies within some of the other cores were unknown, they were initially sampled at 5 cm intervals. As noted previously all plotting of diagrams were plotted using C2 from imported Excel files or Excel plots, unless stated otherwise.

4.7 Results

4.7.1 Loss on Ignition (LOI)

Core 3/D6

This core (figure 55) had the highest organic matter content of any of the cores, particularly during the Roman period. The results are presented as % organic carbon not organic matter as they were converted using 'Von Bemmelen' factor of 1.724 as devised by Broadbent (1953). The results show a peak during the Roman period (based on age depth model for Core 3) at 136 cm depth, which is followed by an increase in the macrocharcoal influx (CHAR). By 133 cm, the organic matter is declining, but the CHAR is beginning to increase. The effect of fire on the total soil organic matter (OM) content is highly variable, and depends on several factors including fire type (canopy or above ground, underground fires), intensity, and even

slope. These effects may range from the almost total destruction of the soil OM to increases that may reach 30% in the surface layers as a consequence of external inputs, mainly from dry leaves and partially burnt plant materials from fires affecting the tree canopy (Chandler *et al.*, 1983). Soon after a fire, a sharp decrease in OM content may be observed in some soils, this could be accelerated by changes in soil physico-chemical properties (i.e., water repellency; Savage 1974 and DeBano 2000) and the temporal removal of the herbaceous layer, with effective erosion-controlling below ground root structures. This increase in soil erodibility may lead to rapid loss of the upper cm of soil (Díaz-Fierros *et al.* 1987; McNabb and Swanson 1990; Andreu *et al.* 1996), but this may not be true of the local conditions at Castelporziano.

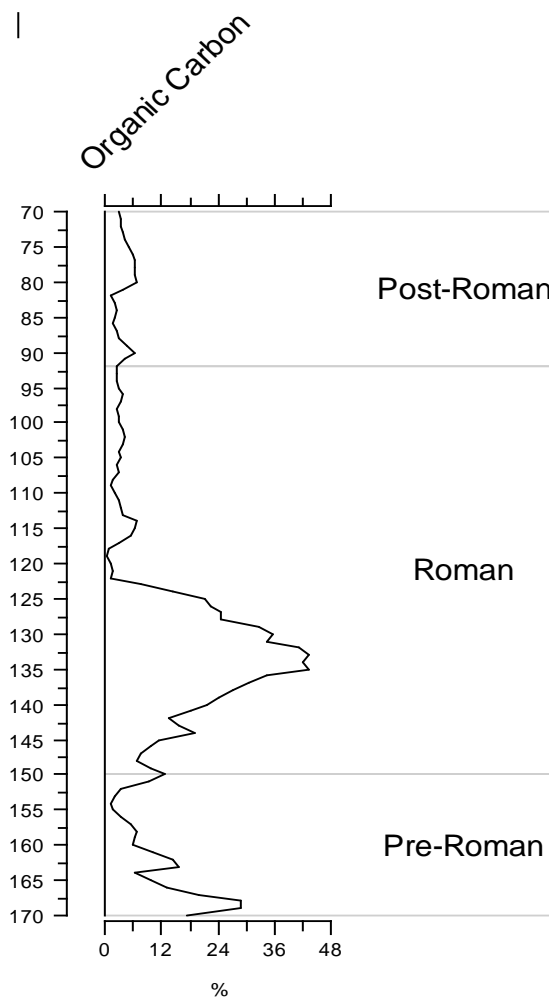


Figure 54 Loss on Ignition Core 3 (based on age depth model for Core 3)

Core 4/near Vicus Augustanus

This core was one of a series taken in dry interdune depressions north of the Vicus Augustanus. Core 4 (figure 56) had a high proportion of sand and low organic matter.

The highest organic matter was found in the top 10 cm and was 1.5%, this was similar to that found at D5 and Infernetto. When analysed, it was found not to contain any macroremains.

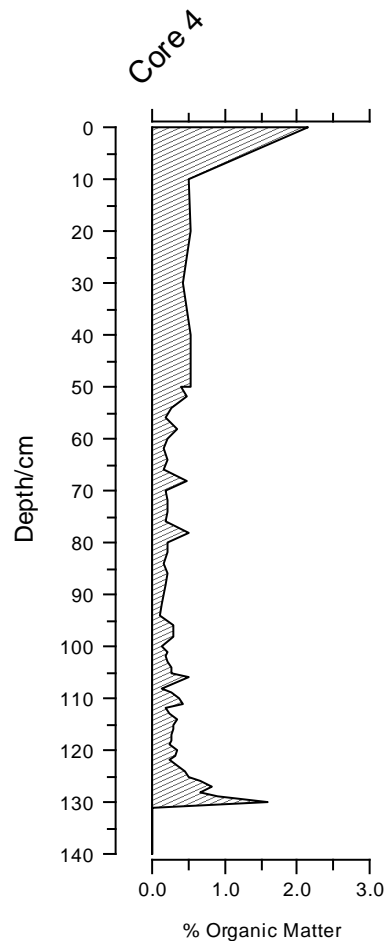


Figure 55 Loss on Ignition results Core 4

Pozzo Napoliello/Cores 7 and 8

For core 7 (figure 57) the organic matter percentages reflect the composition of the core, i.e. the highest organic matter in the peat (85-0 cm), whereas the low organic matter values were found in the sandy part (85-175 cm). Core 8 (figure 56) on the other hand has higher organic matter, which may be reflecting the presence of a calcic horizon from 25 to 125 cm. The LOI profiles are similar (Figure 56).

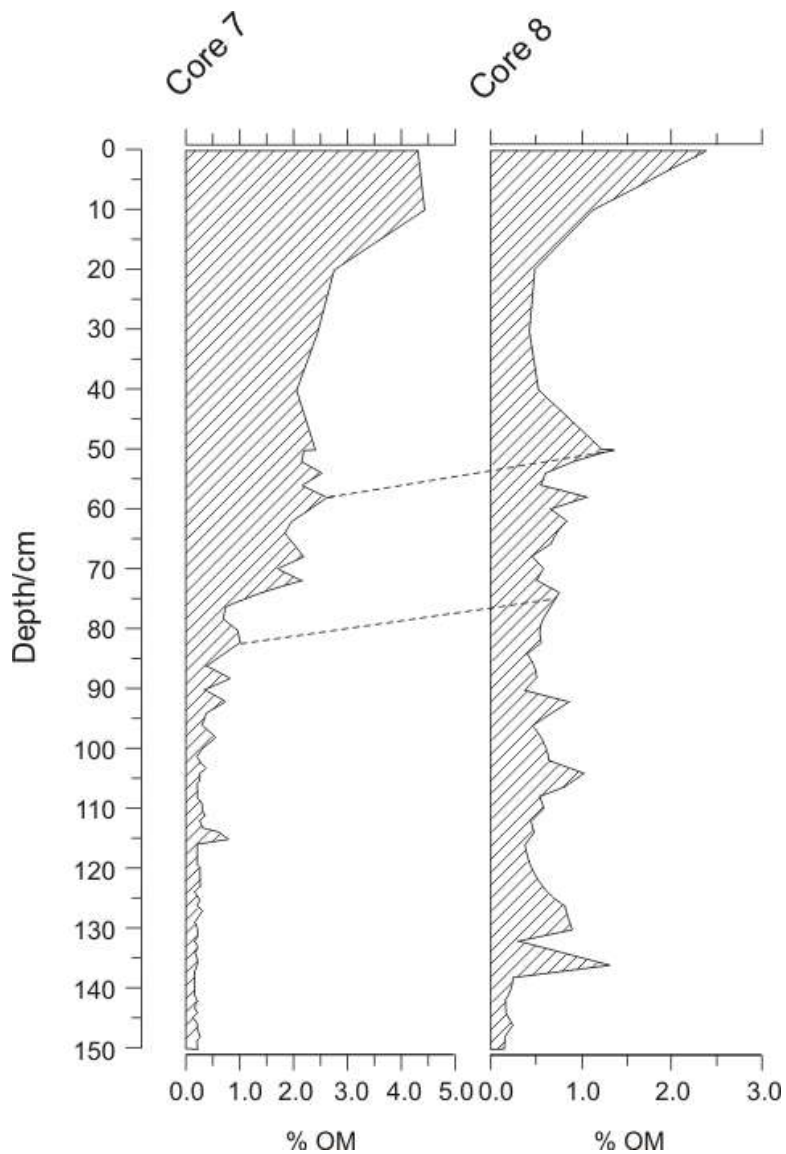


Figure 56 Loss on Ignition results Cores 7 and 8

Core 9/Muraccioli

For core 9, the organic matter was highest in the upper 92 cm of the core (figure 58) and only the top 80 cm preserved any macrofossil or other remains.

Core 16/Castelfusano

This core, like those taken near the Vicus Augustanus and at D5 showed low levels of organic matter (figure 59); the core contained a very limited number of plant macrofossils. The core was therefore deemed unsuitable for a detailed palaeoenvironmental reconstruction. The top 20 cm were dug out on site, thus the modern organic matter could not be measured.

Core 17/Infernetto

This core also showed comparatively low levels of organic matter (figure 59), on average having 0.75%. The low organic matter and the absence of macroremains meant that, unfortunately, no palaeoenvironmental reconstruction was possible. Like core 16, the top 20 cm were dug out on site, thus the modern organic matter could not be measured.

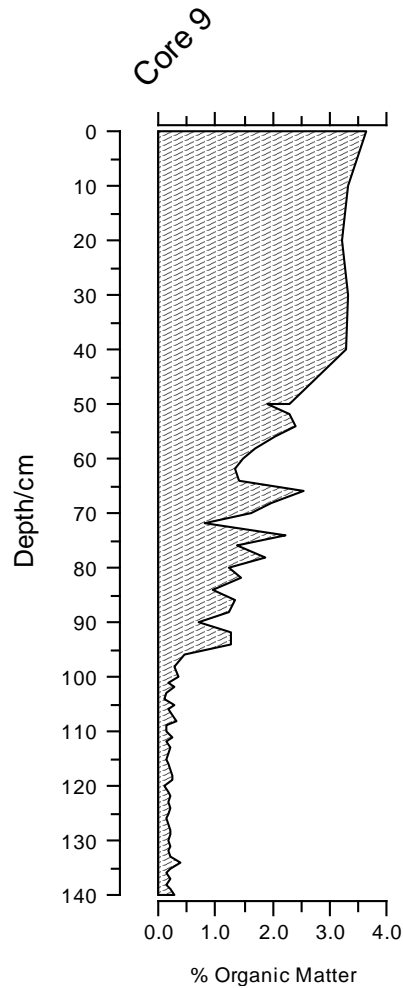


Figure 57 Loss on Ignition Results core 9

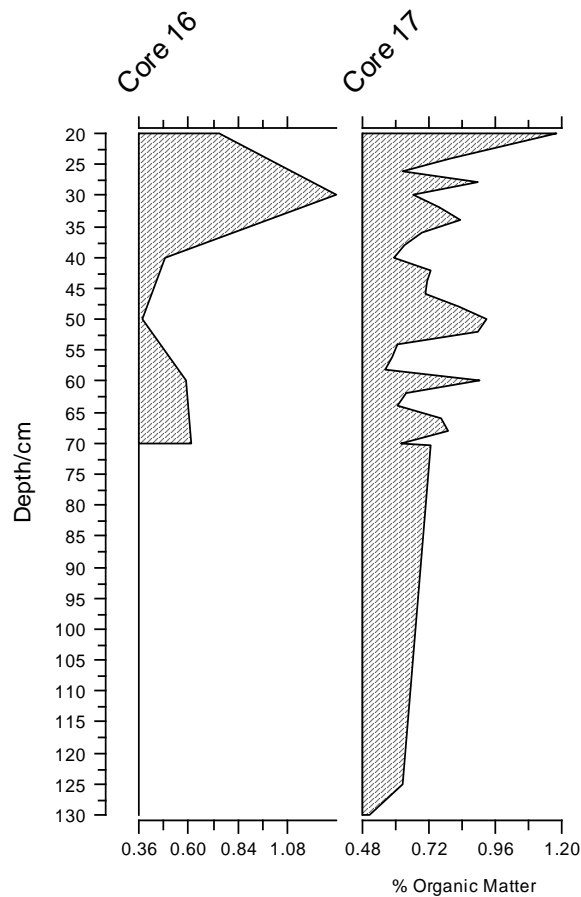


Figure 58 Loss on Ignition Results cores 16 and 17
(N.B. Differences in scale due to different lengths of core)

Discussion of Organic Matter content of Cores

The organic matter concentrations as calculated from loss on ignition show considerable variation both within and between cores. Mackereth (1966) suggested that LOI does not give reasonable estimates of organic carbon where those values are under 10%, however in some cases the low organic matter values appear correct due to the high minerogenic content of the cores that was noted when describing the cores and preparing the samples for LOI. Most of the cores examined showed a decline in organic matter with decreasing depth. One exception to this trend was provided by core 3, which may be related to the high sedimentation rate noted in the age/depth model. Some of the areas cored (e.g. Infernetto) have been subject the draining of marshes, that also occurred at the Castelporziano estate, from the 1880s. It is unclear whether this may have led to decomposition and compaction of the organic matter within the cores. In well-drained floodplains, organic matter, even in isolated flood basins, is more likely to become oxidised, resulting in little organic matter preservation (Aqrawi and Evans 1994).

4.6.2 Macrocharcoal

Method development

One key issue in fire-history studies has been the lack of a standardized methodology, and thus pilot studies conducted as part of this thesis (chapter 3) highlighted the potential issues arising as a result of the minerogenic nature of the cores, particularly with regard to the presence of haematite. Although this may have been removed using flotation or magnetic separation on hindsight, none of the methodologies examined or found at the literature at the time acknowledged this. Therefore, a second series of pilot studies was undertaken in order to optimise the charcoal methodology, and thus to produce a standard method for the analysis of charcoal from dune slacks. The methods tested included one for microcharcoal, and three for macrocharcoal, therefore potentially interrogating the local and regional fire signals.

Method 1: Pollen slides

This method, applied by Vanniery *et al.* (2008) and others, was used to establish the regional charcoal signal, with the microcharcoal counted alongside pollen. Preservation was a major issue on the pollen slides, as will be discussed later in the chapter. Unfortunately, the micro charcoal was scarce on the pollen slides, which may indicate there were no fires regionally, whereas the pilot studies had shown the presence of charcoal, in the form of macrocharcoal. As the regional fire record could not be established, the other methods tested were all for macrocharcoal, to establish local fire history at each site.

Method 2: Macroscopic Sieving

This was the original method used in the pilot studies and taken from Whitlock and Larsen (2001) and provided a simple way to measure the presence or absence of macrocharcoal. However, as noted in the pilot studies, the biggest problem was the presence of haematite particles, which may artificially increase the particles counted. Based on Whitlock and Larsen criteria for lakes, >50 particles cm^3 represented a fire event and a non-fire event resulted in substantially fewer particles (2001, p11). The results from this methodology were converted to a charcoal influx, see below.

Method 3: Chemical Digestions and bleaching

This method by Rhodes (1998) has been highly cited. It uses a series of extractions to remove excess material; however, this did not remove all the “excess” material

found in the dune slacks such as quartz grains, and other minerals such as olivine and haematite. In addition, the number of steps involving sieving material may have resulted in the smaller macrocharcoal fragments being removed. When examined under the microscope, the prepared sample also still contained a substantial portion of haematite, and the other minerals noted above, therefore a count was not made using this method, as this did not eliminate the problems noted in the pilot studies, and could be done quicker using method 2 without the need for the digestions and bleaching.

Method 4: Image Analysis

This method by Stevenson and Haberle (2005), is an adaption of the third method, which although simple to use and quicker than Rhodes' method, it relies on the use of Image-J to count the particles, which is a public domain open source software, Java-based image processing program developed at the National Institutes of Health. It has been used to count cells, as it can facilitate manual counting with the "Point Picker" or "Cell counter" plug-in (Collins 2006). The count using Image-J was not as straightforward as the authors claimed. This was because of the software itself, as at first it was hard to adjust so it only counted particles most likely to be macrocharcoal over counting any particles present, as it counts based on pixels and shade. This method was tested on for cores 8, 14 and 17 (from Napoliello, D6 and Infernetto respectively). Core 14 was used as it was a parallel core to core 3, which was used for the majority of the palaeoenvironmental reconstruction. The final results were based on trying to limit other particles counted, but some erroneous particles may still have been counted, thus the number counted per cm^3 appeared to be higher than when using method 2. Due to the unreliability in using Image-J, it was not carried on for other core material.

However, of the four methods tested, only methods 2 and 4 provided useful results. Method 2 proved to give the best overall results, in terms of eliminating other minerals such as haematite, and ease of use. Whereas method 4 was used for the upper 50 cm for three other cores, but it is unclear how representative the results actually are of the levels of macrocharcoal. Therefore, for cores 7 and 9, from Pozzo Napoliello and Muraccioli, respectively, method 2 was used to ascertain the macrocharcoal count, thus give a representation of the local fire history.

Results

Macrocharcoal counts for each sample were converted to macroscopic charcoal concentrations (CHAC) and then a signal analysis based on the decomposition

method initially described by Long *et al.* (1998) and by use of the software CHARSTER v.0.8.3 (<http://geography.uoregon.edu/gavin/software.html>). The principal steps of the signal decomposition are as follows: From the age–depth model for each core, the macroscopic charcoal raw data were re-sampled to interpolate them with respect to a constant time interval. Then charcoal values were divided by the deposition time of the binned interval to obtain charcoal influx or charcoal accumulation rate (CHAR; #/cm²/yr). The CHAR data was then separated into two components (as per Long *et al.* 1998): a slowly varying trend often referred to as background charcoal (BCHAR), which represents gradual variations in regional fire activity and/or charcoal production per fire and peak charcoal (PCHAR), the high-frequency variability representing local fire episodes (i.e., one or more fires occurring within the time span of the bin) and noise. To calculate the BCHAR the CHARSTER software (Gavin 2006) was employed and determined with a 500-year lowess smoother, robust to outliers. This smoothing technique was used to distinguish between peak (i.e. the residuals) and background (i.e. values below the smoothing function) influx values. This analysis is used to identify an intermediate range of charcoal influx between background and the largest peak values (Clark *et al.* 1996; Lynch *et al.* 2002), and thus to allow a more conservative identification of past fire events. The smoothed background is then subtracted from the raw data to derive residual peaks. The PCHAR was determined by subtracting BCHAR from CHAR. It should be noted that the possibility always exists that changes in sedimentation rate alone, and not charcoal production and deposition, could generate patterns of variation in CHAR time series (Clark *et al.* 1996).

D6/Core 3

Max concentration: 647 pieces/cm³

Min concentration: 51.5 pieces/cm³

Max sedimentation rate: 0.2 cm/year or: 5 year/cm

Min sedimentation rate: 0.04 cm/year or 26 year/cm

Max CHAR: 129.4 pieces/cm²/year

Min CHAR: 4.14 pieces/cm²/year

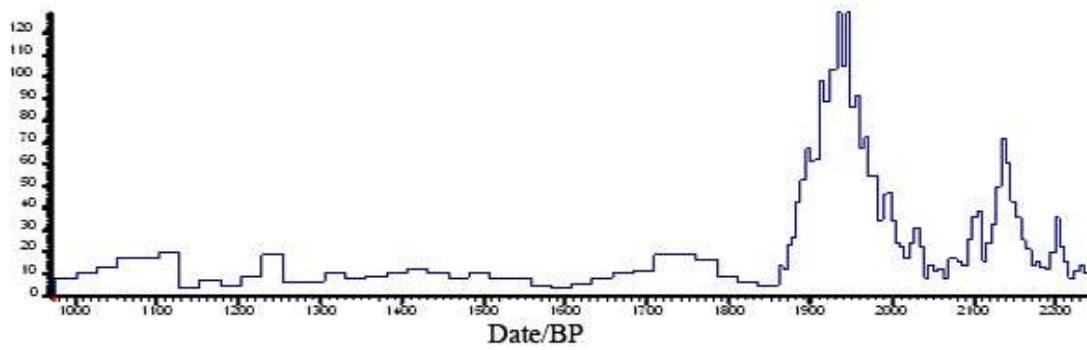


Figure 59 CHAR for Core 3

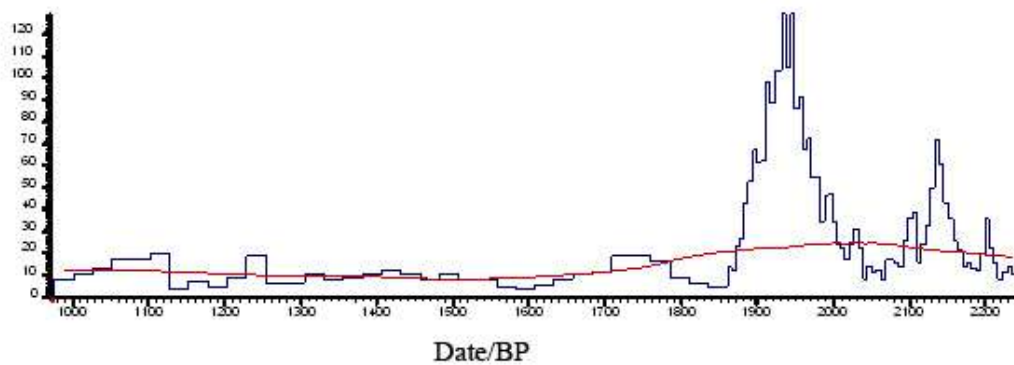


Figure 60 CHAR (blue line) and BCHAR (red line) for core 3

The results from Core 3 (figures 60 and 61) show the highest influx of charcoal occurring in the pre-Roman and early-mid Roman periods (2150 BP, and 2000-1900 BP). The influx of charcoal pre-Roman is similar to that found at Pozzo Napoliello (see below), which could relate to the “slash and burn” agriculture practising by the pre-Roman settlers elsewhere in central and southern Italy (van Joolen 2003), although it could also be due to natural fires. Forni (1990, p247- 250) uses the term *ignicoltura*, which he uses to describe an early form of “slash and burn”, which was “in order to create new cultivation spaces at expense of the forests”, thus is more “burn beating” the wild vegetation or seeds. The use of this type of agriculture is described by Rescio (2009, p28) who noted that at Tavoliere, north Apulia, where archaeological evidence spans from the Neolithic to the Middle Ages: “A progressive colonization of land can be seen, including the steepest slopes and hilltops, where frequent use was made of so-called ‘slash-and-burn’ techniques, where cutting of vegetation and subsequent burning are used to prepare land for cultivation”. These practices and the environmental factors, such as increased riverine incision, caused significant environmental deterioration, have strongly influenced post-medieval

settlement and agrarian production. However, Rescio does not offer a timeframe that this agricultural pattern lasted, and there is little evidence of “slash and burn” in other studies beyond the Bronze Age/Iron Age. The peak during the Roman period could be due to local fires, particularly wildfires, which are known in modern Mediterranean environments. However, given the close proximity of several Roman bath-houses (ca. 1 km from D6) with the early ones being heated by charcoal stoves, could the macrocharcoal be from them? If it had been microcharcoal this may have been the source, but with macrocharcoal it is less likely to have been wind-borne (Clark 1988), thus not travel far from their source. The increased CHAR led to an increase in sedimentation rate and thus organic matter noted in the LOI.

Pozzo Napoliello/Core 7

Max concentration: 349.5 pieces/cm³

Min concentration: 0 pieces/cm³

Max sedimentation rate: 0.2 cm/year or 6.6 year/cm

Min sedimentation rate: 0.03 cm/year or 32.8 year/cm

Max CHAR: 28.9 pieces/cm²/year

Min CHAR: 0 pieces/cm²/year

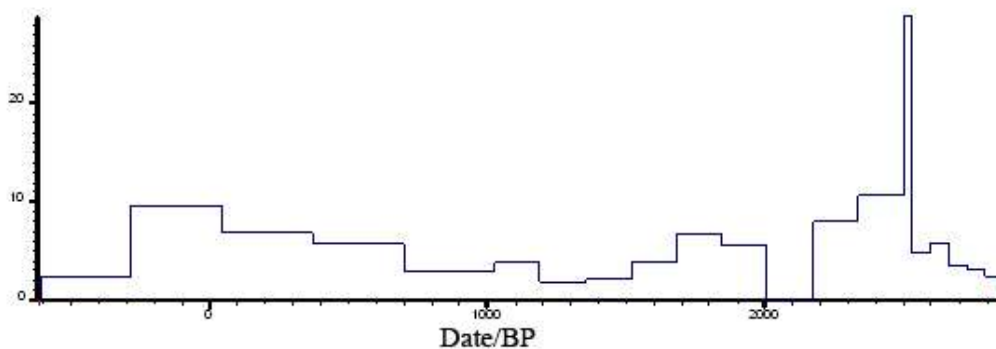


Figure 61 CHAR for Core 7

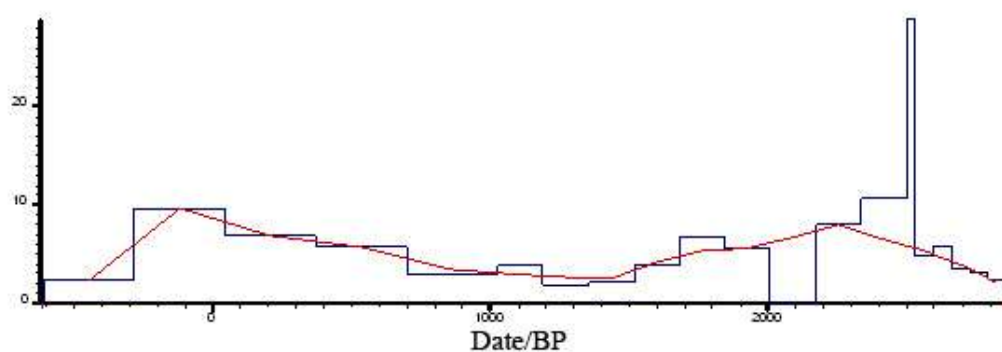


Figure 62 CHAR and BCHAR for core 7

The results (figures 62 and 63) show the highest influx of charcoal was during the pre-Roman period, as per core 3 at D6, before declining during the Roman period. As noted above the pre-Roman peaks could be natural climatic driven fires or anthropogenically induced to improve pasture quality (Fujisaka 1996). The contemporary peak at 0 BP may relate to the influx from a known recent fire, which will be discussed in the next chapter. The minimum number of fragments (0 pieces/cm³) falls well below the Whittock and Larsen criteria of greater 50 pieces/cm³ being an event, thus suggesting no fires locally at these periods. In comparison with core 3, there highest total influx is 349.5 pieces/cm³ c.f. 647 pieces/cm³ suggesting smaller fires, but both show a decline before 2000 BP and after 1850 BP, which could be either anthropogenic or climatic.

Muraccioli/ Core 9

Max concentration: 306.5 pieces/cm³

Min concentration: 67.5 pieces/cm³

Max sedimentation rate: 0.07 cm/year or: 14.2 year/cm

Min sedimentation rate: 0.06 cm/year or: 16.6 year/cm

Max CHAR: 18.5 pieces/cm²/year

Min CHAR: 4.4 pieces/cm²/year

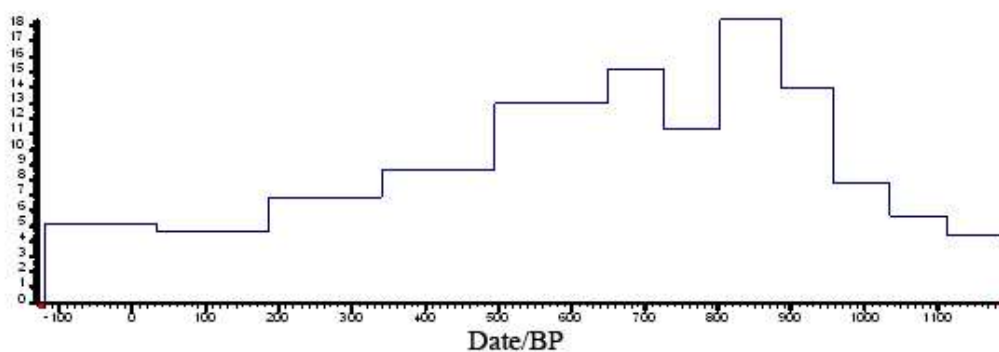


Figure 63 CHAR for core 9

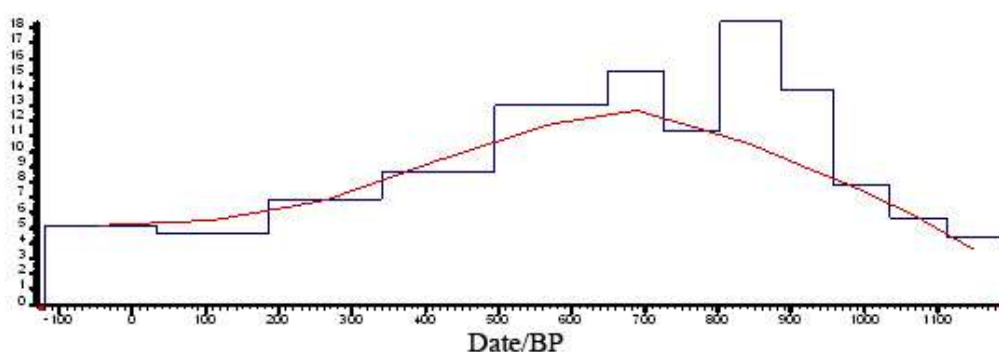


Figure 64 CHAR and BCHAR for core 9

The overall CHAR concentrations for core 9 (figures 64 and 65) are less than at D6 and Pozzo Napoliello. The higher influx around 700 BP maybe related to the later settlement at nearby Tor Paterno by monks (Manes *et al.* 1997) from 1000 BP to 380 BP, given the close proximity of Muraccioli to Tor Paterno, and wildfires

In general, the macrocharcoal for all 3 cores show that the highest CHAR was during the pre-Roman period and into the early-middle Roman period before declining, where as the post-Roman period is lower, which may simply reflect a lower level of anthropogenic disturbance at the site or a change in climate. The relationship between meteorological conditions and fire occurrence is well known (Chandler *et al.*, 1983), with forest fires tend to be concentrated in summer months when temperature is high and air humidity and fuel moisture are low to for modern climatic conditions, thus a change to wetter conditions may have reversed this situation.

4.6.3 Pollen

D6/Core 3 (Method 1)

The first set of pollen samples were prepared and mounted by Durham University's Archaeology Unit. Initial sampling was undertaken every 10 cm, to ascertain the quality of preservation throughout the core. The pollen count varied widely with depth, with the less than a hundred counts for all depths, and with the pre-Roman period having some of the lowest counts throughout the core length. This count was based on a "count everything present" basis that was pollen, however as the methodology employed by Durham did not employ hydrofluoric acid, the remains of a limited number of grass phytoliths were also present, but were not counted. Many factors can affect pollen preservation. The percentage of sporopollenin may be one of the most important factors for pollen itself. The lower the amount of sporopollenin in the wall, the easier it is for pollen to be oxidized, and therefore the potential for preservation is lowered (Havinga 1967). Kwiatkowski and Mianowska (1957) found that *Populus* sporopollenin content was only 5%, *Betula* 8%, but *Pinus* was as high as 19.6%. So in most cases, *Pinus* pollen could differentially preserved. Elsik (1971) found that sub-aerial exposure created an opportunity for oxidation and degradation of pollen grains, and possibly for further degradation by bacteria or fungi. Environmental factors are also very important for pollen preservation. Andersen (1986) thought that pollen preservation in soils was subject to oxidation and degradation, but the importance of these processes could be expected to vary depending on climatic conditions. Campbell (1999) found that pollen could be easily oxidized in aerobic conditions. Dimbleby (1957, 1961) suggested that soil pH values are one of the most important factors in pollen preservation, and in some respects it is even more important than just having an oxidizing or reducing environment. He found that when a pH value was higher than 5.5, the pollen concentrations fell sharply. The low numbers of pollen grains recorded from core 3 may be related to the pH of the system, (i.e. >7), thus saprophytic microorganisms may have attacked the pollen, as noted by Bryant *et al.* (1994). However, the low numbers counted on the slides should probably not be discounted as non-viable counts. In pollen counts within caves are often less than one hundred grains, but the count is still valid and representative of that assemblage (Bunting pers. comm. 2009).

Since pollen is a distance-weighted proxy of plant abundance, with most arboreal species producing far more pollen than typical Mediterranean macchia species, the results (figure 67) were normalised by taking the square root of the counts. This was

then converted into arboreal pollen vs. non-arboreal pollen, which shows distinctly different ratios in pre-Roman (50:50), Roman (50:50 to 70:30 to 35:65) and Post-Roman periods (50:50 to 75:25).

When analysed using the Pearson correlation coefficient, the arboreal pollen showed a positive correlation with the influx of charcoal between 70 and 170 cm, particularly with *Quercus* and *Pinus*, whereas *Betula*, *Alnus*, *Salix* and a negative correlation with aquatic pollen. The influx of pollen of these species was calculated from pollen grains per cm² per year, which theoretically measures the contribution of each plant taxon independently of the others and can be considered to reflect relative productivity of the taxon with nearby vegetation (Delcourt and Delcourt 1991). Changes in the influx maybe due to changes in vegetation density and therefore in sunlight availability influencing flower and seed set, as well as the dominance within the plant community. The results show that the period of highest influx of aquatic pollen was pre-Roman.

D6/Core 3 (Method 2)

A more detailed programme of pollen work was set up to sample the same core every 2 cm, using hydrofluoric acid to remove the phytoliths (Appendix 2). These samples were prepared by Hull University's Wetland Unit, and mounted by the author. However, preservation was worse than the previous count, with 85-95% of the pollen grains either corroded or damaged. In some cases it was impossible to distinguish *Betula* from *Alnus* due to damage to the aspidate pores of those species, leaving them out of shape. One species that could be identified was *Salix*, but this was present in small amounts. The slides showed high proportions of *Botryococcus*, a non-pollen palynomorph in the upper metre, which has been found contemporarily in littoral faciès and small temporary lakes (Clausing 1999). Again the numbers of grains for counting < 100 and therefore due to this, and the other issues noted above, further work was abandoned on this core and, on the advice of Jane Bunting (a pollen expert from Hull University), other cores were not prepared as she was uncertain that there would be any preservation based on viewing the core material.

Modern Pollen (Traps and Pollsters)

10 Cundill pollen traps were set in 10 different sampling locations to show changes in relation to location within site, changes due to presence of buildings (i.e. archaeological remains), relationship to palaeo pollen and differences with cover (in open or closed forest). The traps were left for a year (May 2008-2009), to give a full

years worth of pollen. However, when they were due to be collected in May 2009, they had all been removed or destroyed, which may have been due to disturbance by *Sus scrofa* (Wild boar) as they usually forage for food, often by digging with their trotters and snouts. Anthropogenic impact is doubtful, as this was considered when planning where to place the traps in the first place, as the areas are off the trail by the used visitors to the estate.

At the same locations as the pollen traps, pollen pollsters were also collected. Studies by Cundill (1991) and Spiekma *et al.* (1994) suggested inconsistencies between the two methods, with the traps showing a bias towards wind pollinated species. However, as there were no results from the traps, comparisons could not be made. The pollsters from four areas showed the best counts and preservation (some pollsters contained less than 10 grains), which were at the Vicus Augustanus, D5, D6 and Imperial Villa (figure 66). The results were normalised as per the palaeo pollen, thus to minimise the bias towards *Pinus* within the samples. All four areas show high proportions of *Pinus* and *Quercus*, which reflects the contemporary dominance of these species throughout the Castelporziano Estate. The presence of *Acer* and *Alnus* at the Vicus Augustanus and Imperial Villa, have been found in the contemporary vegetation studies of Muraccioli, thus suggesting an extra-local signal, where as *Typha* in the Imperial Villa pollen is likely to be local in origin. The *Ericaceae* and *Cyperaceae* were both found in the contemporary vegetation growing in and around D6, thus the pollen of these species is local. D5 and D6 although adjacent showed differences in their pollen, which may be due to the lower species diversity and numbers at D5, noted during the vegetation survey (chapter 5), with the abundance of *Quercus* and *Pinus* pollen blowing into and around D5, the other species present were typical macchia plants, and relatively low pollen producers.

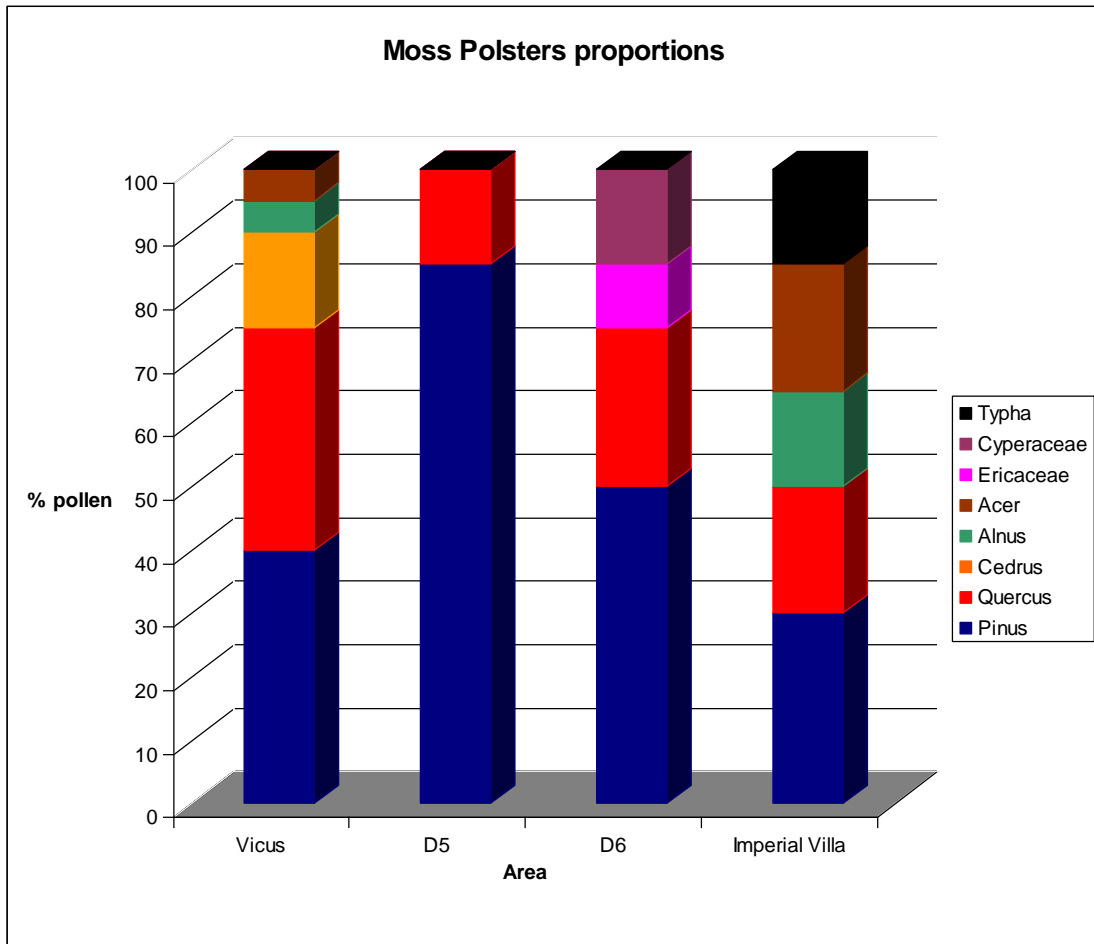


Figure 65 Pollen from moss pollsters

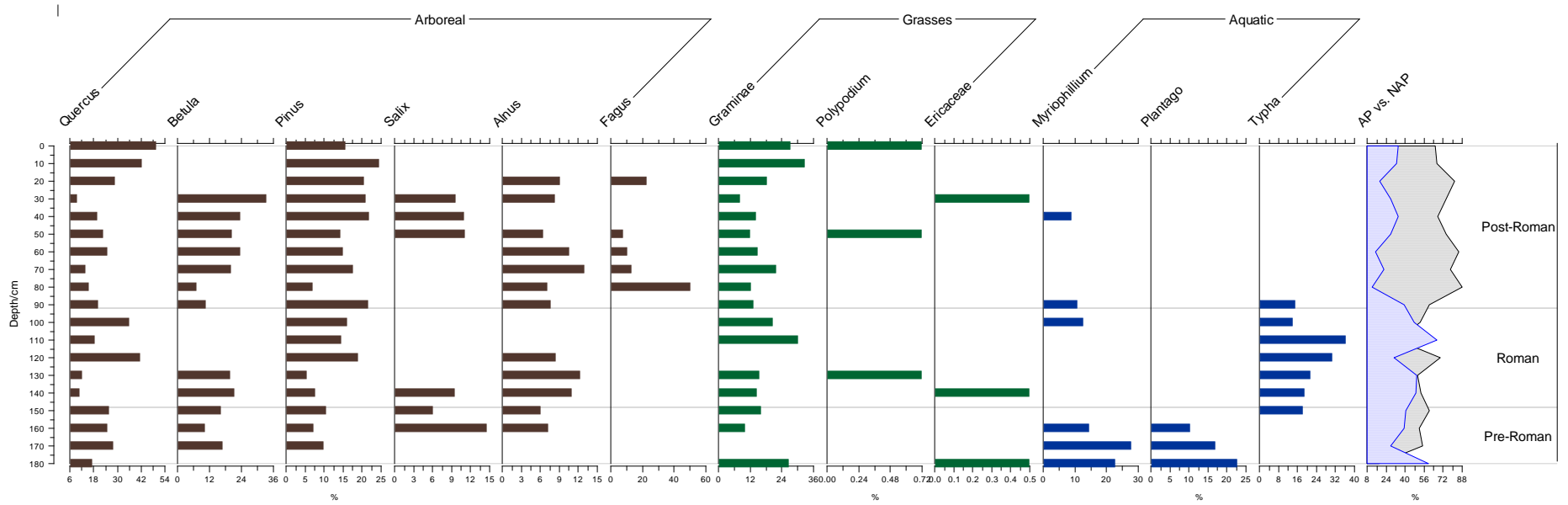


Figure 66 Pollen results from D6/Core 3 (Method 1)

4.6.4 Plant macrofossils

D6/Core 3

The plant macrofossil results shown split into two (Figure 68) from D6/Core 3 were subdivided into arboreal (brown), aquatic (blue), herbaceous (green), grasses and sedges (black). The arboreal macrofossil record in the pre-Roman period shows relatively few species present, with *Betula pendula* becoming increasingly dominant into the Roman period, however it is largely absent between 132 to 101 cm (although two seeds were found at 126 cm) equivalent in time to 59 BC to 191 AD ± 40 , and then present again during the post-Roman period. This record also correlates with the pollen record and with the influx of charcoal, which suggests that this species may be absent as a result of increased local fire frequency (see Simmons, 1969). In general, abandonment ca. 420 AD is associated with an increase in arboreal species within the plant macrofossil record.

The presence of *Betula* in the pre-Roman, and part of the Roman period is also shown in the pollen record, which is indicative of the presence of such vegetation within 100 m to several km, thus, although *Betula* is not found locally during the later Roman period there was still a presence nearby. As noted in the pollen records *Alnus* tends to have a local signal, therefore, despite its absence within the plant macrofossil record until the Post-Roman period, it is likely that this species grew not far from D6. Together with the *Salix* in the pollen record suggests the presence of a wet woodland and/or fen around D6.

Aquatic species dominate the pre-Roman vegetation, with species such as *Myriophyllum*, *Potamogeton*, *Apium* and *Ceratophyllum*, which are macrophytes or pond weeds. In the Roman period there are fewer aquatic species, with *Myriophyllum* being replaced by *Ceratophyllum* at 135/134 cm (age equivalent 76-70 BC ± 40) Both *Myriophyllum* and *Ceratophyllum* are oxygenating plants, i.e. they quickly assimilate excess nitrogen in the water, however other proxies such as the bryozoan statoblasts suggest that the local environment was becoming increasingly eutrophic which may have led to a decline in macrophytes. In contemporary Finnish lakes, only *Ceratophyllum demersum* appears to be resistant to eutrophication. *Typha angustifolia* which replaced *Ceratophyllum demersum* grows in contemporary hyper-eutrophic lakes (Grace 1987), particularly those rich in phosphorous and nitrogen. Contemporary studies are examining the potential of *T. angustifolia* as a remediation

tool for eutrophic lakes (Hall 2009). *Apium nodiflorum* is a valuable indicator of high mineral content in other areas of Europe (Martínez-Taberner and Moyá 1993), and has the ability to oxygenate its substrate (Chorianopoulou *et al.* 2001) and has been reported to be a good competitor in eutrophic waters (Szakowski and Kolsowski 2001). Therefore despite the apparent increase of eutrophication during the Roman period *A. nodiflorum* may have remained present. During the Post-Roman period macrophytes return (e.g. *Potamogeton obtusifolius*), and eventually the bryozoan *Plumatella repens* also returns.

Based on the species within the aquatic macrofossil record, the depth of water pre-Roman at D6 may have been less than 3m (Canfield *et al.* 1985), as all species found are surface dwelling macrophytes. In the Roman period both *Ceratophyllum demersum* and *Typha angustifolia* were both found, which suggest that a water depth of at least 1.5m (Mitchell and Prepas 1990), which would have been suitable for a fish tank (Pillay and Kutty 2005) or fish pond (for example Koi require a depth of at least 91cm (Blasiola 1996).

Herbaceous species also dominate in the pre-Roman period, with species such as *Ranunculus repens*, *Silene dioica*, and *Senecio vulgaris*, all of which suggest a vegetated fixed dune, with *R. repens* indicating a slack. The Roman and post-Roman periods are marked by the absence of any herbaceous species. Eutrophication of herbaceous wetlands has been found to lead to a decrease in species density and richness, dominance by a few nutrient-responsive species, and loss of common and characteristic species (Bedford *et al.* 1999).

Grasses and sedges are present pre-Roman, and during the Roman period, *Eleocharis palustris*, *Poaceae* and *Juncus effusus* appear to dominate. The addition of nitrogen to dune slacks has been shown to lead to an increase in *E. palustris* (Lammerts and Grootjans 1997), which again is an indicator of eutrophication. Furthermore, *E. palustris* also shows a correlation with the influx of charcoal, this may be due to fire tolerance when dormant (US Department of Agriculture 2006) and the tops are killed by fire during the growing season (Young 1986; Kovalchik and Clausnitzer 2004). The post-Roman absence of grasses and sedges may be linked to an increased arboreal presence in the local environment, as noted in the arboreal plant macrofossil record. Thus suggesting a change in the local environment in post-Roman times from a sedge-dominated environment into wet woodland with seasonal

wetness, at least ephemerally if not permanently, as indicated by the presence of *P. Obtusifolius* macrofossils.

Pozzo Napoliello/Core 7

The results of core 7 (figure 69) shown an immediate difference between this and the previous record at D6, with the presence of mosses, in particular *Lycopodiella inundata* (marsh club moss) and *Polytrichum commune* (hair-cap moss) suggesting a wet sandy location. The only arboreal macrofossils were those of *Alnus glutinosa* in the Roman and post-Roman periods, indicates the presence of local wet woodland or fen. Wet woodlands can also be thought of as swamps, in the same way that wet grassland is a marsh (Oplinger and Halma 1988), however the boundary between the two may be indistinct. The influx of charcoal to this area in pre-Roman times may be associated with early (Iron Age) settlement. The absence of arboreal plant macrofossils in the pre-Roman period with only *A. glutinosa* being found later may be indicative of the practice of cutting and burning of forests or woodlands to create fields for agriculture or pasture for livestock (Cornell 2007), which has been found to improve the nutrient content, and increases digestibility of forage (Lewis *et al.* 1982). This absence also maybe due to natural wildfires as noted in relation to D6, hence the absence of arboreal plant macrofossils pre-Roman, thus an artifact of the climate and as the pollen record for D6/Core 3 showed that trees were present at Castelporziano during this period. The presence of *A. glutinosa* in recently burnt sites has been shown to be due to its resistance to fire due to its relatively thick bark and recovers quickly after burning by resprouting from the base of the trunk and through new seedling establishment (Grau *et al.* 2000). Thus alongside the presence of *Betula* from D6 maybe a sign of an area prone to fires, therefore more likely to be wildfires and not anthropogenic in origin.

The record of aquatic plant macrofossils is equally sparse, with the presence of *Potamogeton* sp., throughout the record until recent times. This macrofossil, along with the *Lycopodiella inundata*, *Polytrichum commune*, and *Alnus glutinosa* shows the presence of a fen or wet woodland.

The dominant group of species are grasses and sedges with the domination of Poaceae throughout almost all of the three time periods, thus suggesting a *sedge fen*. Other species, such as *Juncus effusus* and *Schoenus compressus* are present during the Roman and post-Roman periods and are also consistent with the

presence of a fen environment. Although no crop remains were found in the core, the presence of *Aegilops cylindrica* was noted at a depth of 70-65 cm (age equivalent 270-434 AD), this plant can be found in wheat fields or other cereal grain fields. This does not demonstrate the presence of agriculture at the site, but it is possible that this is the remains of cattle feed, which may suggest possible grazing activity, which the other plant macrofossils may also suggest in terms of being either, suitable for grazing or indicators of disturbed ground, which maybe anthropogenic in origin.

Evidence of ground disturbance comes from the presence of the non-pollen palynomorph of *glomus c.f. fasciculatum* chlamydo spores (van Geel *et al.* 2003); this fungus was present throughout the Roman period only, whose presence is another indicator of fire (Argant 2006) and possible grazing.

It appears that this area started off as a dune slack fen, before becoming a sedge fen in *Character* and then a wet forest. The pre-Roman period potentially used "*ignicoltura*" to improve the pasture of the area and for grazing. As Forni (1992) notes "*The employment of the fire within this is limited deforestation began in the Neolithic, and with successive control of the herbaceous and shrubby vegetation*". The Roman period along with the CHAR represents the presence of local fires, i.e. wildfires. The other proxies show the presence of grazing or disturbed ground. As there are inscriptions suggesting the use of Castelporziano was used as a game park in the late 2nd century AD, which could be the source. This dune slack area was subsequently examined by sampling a second depression along the same line of slacks as Pozzo Napoliello to ascertain any further evidence for what this grazing/disturbed ground signal related to.

Core 8

This was taken from a dune slack WNW of Pozzo Napoliello. This core contained a prominent band of calcium carbonate nodules present from 25 to 125 cm depth within the core. The reason for these presence of nodules in core 8, but not core 7, maybe due to differences in groundwater discharge and the hydrochemical gradients at each coring point, despite being from the same line of slacks. Another possible cause is that core 8 represents a marl fen, which occurs as small patches within grass rich fens. The results (figure 70) combined with the ¹⁴C dating show that this whole core represents a post-Roman sequence.

The arboreal macrofossils show the presence of *Salix repens* at 140-125 cm before being replaced by *Alnus glutinosa* for the rest of the core length, both species are typical of wet woodlands but *S. repens* is also found in dune slacks. The presence of *Fraxinus excelsior* at 60-55 cm also indicates the presence of wet woodlands. In the upper 50-20 cm of the core *Betula* has replaced *Fraxinus excelsior* but is still a typical wet woodland species. The uppermost 20 cm contains *Quercus robur* and suggests the development of a slightly drier woodland environment, perhaps linked to the draining of the swamps nearby.

Potamogeton pectinatus is the sole aquatic plant macrofossil identified in this core. The final group of plant macrofossils are grasses and sedges, with all species being typical of wetland environments, particularly fens, thereby correlating with core 7. These results suggest that both Pozzo Napoliello and the neighbouring dune slacks were wet forests.

Muraccioli/Core 9

The ¹⁴C dating results from this core (figure 71) show that it effectively represents a post-Roman sequence only as no plant macrofossils were found below 95 cm. The arboreal plant macrofossils of *Alnus glutinosa*, *Quercus robur* and *Betula pubescens* suggest a wet forest. The presence of *Lycopodiella inundata* shows the presence of a wet woodland. This is further shown by the presence of *Silene dioica*, *Potentilla anserina*, *Senecio paludosus* and *Carex nigra*, which may also indicate the grazing of animals.

The plant macrofossils from Muraccioli together with core 7 and 8 show the development of this part of the estate from a fen into a wet woodland in the post-Roman period

Castelfusano/Core 16

The main plant macrofossils found in core 16 (figure 72) were *Alnus glutinosa* and *Betula pendula*. As no radiocarbon dates were obtained for this core it is not possible to constrain the chronology. As no other types of plant macrofossil were found at Castelfusano, other than the arboreal species mentioned above, no evidence for grazing or anthropogenic impact can be determined.

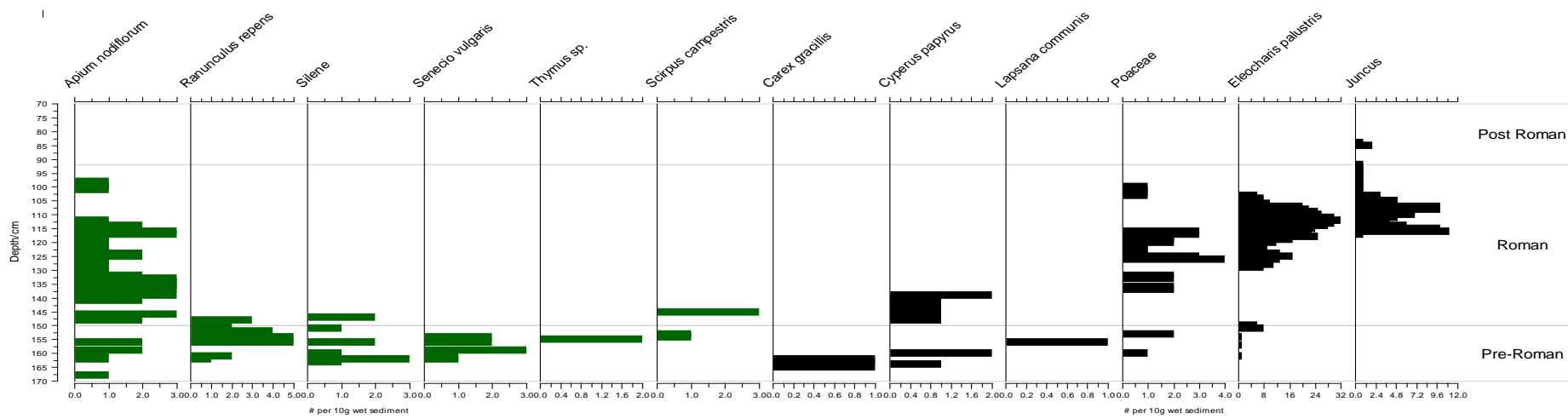
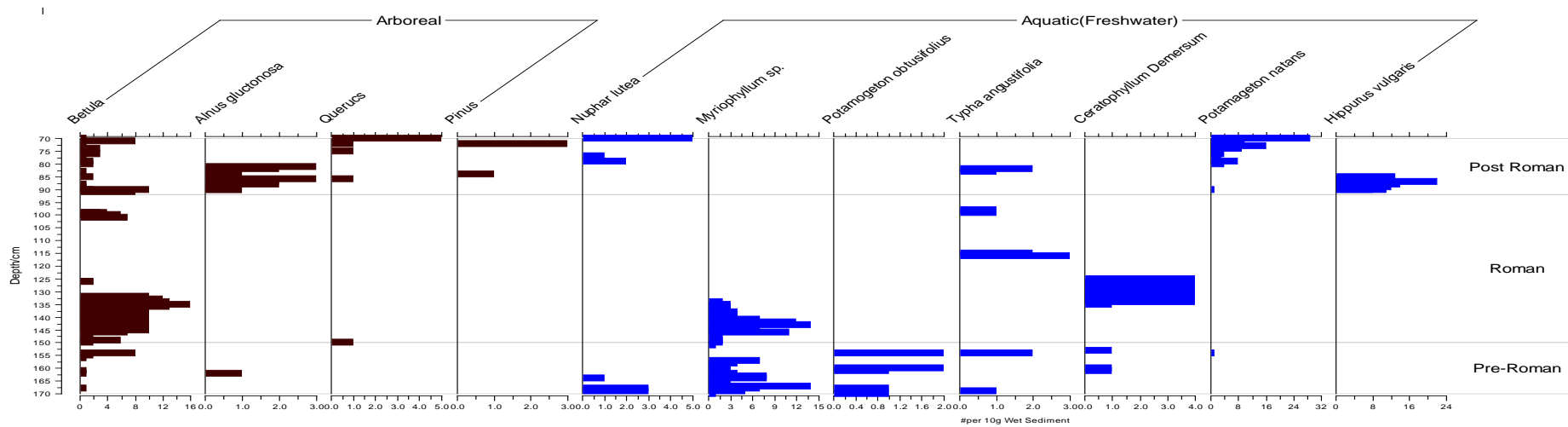


Figure 67 D6/Core 3 Plant Macrofossil results

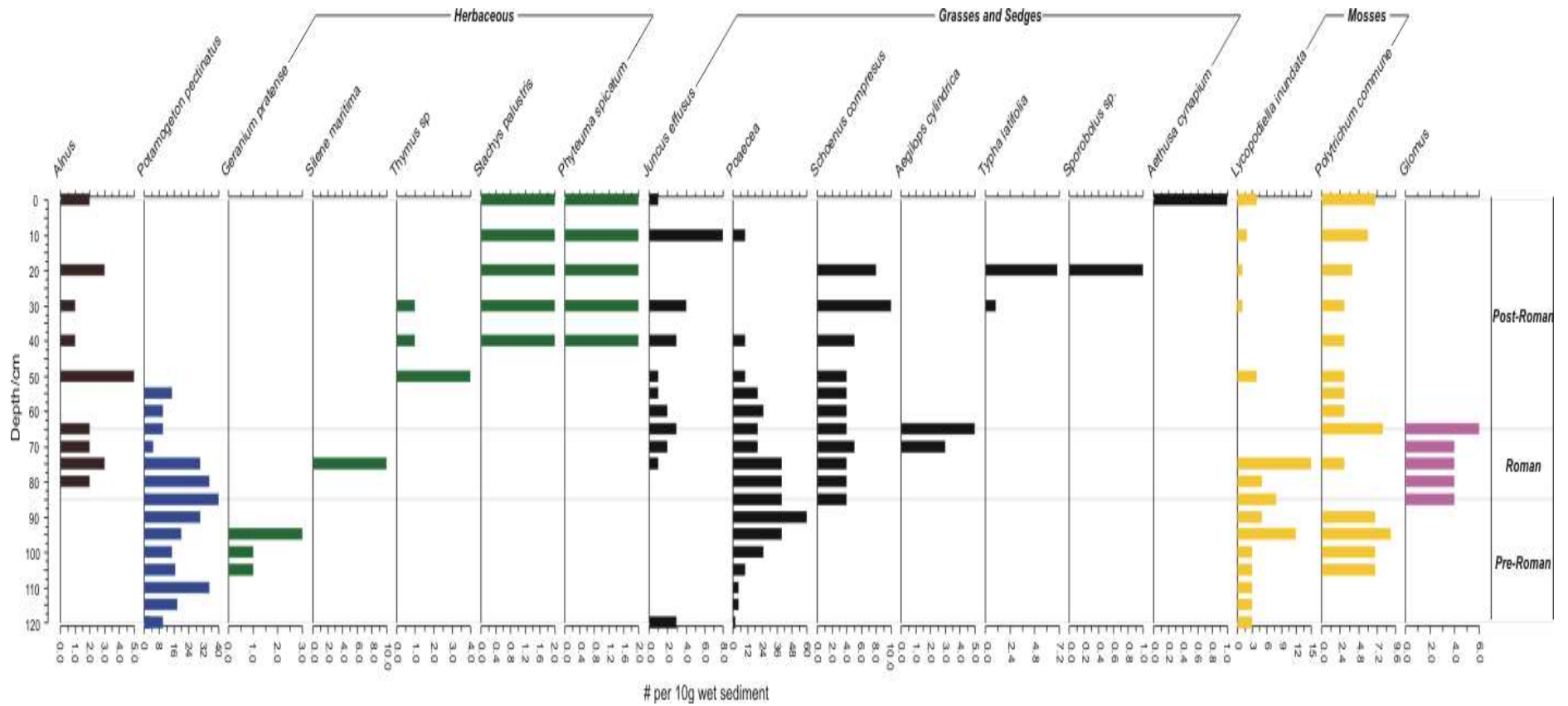


Figure 68 Pozzo Napoliello/Core 7 Plant Macrofossil results

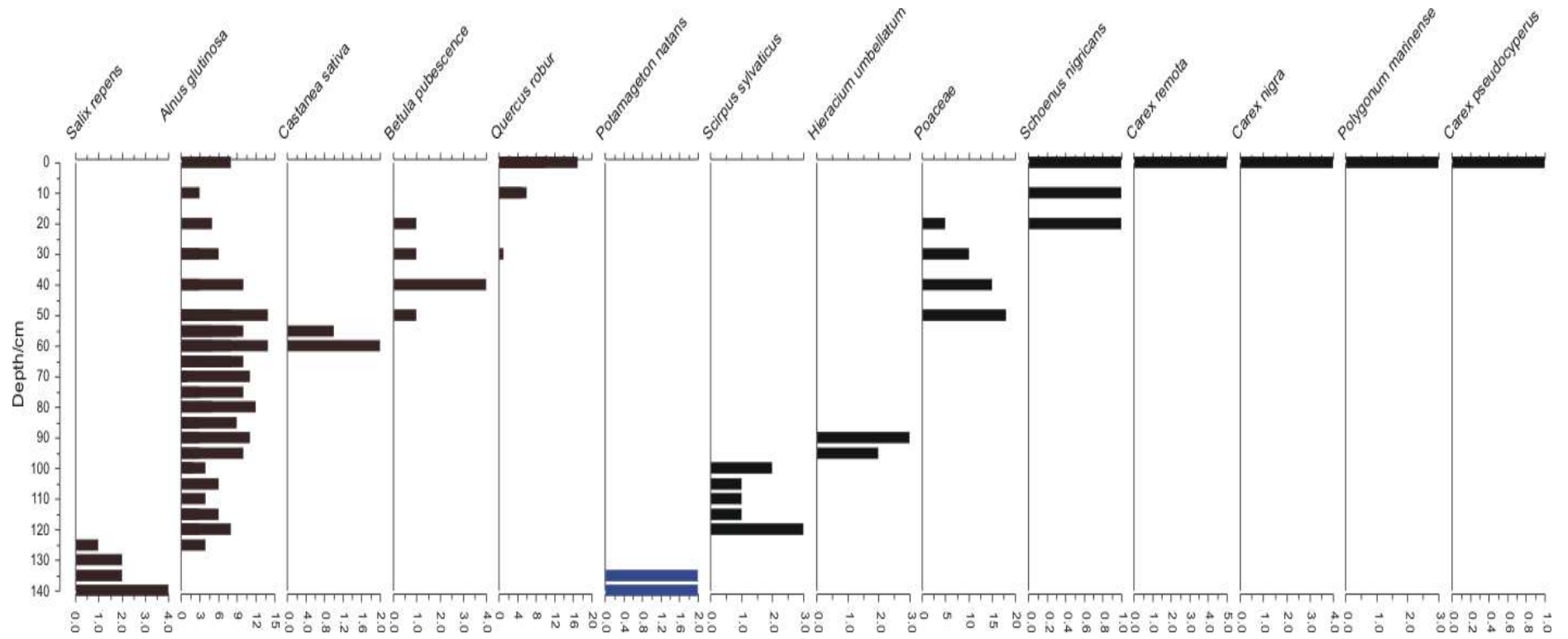


Figure 69 Pozzo Napoliello – neighbouring dune slack Core 8 Plant Macrofossil results

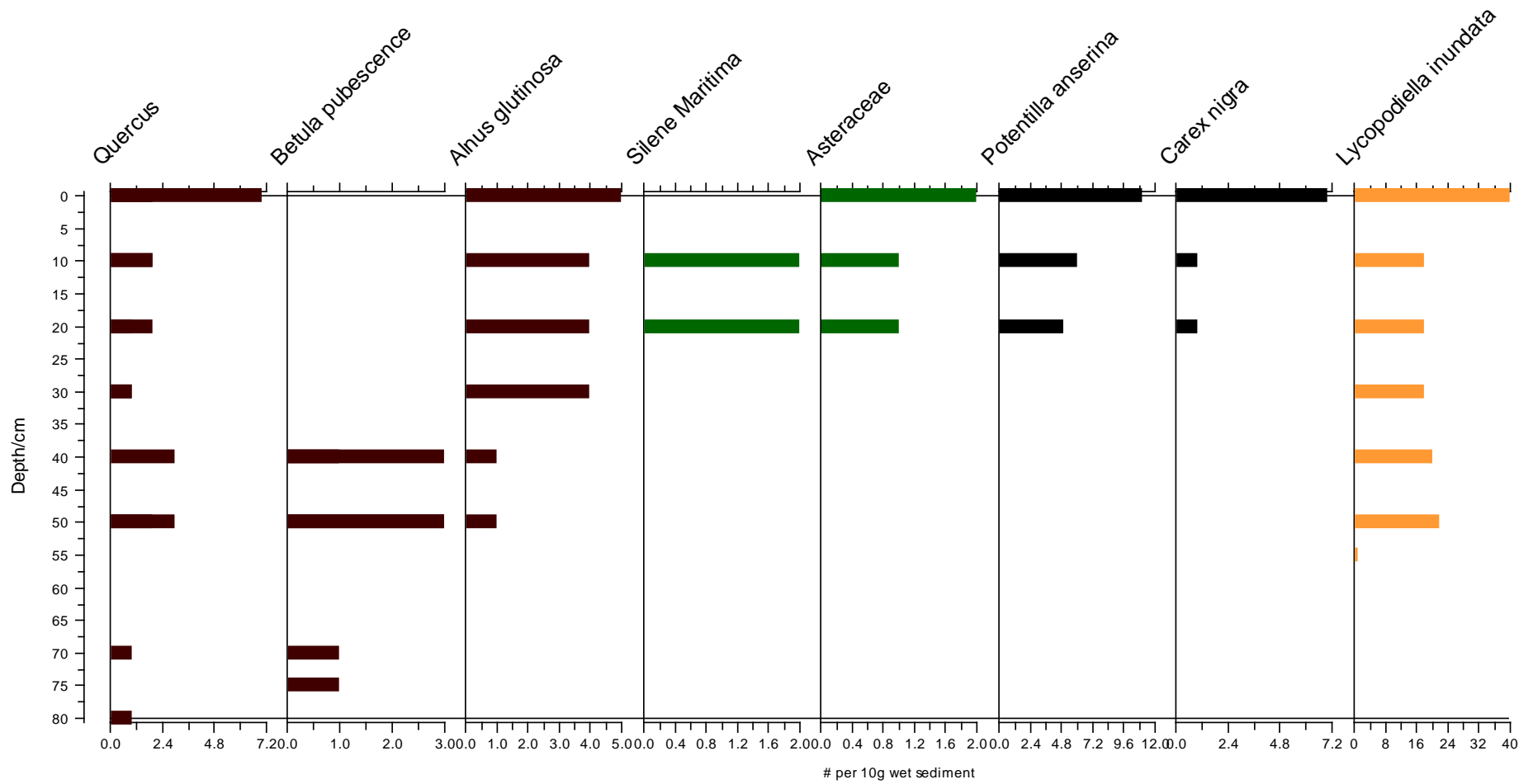


Figure 70 Muraccioli/Core 9 Plant Macrofossil results

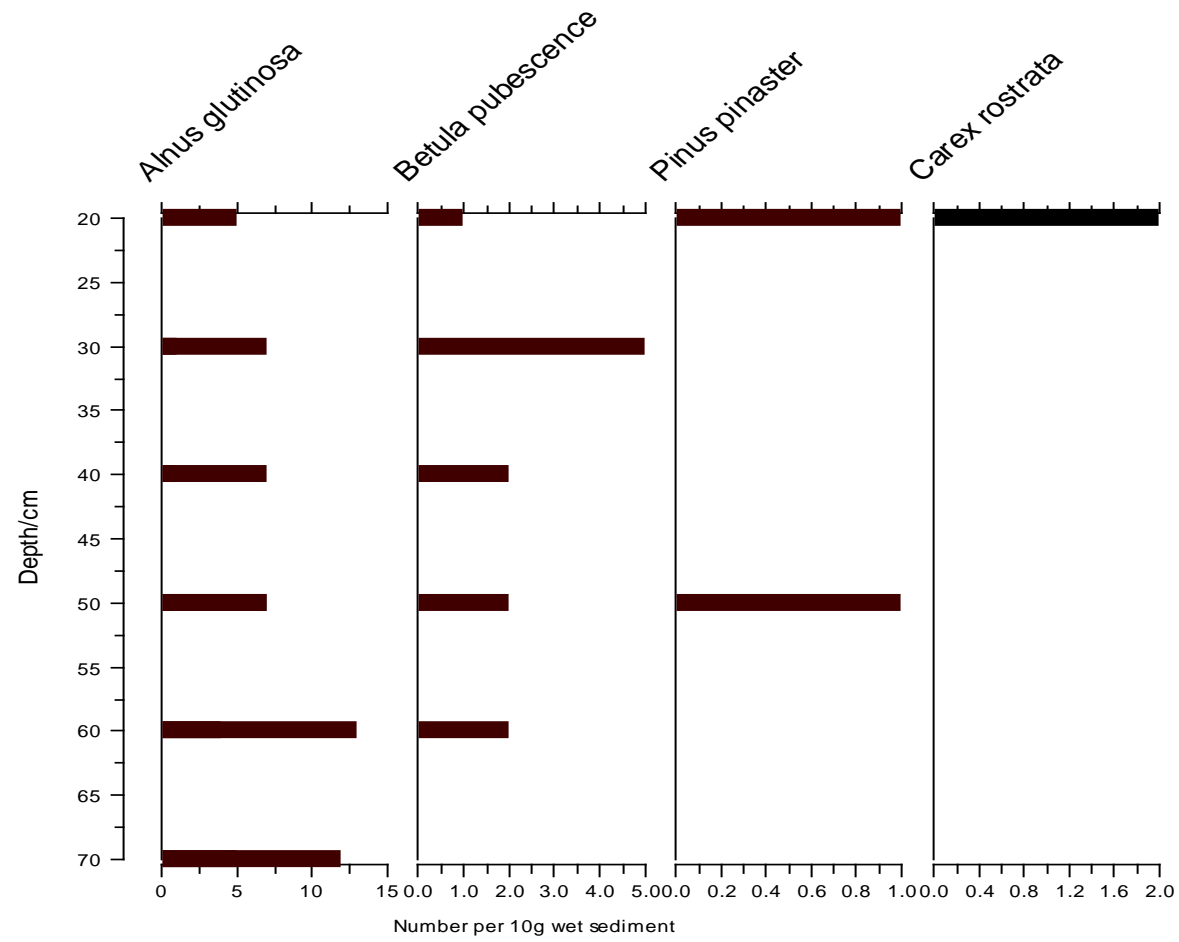


Figure 71 Castelfusano/Core 16 Plant Macrofossil results

4.6.5 Molluscs

Despite showing good promise in the pilot studies, only core 7, of the additional core material analysed, showed the presence of molluscs.

Pozzo Napoliello/Core 7

All the molluscs found in core 7 come from the post Roman period (figure 73), with the main four species, *Vitrea crystallina*, *Zonitoides nitidus*, *Acroloxus lacustris* and *Vertigo antivertigo*, were also found in the pilot studies in cores 1 and 6, at D6 and D5 respectively, which also cover the post-Roman period. The molluscs can be interpreted as being indicative of wet woodland. Other molluscs found in Core 7 included: *Trochoidea elegans*, which is common in Mediterranean stabilised dunes; *Segmentina nitida*, which has been found in the UK in areas of traditional grazing where phosphate and nitrate and remains low, which would correlate with the results from the plant macrofossils; *Sphaerium corneum* is a common aquatic species that has been found in drained UK marshes, which would correlate with the known recent history at Castelporziano.

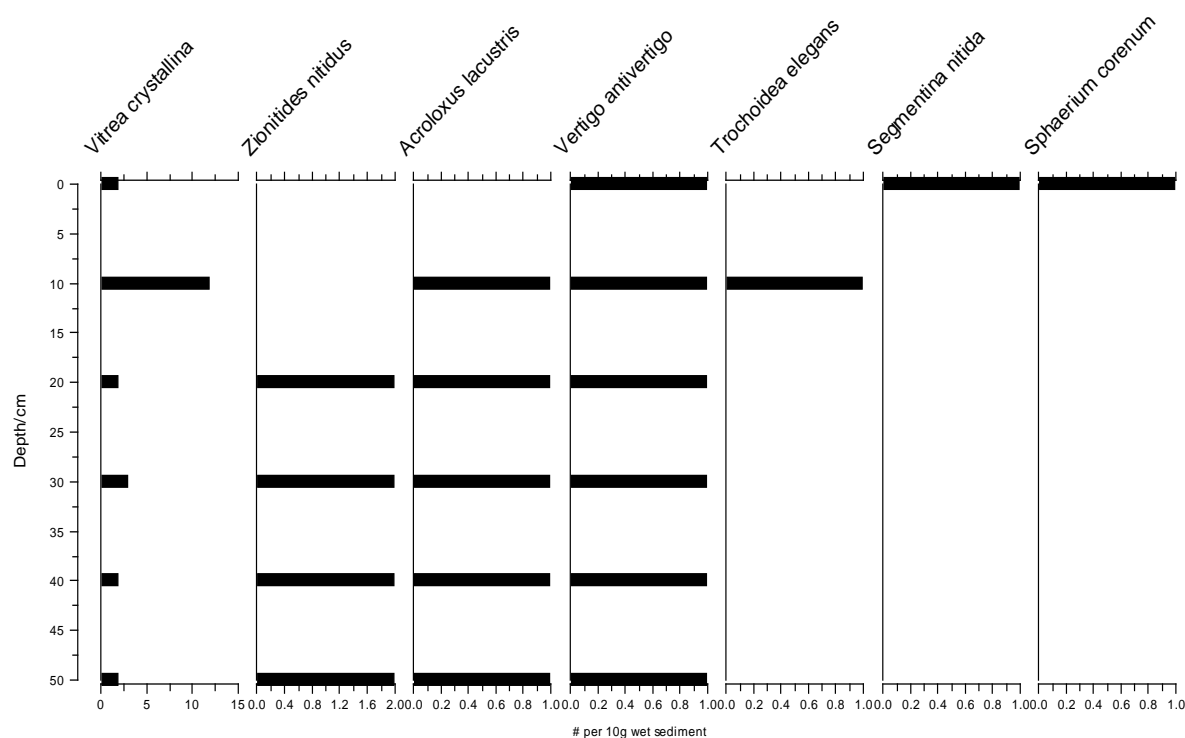


Figure 72 Mollusc results Napoliello/Core 7

4.6.6 Ostracods

Ostracods were only found in Core 3 from D6, a factor which may reflect the very specific environment of D6 compared to the other dune slack deposits.

D6/Core 3

The results (figures 74 and 75) show the presence of *Cyclocypris serena* only in the pre-Roman period and four species in the post-Roman periods only, which are *C. serena*, *Potamocypris villosa*, *Ilyocypris inermis* and *Limnocythere inopinata*, with the most common species being *C. serena*. *P. villosa* (figure 74) are known to be restricted to alkaline waters (Roca and Baltanás 1993) as are *L. inopinata* (Bunbury and Gajewski 2005). Among all four species, none can be classified as benthic. All the present species can live in the shallow littoral layers of lakes, in ponds or in temporary pools (Meisch 2000). The absence during the Roman period may be linked with eutrophication as these species are all found in alkaline waters, thus suggesting a change in pH during the Roman period.

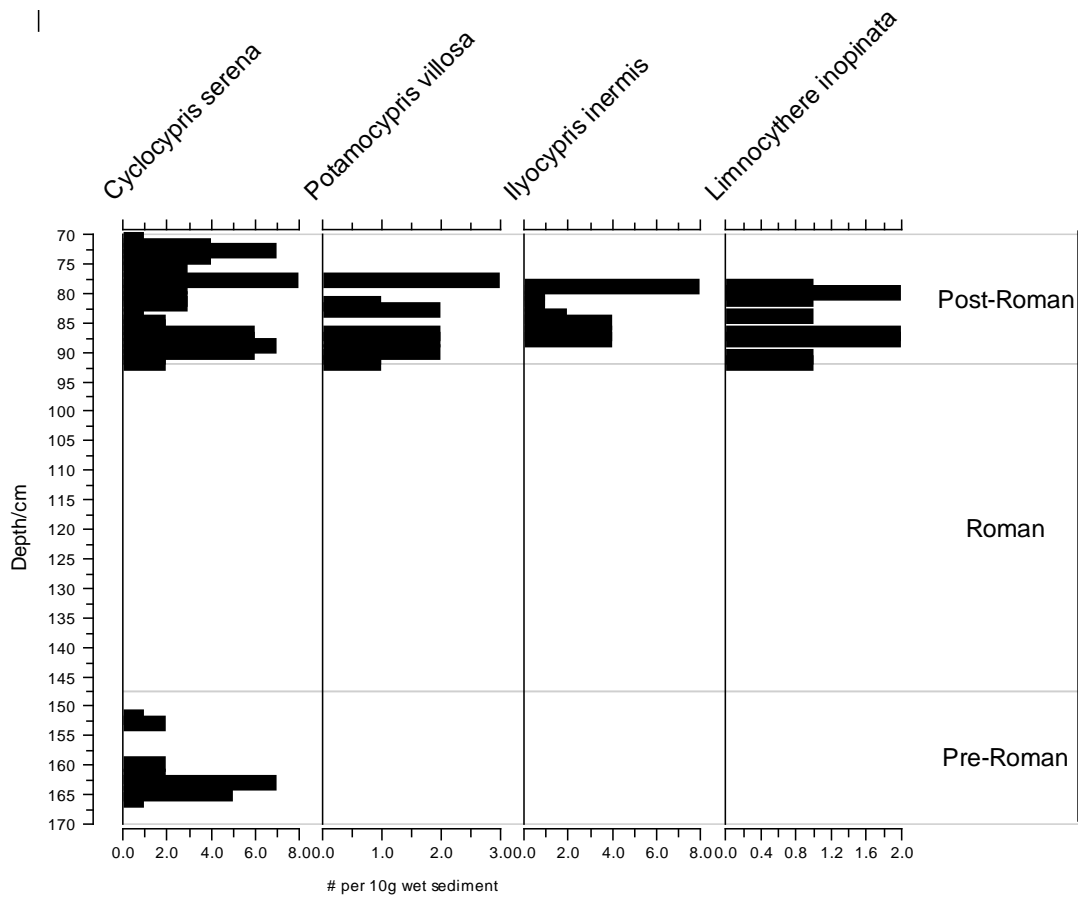


Figure 73 Ostracod results D6/Core 3

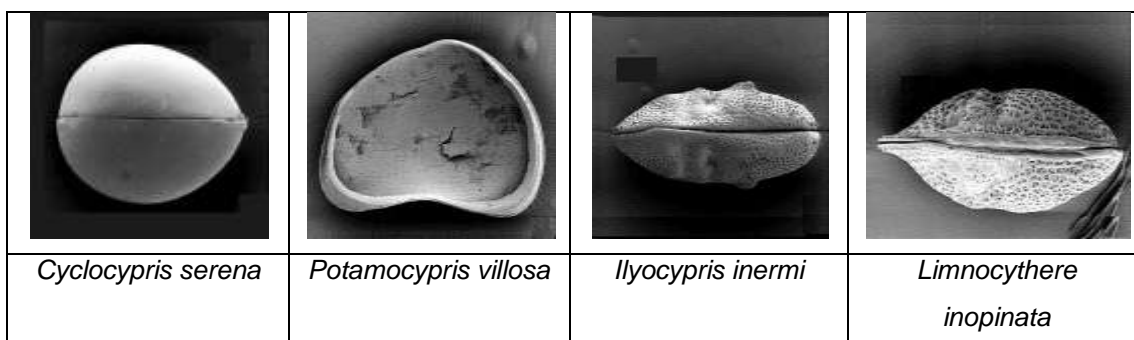


Figure 74 Scanning electron microscope images of the four ostracod species (*Cyclocypris serena*, *Potamocypris villosa*, *Ilyocypris inermis* and *Limnocythere inopinata*) (UCL)

The Mutual Ostracod Temperature Range (MOTR) (Horne 2007) provides a method of inferring past air temperatures for the post-Roman period from the non-marine ostracod assemblages. From Horne (2007) demonstrated the application of a large ostracod database, used in conjunction with a Geographical Information System (GIS), to develop a Mutual Ostracod Temperature Range (MOTR) method of inferring past air temperatures from nonmarine ostracod assemblages. This method involves identifying the species of ostracod and then plotting the T_{MAX} and T_{MIN} ranges of each species from Horne's data. From this it was possible to ascertain the T_{MAX} and T_{MIN} , for the January and July, the range of values over which the temperature ranges of all the plotted species overlap. From this the both the OTC (Ostracod-inferred Temperature range of the Coldest month, January) and OTW (Ostracod-inferred Temperature range of the Warmest month, July) were calculated the post-Roman period.

The mutual mean July temperature range (OTW) of the 4 species found in core 3 was +17 to +18.5 °C (figure 76) and the mutual mean January temperature range (OTC) was -1.5 to 4 °C (figure 77). This shows dissimilarity between the OTW and OTC than those of contemporary July and January temperatures, showing a marked colder climate (the mean July temperature is 24°C and mean January is 8.7°C for the last 50 years). This period corresponds to the time following the Roman Empire collapse around AD 480 and the Justinian plague ca. AD 540 (Lamb 1982; Ambrosiani 1984). Climatically this period was one of rapid cooling indicated from tree-ring data (Eronen *et al.* 1999) as well as sea surface temperatures based on diatom stratigraphy in Norwegian Sea (Jansen and Koc 2000), which can be correlated with Bond's event 1 in the North Atlantic sediments (Bond *et al.* 1997).

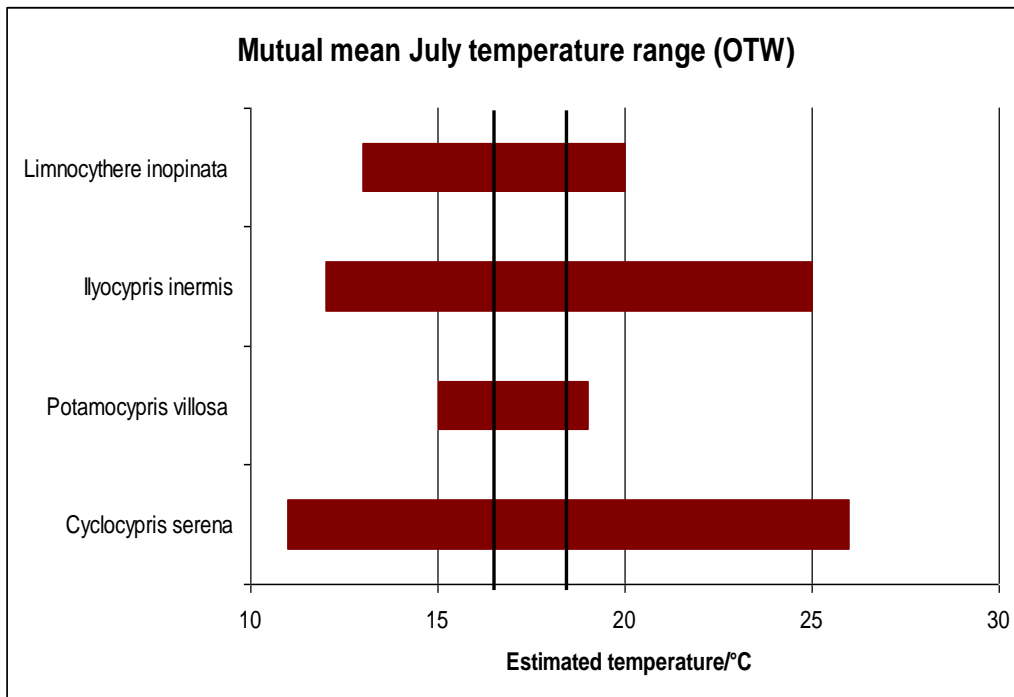


Figure 75 Mutual mean July temperature range Post-Roman

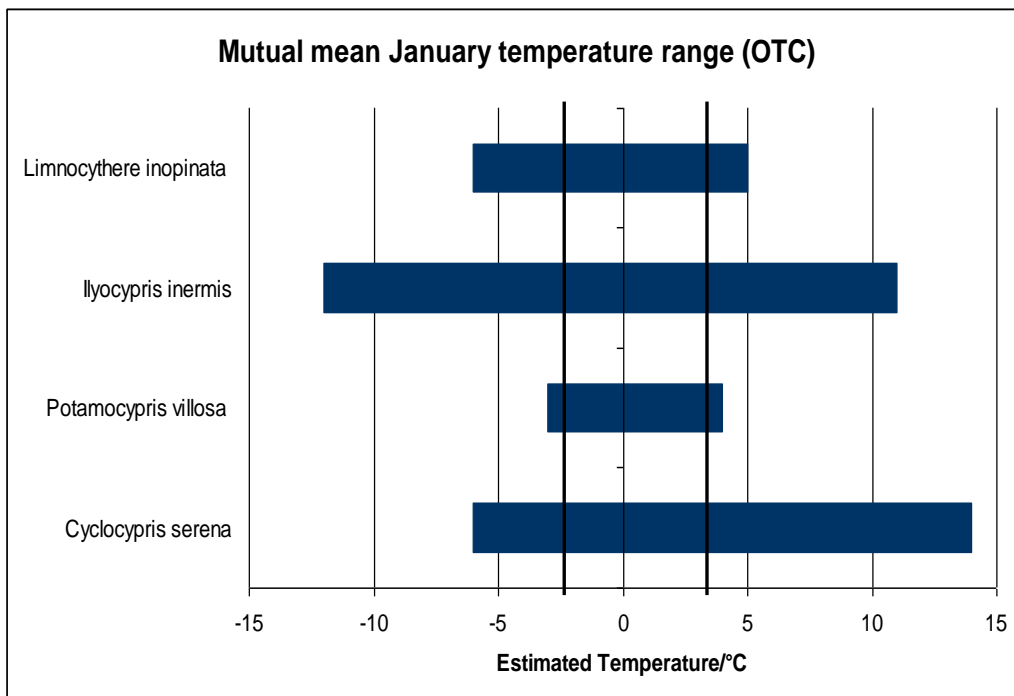


Figure 76 Mutual mean January temperature range Post-Roman

4.6.7 Bryozoan statoblasts

Core 3/D6

Three species of bryozoan statoblasts were found in core 3 (figures 78 and 79), which were *Plumatella repens*, *Cristatella mucedo* and *Lophopus crystallinus*. *P. repens* was found both pre-Roman and Roman periods, but with noticeable absence at 136 to 113 cm and 105-70 cm (age equivalents 82 BC to 46 AD, and 90 AD to 975 AD, respectively), whereas *C. mucedo* and *L. crystallinus* were only found during Roman period (at 129 to 114 cm and 141 to 114 cm respectively). The absence of statoblasts in the upper (late Roman-post-Roman; 105-70 cm) suggests changing conditions.

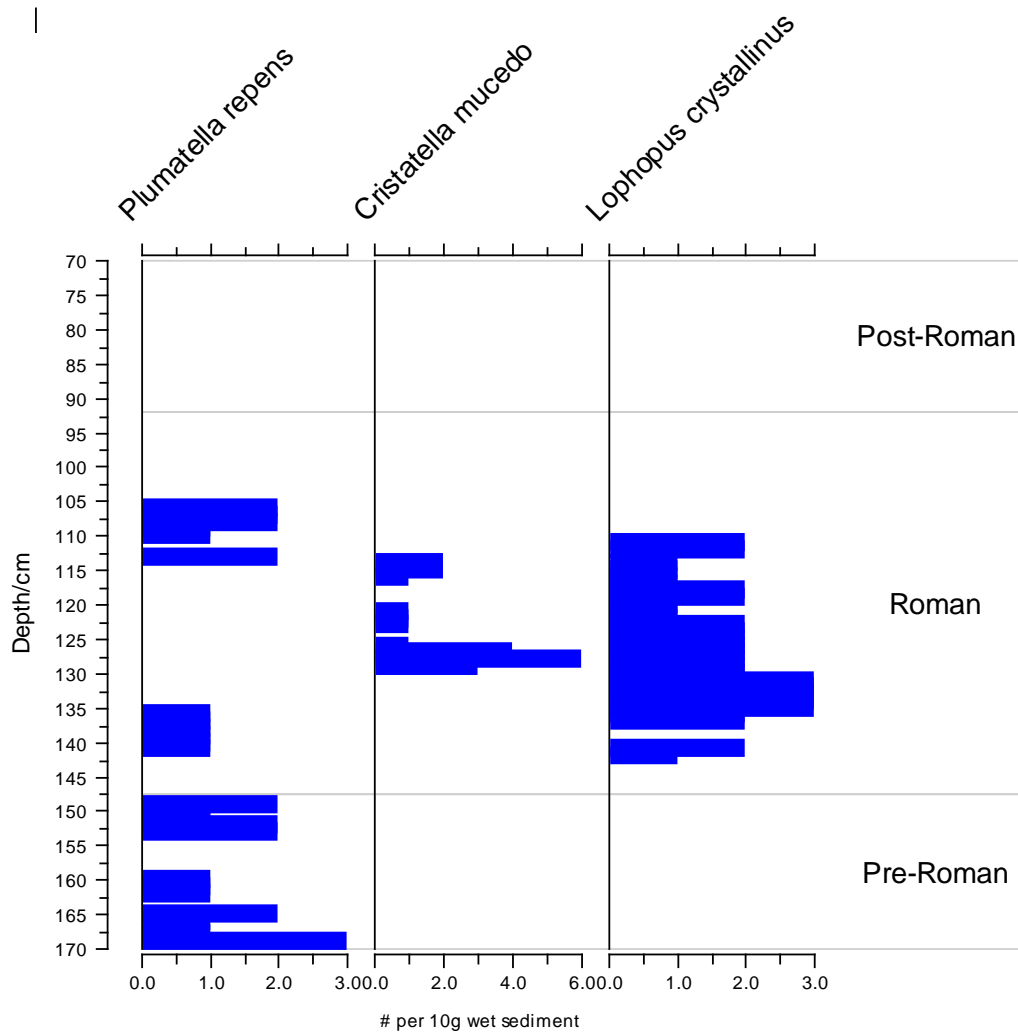


Figure 77 Bryozoan statoblast results D6/Core 3

The absence of *P. repens* during the Roman period (136 to 113 cm), as noted above, may be explained by the increased organic matter (from LOI) and the increased sedimentation rate (from the ¹⁴C dating) respectively, which may have led to eutrophication. Additionally, *P. repens* feeds on macrophytes, and as noted in the plant macrofossil record, these became absent during the Roman period and into the post-Roman period.

The presence of *Cristatella mucedo* is found at the same depths as the presence of *Ceratophyllum demersum* in the plant macrofossil record, as *C. mucedo* needs a plant to attach itself to (figure 78) it is possible this was what it lived on. The presence of the statoblasts of the bryozoan *Lophopus crystallinus* is rare, both in terms of contemporary and palaeoecology, as so little is known of its ecology. Hill and Okamura (2005) determined that the presence of *L. crystallinus* indicates low levels of forest, which agrees with the absence of arboreal plant macrofossils. This species' presence on the age/depth model correlates with the use of D6 as a fish pond, which may be explained by the affinity of *L. crystallinus* with highly eutrophic water, as it has been found in waters with concentrations of at least 0.2–1.6 mg P/l (Hill and Okamura 2005) and tends not to occur in waters with low phosphate concentrations. Lakes with phosphorus concentrations below 0.010 mg/L are classified as oligotrophic, phosphorus concentrations between 0.010 and 0.020 mg/L are indicative of mesotrophic lakes, and eutrophic lakes have phosphorus concentrations exceeding 0.020 mg/L (Muller and Helsel 1999). Similarly, *L. crystallinus* tended to not occur in systems with low nitrate concentrations and has been associated mainly with concentrations ranging from 20 to 50 mg NO₃/l, i.e. moderate to very high (Hill and Okamura 2005). Both phosphorous and nitrogen are important waste products of fish farms (Porrello *et al.* 2005) and thus could be a proxy for the use of D6 as an active fish pond, or at least further evidence for eutrophication. Ammoniotelism is the predominant process of N excretion in teleosts (Forster and Goldstein 1969). Ammonia is excreted mainly through the gills and represents 75 to over 85% of the nitrogen loss, while phosphorus is mainly excreted as phosphate by the kidney (Handy and Poxton 1993), but as noted previously no fish bones were found in any of the samples analysed.

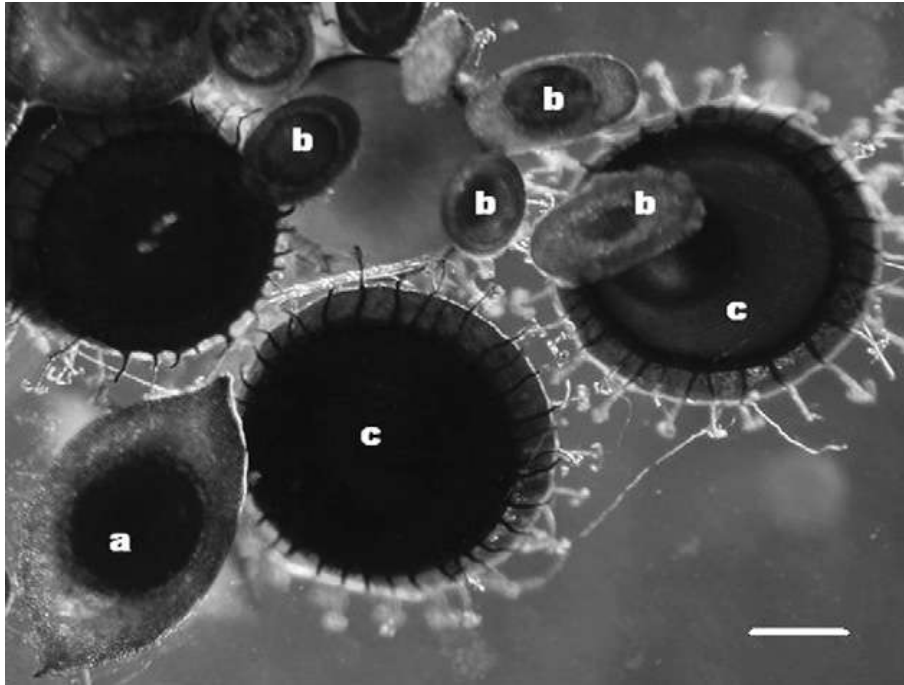


Figure 78 Statoblasts of (a) *Lophopus crystallinus*, (b) *Plumatella* spp. and (c) *C. mucedo*. Scale bar = 200 μ m. (Hill and Okamura 2005)

4.6.8 Stonewort oospores

D6/Core 3

The results (figure 80) show the presence of oospores throughout the core length, which were identified as *Chara tomentosa*. This species today is found in lakes from Sweden and the Baltic coast to the Mediterranean Basin. They confirm the local aquatic environment is freshwater, and not brackish. Hallet *et al.* (2003) found low numbers of oospores correspond to times of regional drought and large forest fires around lakes. Higher lake levels, represented by increased *Chara* oospore accumulation rates, corresponded to wetter climate periods. The highest oospore concentrations were post-Roman and at the times when the Ostracod record shows highest numbers, diversity, and the mutual temperature record suggests a colder climate than at present.

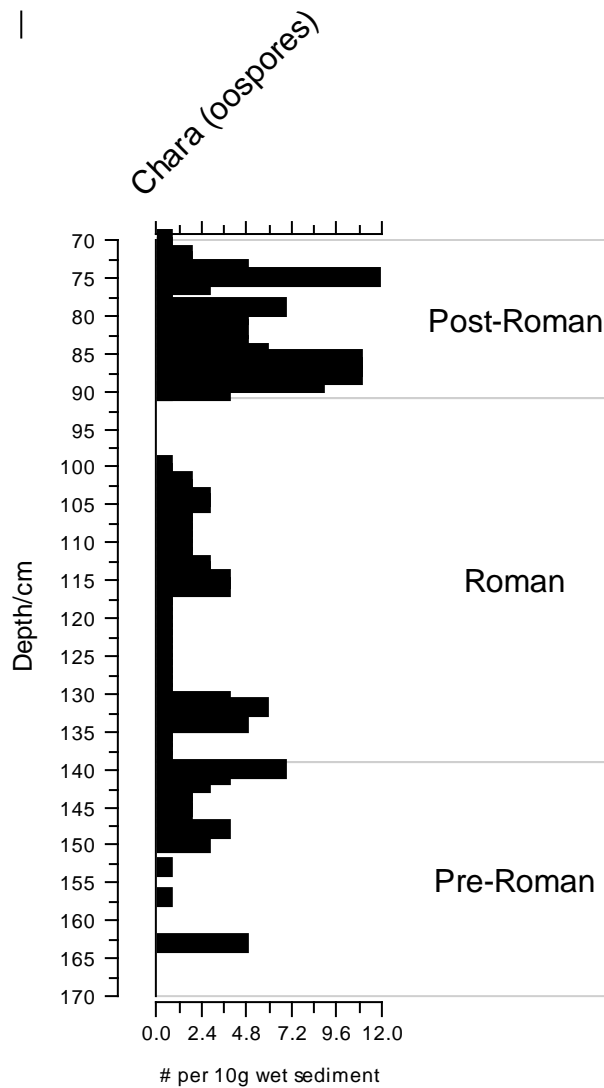


Figure 79 Results of Stonewort oospores D6/Core 3

Napoliello Core 7

The oospores of *Chara tomentosa* and *Nitella sp.* were found in the core (figure 81). *Nitella* was found to be present in the Roman and Post-Roman sections of the core, as were *Chara*, although one oospore was found at the base of the core. Their presence suggests the existence of a small pool within the fen during the Roman period, which would also be reflected in the presence of *P. pectinatus* within the plant macrofossil record, with the stoneworts acting as buffers for the nutrient levels in the water. After the Roman period, as the area became wet woodland they continued to grow until at 40 cm the environment became drier, and returned in the upper 20 cm with the onset of wetter conditions.

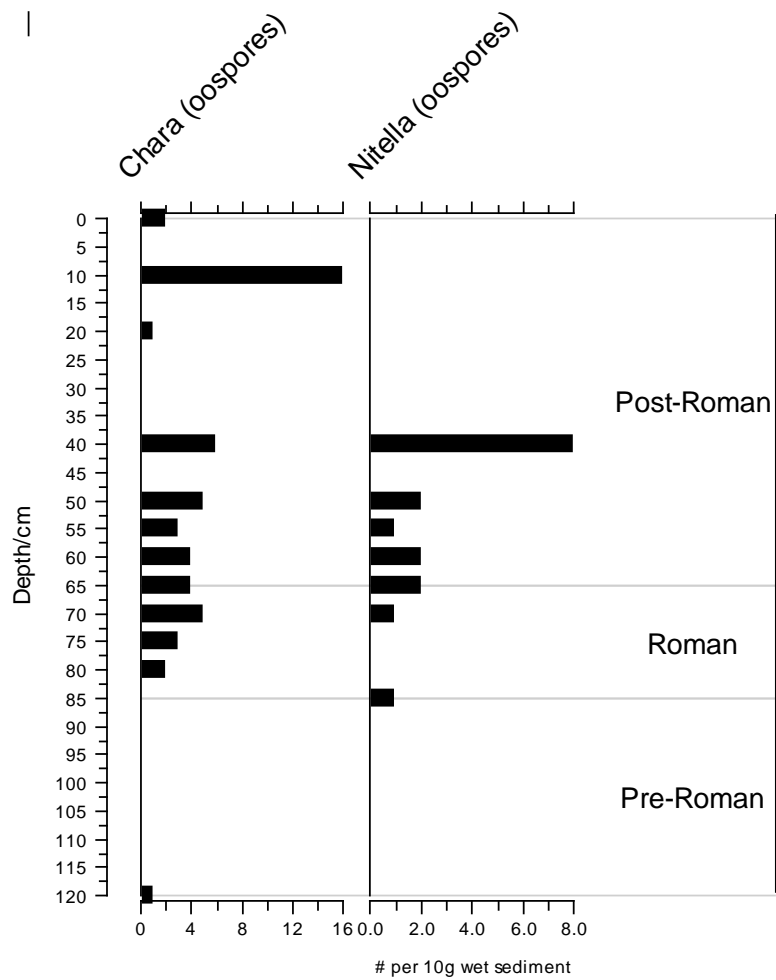


Figure 80 Results of Stonewort oospores Pozzo Napoliello/Core 7

Muraccioli/Core 9

Few oospores (figure 82) were found at all in the core, all belonging to *Chara tomentosa*, were found at depths of 65, 30- 0 cm, which also show the presence of *A. glutinosa*, *Q. robur* and *L. inundata* in the plant macrofossils, which again support the interpretation of this area as a wet woodland.

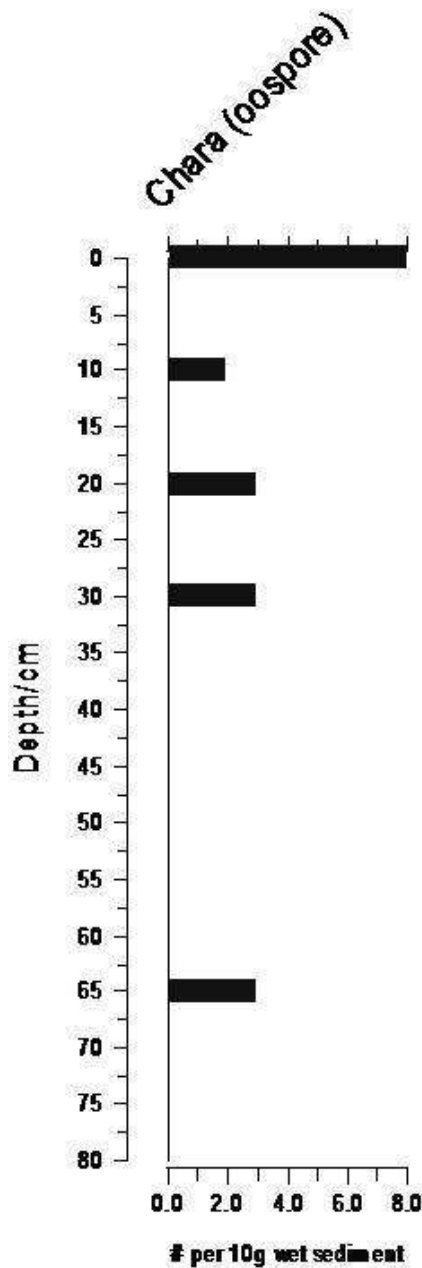


Figure 81 Results of Stonewort oospores Muraccioli/Core 9

4.6.9 Branchiopod Crustaceans

D6/Core 3

The branchiopod crustaceans were found in the form of *Daphnia magna ehippia* infrequently in core 3 (figure 83), providing further proxies for freshwater conditions. Korhola and Rautio (2001) highlighted the sensitivity of *Daphnia* to trophic state, predation, acidification and transparency of lakes. *Daphnia* produce diapausing eggs during sexual reproduction, which are encased in chitinous shells called ehippia

(Pietrzak and Slusarczyk 2006). Ehippia may serve for temporal escape and recolonisation of the habitat or for geographical dispersal and colonisation of other habitats. While dormancy and dispersal of ehippia have been well studied, initial factors determining the fate of the ehippia have remained unknown (Pietrzak and Slusarczyk 2006). The low numbers of ehippia during the early Roman period (130-102 cm) may be due to predation from fish, if any, when it was actually used as a fish pond or even an increase in eutrophication of the pond. The presence of *Daphnia* may be taken as a proxy of high phosphorous levels, indeed Sweetman and Smol (2006) found them dominating in lakes with a total phosphorous range of 14.4–82.5 $\mu\text{g l}^{-1}$. Furthermore, it has been found in contemporary studies in eutrophic lakes that changes in total phosphorous were clearly associated with a shift in species composition and the population structure of evolutionary lineages (Brede *et al.* 2009). The post-Roman period shows a sporadic presence of ehippia, which may be due to changes in phosphorous levels or a change back to more oligotrophic conditions, hence the return of the bryozoan *Plumatella repens*. However, natural populations are subject to a variability of several external factors which may superimpose noise on individual trends. This is exemplified by the fact that inter-annual fluctuations in weather conditions, that cause short-term variability in *Daphnia* biomass, may be of similar magnitude to the long-term variability attributed to pronounced eutrophication.

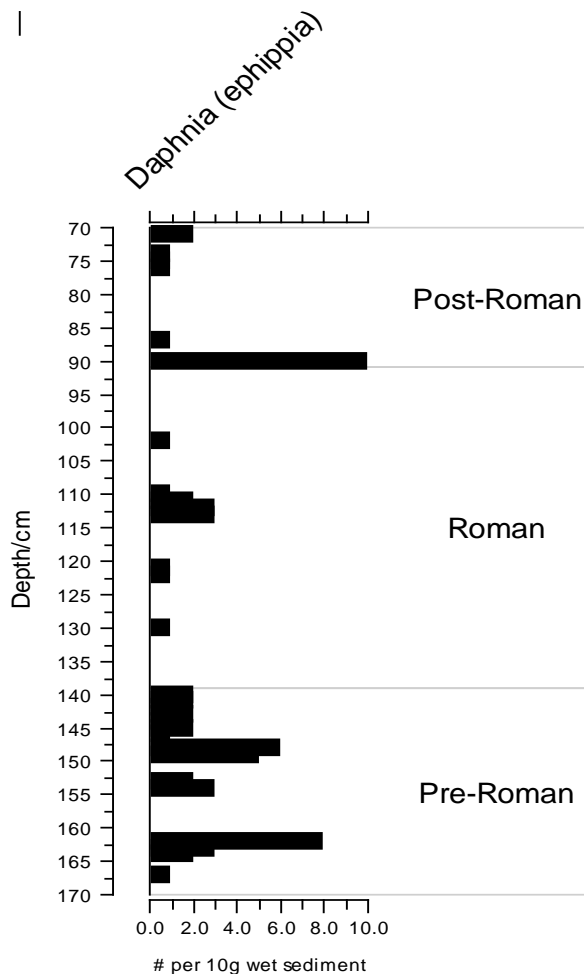


Figure 82 *Daphnia magna ephippia* results D6/Core 3

No other cores showed the presence of *Daphnia ephippia*, which could be due to the pH of the local environment of D6, for *D. magna* lives in environments with pH of 6.5 and 9.5, with the optimum being between 7.2 and 8.5 (Parent and Cheetham 1990). This absence may be due to the fact that none of the other dune slacks provided a perennial ponded environment.

4.6.10 Beetle elytra

Although not one of the shortlisted proxies, the presence of Beetle elytra during the Roman period in core 3 from D6 was noted during the sample analysis. The beetle elytra of the Hydrophilidae were found in core 3, at depths of 121-143 cm (figure 84), which are the family of scavenger water beetles. Within this family, the species is *Hydrobius sp.*, which is very common in weedy or clear standing water, including garden ponds and small temporary pools. Using the age depth model for core 3, the presence of elytra is 112 BC to 2 BC (± 40), which fits with the pottery found during the excavation of the occupation layer of 150-75 BC.

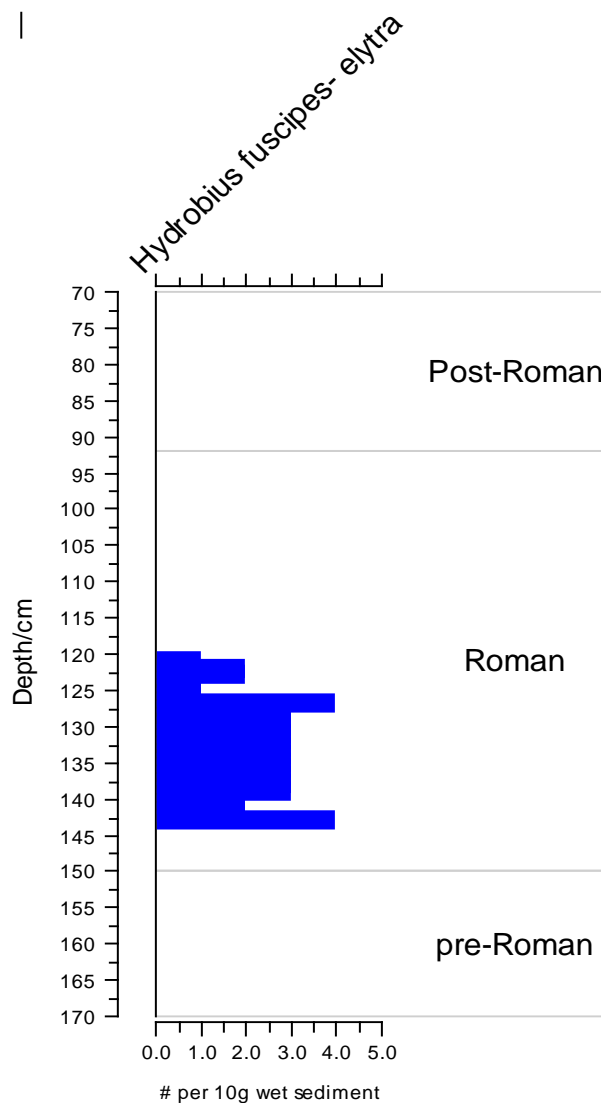


Figure 83 *Hydrobius fuscipes* elytra from D6/Core 3

4.6.11 Particle Size

During the plant macrofossil analysis, the presence of quartz grains was noted in D6 Core 3. Following on from this and the work of de Jong (2006 and 2007) on storminess, it was decided to try to quantify the presence or absence of the quartz grains as well as their size distribution via laser particle size analysis. However, using the protocol based on that of de Jong, i.e. burning off the organic matter, led to the particles clumping together, and this gave artificial peaks in the particle size results. However the ash component from the ashing stage of the protocol allowed quantification of the minerogenic content of the core (figure 85), with the data being normalised so to give the mineral content in mg per g of sample. It can be noted that after Roman abandonment at ca. 420 AD the minerogenic content of the core increases from 0.05 mg/g (at 320 AD/1630 BP) to 0.20 mg/g (464 AD/1486 BP).

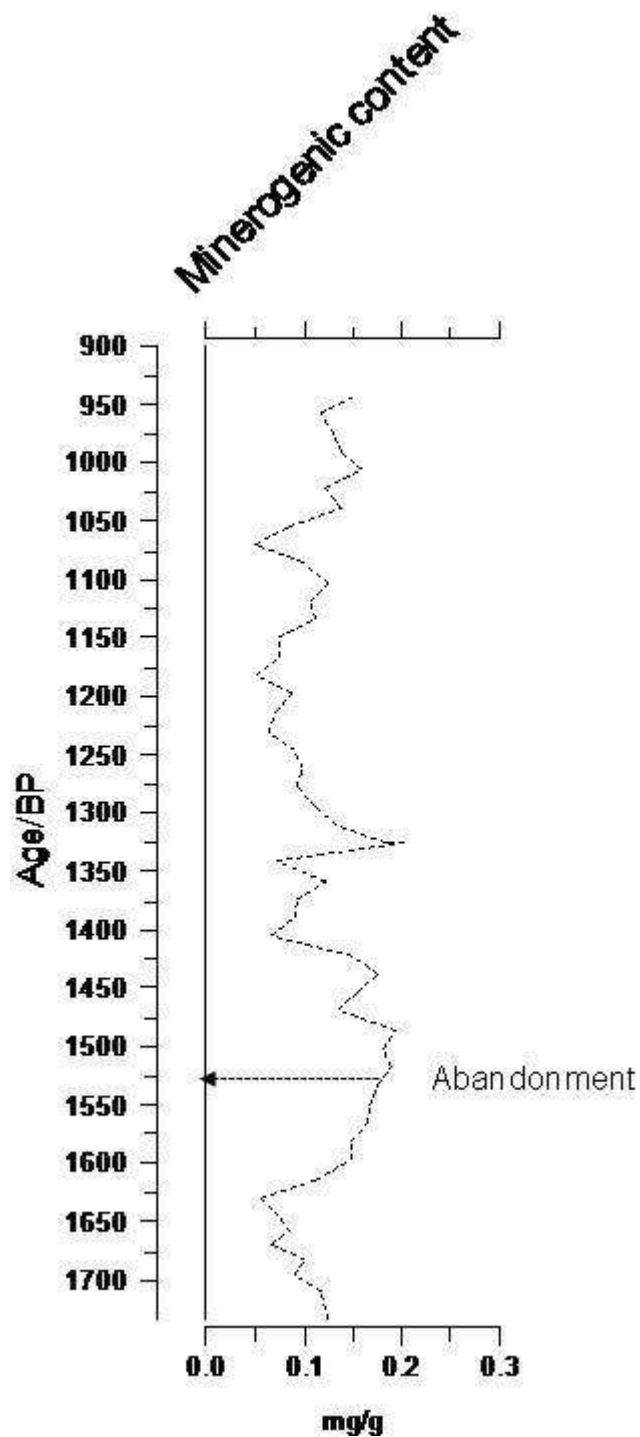


Figure 84 Minerogenic content core 14/D6

4.6.12 Other proxies

C/N ratios were analysed for the basal part of D6/Core 14 by the Chemistry Department at Loughborough University using an elemental analyser. This ratio is an indicator of carbon relative to nitrogen and the results (figure 86) show an increase into the Roman period, peaking at 151 cm (around 100 BC), which maybe further evidence of eutrophication at D6. As dune slacks are generally low in nitrogen, the

increase in nitrogen alone increases from 0.04 mg/g at 173 cm to a maximum of 0.09mg/g at 168 cm, which may be related to the change from freshwater lagoon to slack, before declining at 155 cm to 0.01 mg/g and then increasing again to 0.04 mg/g at 145cm, which may be due to pre-Roman and Roman impact around the slack.

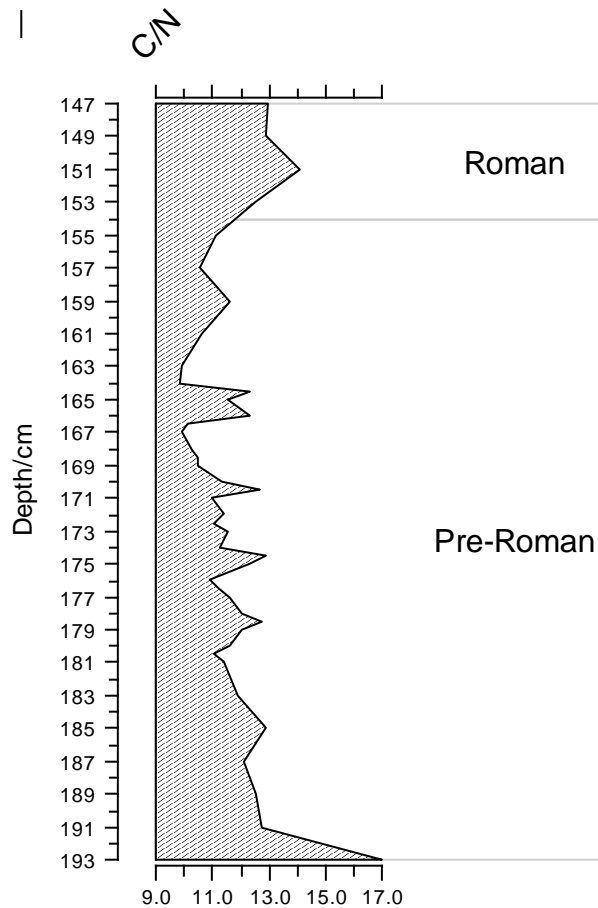


Figure 85 C/N ratio D6/Core 14

4.7 Discussion of proxies

4.7.1 Overview

Prior to the Roman settlement at 100 BC, conditions in the D6 dune slack were similar to Pozzo Napoliello with evidence for a dune slack fen, and whereas the fen environment developed at Pozzo Napoliello, a different environment developed at D6. It is apparent that D6 was altered structurally to become a fish pond, and became permanently, rather than seasonally, wet with the addition of a pipe to pump freshwater into it. The proxies all suggest a change to more eutrophic conditions at

the start of Roman settlement, with the aquatic plant macrofossils showing species of greater eutrophic tolerance with time, this is also seen in the changes in other proxies, with the presence of bryozoans *Cristatella mucedo* and *Lophopus crystallinus*. The decline of *Betula* at D6 during the mid-Roman period may relate to purposeful removal by the Romans, but with the increase in CHAR is an indicator of localised fires. *Betula* is known to be a good firewood, and thus with all the local bathhouses amongst the archaeological remains, it is possible that this was used for fuelling them. The pollen record shows the (extralocal) presence of *Betula* (Bunting pers. comm. 2009) although it is absent from the macrofossil record at this time. The decline or removal of trees, deliberately or not, may aid the eutrophic nature of D6. Another proxy that showed a marked decline was the *Chara* oospores in the early Roman settlement period which correlates with the increased charcoal influx. The absence of *P. repens* statoblasts is also marked by the increase in charcoal influx (CHAR), as noted by Francis (1997 and 2001), which she linked to local deforestation, which may have been removal of the trees around the fish ponds. In addition *Chara* have also been found to become absent during eutrophication but this is not due high phosphorous levels but light levels (Blindow 1988), and have returned in lakes once light conditions improve (Gulati and Van Donk 2002). The pollen results record the presence of arboreal pollen throughout the Roman period; with good correlation between decreasing *Betula* pollen, and increased CHAR, which favours fires nearby (be they natural or anthropogenic in origin). Based on the textual evidence on Roman fish ponds (Higginbotham 1997), the Romans would have had an artificial water system feeding into the pond, to make it permanent. The excavation results from D6 confirm the presence of water pipes (Claridge, pers. comm.).

Inland from D6, at Pozzo Napoliello, the fire history appears to be important particularly in the pre-Roman period, as the CHAR influx showed its highest peak during this period. This was perhaps due to the pre-Roman settlers, using fire to improve pasture or it could local fires produced by lightning strikes. During the Roman period the site may also have been used for grazing, as some of the plant macrofossils found particularly in Core 7 are those of disturbed ground taxa or species that in contemporary settings are found on grazing land. As to what was disturbing the land or grazing it, this may be related to the game park idea that was put forward in chapter 1, but this will be looked at in chapters 6 and 7 in more detail. Few oospores of *Chara* or *Nitella* were found in the pre-Roman part of the Pozzo Napoliello core which may be due to the CHAR influx. The two cores from Pozzo

Napoliello and the neighbouring dune slack, (cores 7 and 8), both show the presence of wet woodlands in the post-Roman period. This can be seen in both the plant macrofossil and the mollusc record. Although some differences in plant macrofossils are distinguishable in both cores, the presence of the calcium carbonate nodules within Core 8 perhaps suggests that part of the area within the wet woodland was a marl fen.

At Muraccioli, core 9, a post-Roman reconstruction, shows a similar environment to that of Pozzo Napoliello (based on core 7). They both show wet woodlands with typical wetland species in the plant macrofossils.

Therefore, as the period of Roman settlement came to an end at Castelporziano, wet woodlands developed at Pozzo Napoliello, D6 and Muraccioli. The influx of charcoal after the Roman period remained comparatively low until recently, which as noted relates to a known modern incident, i.e. a fire from 1944.

4.7.2 Eutrophication – Evidence and causes in the D6 cores

Various lines of evidence based on the proxies from D6 appear to show evidence of the onset of eutrophic conditions at start of Roman period including a rise in organic matter, increased sedimentation rate, fewer aquatic plant macrofossils, and the absences of ostracods, herbaceous plant macrofossils, *Plumatella repens* statoblasts, and the oospores of stoneworts. This eutrophication was confined to D6 only, as no other areas showed proxy evidence for it, thus a localised event. This time period is also associated with the presence of *Myriophyllum spicatum*, *Ceratophyllum demersum*, and *Typha angustifolia* in the aquatic plant macrofossils, *Lophopus crystallinus* and *Cristatella mucedo* in the bryozoan statoblasts. This then raises the question, why did the local environment become eutrophic and was it anthropogenic or natural?

What is eutrophication based on the evidence from D6/Core 3?

The increased organic matter was clear from the LOI data and was likely to be related to nutrient enrichment enhancing primary production with the system, which has been defined by Nixon (1995) as eutrophication. The *Plumatella repens* statoblast became absent as did the ostracods. This absence can be explained by *P. repens* being highly sensitive to organic matter, whereas the absence of ostracods

may be due to hypoxia. Oxygen depletion, or hypoxia, is a common effect of eutrophication in bottom waters. This effect may be episodic, occurring annually (most likely in summer/autumn), persistent, or periodic due to the coastal location of D6. Further evidence for eutrophication came from the presence of *Lophopus* and *Crisatella* given their contemporary environments are high in both nitrogen and phosphorous. The overloading with nitrogen and phosphorus may have led to a series of undesirable effects, for example excessive growth of planktonic algae increasing the amount of organic matter settling to the bottom (Schindler 1977). The following section will examine possible causes of eutrophication.

Climatic induced eutrophication

Quantifying the links between climate variability and coastal eutrophication is important given predictions that the earth's climate may become more variable over the next 100 years (Houghton *et al.* 2001). Precipitation, evapo-transpiration and runoff are all expected to increase globally (Miller and Russell 1992), and hydrologic extremes such as floods and droughts may become more common and more intense (Easterling *et al.* 2000). Changes in global temperatures and the hydrologic cycle may influence estuarine and coastal eutrophication in two main ways. First, the magnitude and seasonal patterns of freshwater and nutrient inputs would alter and influence nutrient-controlled coastal productivity. Second, the characteristics of the physical environment may change, thereby affecting the susceptibility of coastal and estuarine ecosystems to eutrophication. Therefore, if the climate as hypothesised changed from a colder period ca. 975-250 BC (the Subatlantic period) to a warmer period ca. 250 BC-450 AD (the Roman warm period) and to a colder period again ca. 450-950 AD (the Dark Ages cold period), similar scenario as expected today maybe noted in the palaeoenvironmental reconstruction. Therefore, the change to eutrophic conditions at D6 may have been climatic, rather than anthropogenic in origin. However, the local environment was changed from being seasonally wet to permanently wet, but this was not due to climatic factors but anthropogenic, ones are examined in the next subsection.

In relation to literature on climate at the time of the Romans, Purcell (1998, p4) claims that "*Much of the west coast of central Italy was in Antiquity very wet*", which is a vague statement but if this was the case, increased precipitation would result in more water, sediments, and nutrients reaching D6, where they are may have enhanced eutrophication, through nutrient-enhanced production, or increased

stratification, or even both (Cloern 2001; Rabalais 2004). However, reduced precipitation would result in a lower amount of nutrients and water reaching the coastal zone and, perhaps, result in oligotrophication (Rabalais *et al.* 2009), not eutrophication.

Anthropogenic induced eutrophication (1): Use as a fish pond

As well as climatic influences, anthropogenic impacts can cause eutrophication via cultural eutrophication, which is the process by which human activities increase nutrient input rates to aquatic ecosystems and thereby cause undesirable changes in surface-water quality. One example of this is the eutrophication event that occurred in Lago Monterosi associated with deforestation during the construction of the Via Cassia in 171 BC (Hutchison 1970).

As stated many times throughout this thesis, D6 was made permanently wet by its adaption as a fish pond fed by piped freshwater. The fish ponds were early forms of aquaculture; therefore impacts from contemporary fish farms may point to reasons why eutrophication may have occurred at D6. Despite the fact no fish bones were found in any of the cores, it is now known from the archaeological evidence this was the intended use of the site (Claridge pers. comm.). The eutrophication effects of modern fish farming can be considered at several different scales, from local effects in the immediate surroundings of the fish farm to the contribution to a larger area away from the farm. Farm emissions consist of uneaten feed, faeces and urinary excretions. The uneaten feed and a considerable part of the faeces are emitted as rapidly sinking particles that settle on the sediments under the fish cages if conditions are still, if not they will take longer to settle, and thus have an impact further afield (Brown 2002). Most of this material is organic and the nutrient concentrations are high. Phosphorus concentrations in the farm emissions are typically a magnitude higher than in unaffected sediments (Hall and Smol 1992; Holby and Hall 1991; Kelly 1993).

Anthropogenic induced eutrophication (2): Site alteration = Eutrophication?

Another possible cause of eutrophication within D6 is also related to the use of it as a fishpond. The addition of water to make the slack permanently wet, would be done via artificial piping, which would raise the water table in the slack, but at the same time may have led to the nutrient enrichment of the dune slack habitat through

increasing calcium from calcium carbonate from molluscs, gastropods, sand, etc, being washed along in the pipe to the pond.

Unlike other piscinae, there was no evidence that this pond was brackish, as the results from all the proxies from Core 3 indicated a freshwater pond environment. D6 is larger than the rock-cut fish ponds described by Higginbotham (1997). Although fish ponds were a fashionable accessory for rich Roman households, they were also extremely expensive to maintain (Higginbotham, 1997). The archaeological evidence from D6 points to a relatively early date, the structure is one of the oldest on the Tyrrhenian coastline (of those that are known and have been excavated), but also that any use was short-lived.

4.8 Results of analyses of samples from archaeological excavations at Castelporziano

4.8.1 Overview

As well as taking cores from the dune slacks, bulk sediments from the archaeological excavation were analysed for archaeobotanical remains, i.e. seeds, as well as molluscs, stonewort oospores, Bryozoan statoblasts, *Daphnia* ephippia, and geochemistry. The bulk samples were from the Vicus Augustanus (the village part of the Roman settlement) and D5 (a fishpond/figure 87), see table 14. Additional material came from the excavation archives, which contained all the molluscs found during excavations over a fifteen year period, and molluscs found during flotation of other bulk material from the Vicus Augustanus.

- CPS 07 D5 Tr. 1 (1)
- CPS 07 D5 Tr. 1 (5)
- CPS 07 D5 Tr. 1 (6)
- CPS 07 D5 Tr. 1 (7)
- CPS 07 D5 Tr. 1 (8)
- CPS 07 D5 Tr. 1 (9)
- CPS 07 D5 Tr. 1 (10)
- CPV 02 H3 11
- CPV 02 H3 16
- CPV 03 YG 24
- CPV 04 YG 52
- CPV 04 YG 81
- CPV 05 YH 10
- CPV 07 H Tr. 9 (6)
- CPV 07 H Tr. 9a (1)
- CPV 97 SA 69

Table 14 Locations of bulk sediment samples (CPV = Vicus Augustanus; CPS = Survey)

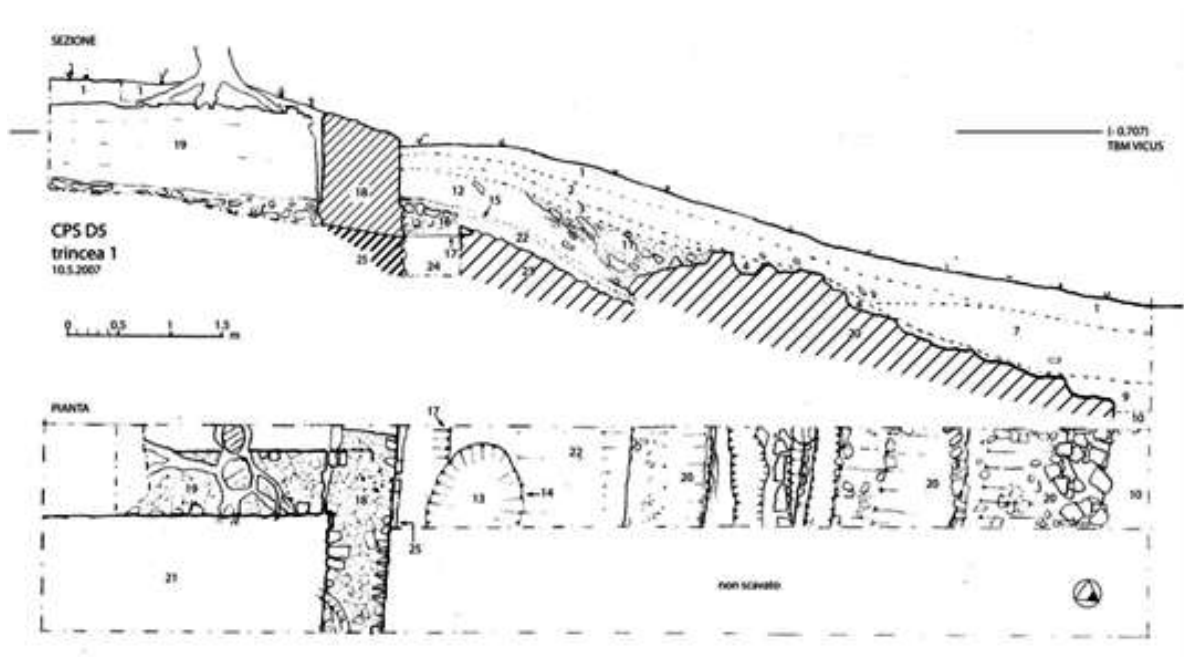


Figure 86 Excavation plan of D5 Trench 1

4.8.2 Methodology

All bulk samples were treated in the same way as the other sample material. (See Appendix 2 for details). All data is presented as tables drawn with Microsoft Word or plotted using Microsoft Excel.

4.8.3 Results

Molluscs

The molluscs from the flotation of excavation samples from the Vicus Augustanus showed the presence of four species (Table 15): *Astarte sulcata*, *Eobania vermiculata*, *Turritella communis* and *Truncatella pulchella*. Each species indicates different aspects of the local environment: *A. sulcata* is a marine bivalve living in wet soil; *E. vermiculata* indicates a dry coastal location and is terrestrial. As no archaeological spatial information, as to where the samples were taken in relation to the remains or the modern sea front, as well as any pottery or other datable finds in relation to the samples. Both *Turritella spp.* and *A. sulcata* are both marine species, with *Truncatella ssp.* live in a habitat that is neither fully terrestrial nor fully marine all suggest a near shore position but as no spatial or chronological information was found in relation to the archaeological record beyond from the Vicus Augustanus only this general picture can be gleaned.

The 2nd set of molluscs came from the excavation were all marine in origin, with the key species being *Donax variabilis* and *Ostrea edulis* (figure 88), which can both be used as food. The samples came from four areas, Via Severiana, Street B (of the Vicus Augustanus), the forum and building Y of the Vicus Augustanus, which showed high abundances of remains, particularly the species *D. variabilis* and *O. edulis*. Whereas other areas did show the presence of molluscs, but not in as high numbers as these areas and only contained *D. variabilis* and *O. edulis*. Could the *O. edulis* have been growing in the fish ponds or were they living locally? Given the pottery dates for the contexts they were found, 1st century AD at the Via Severiana and Street B, this is later than the earliest pottery dates associated with the use of D5 from 1st century BC. However, as no remains were found in Core 6 relating to the Roman settlement, it is not possible to know if D5 was brackish, c.f. D6 which contained freshwater proxies.

Context (CPV 86)	Astarte Sulcata	Eobania vermiculata	Turritella communis	Truncatella pulchella
11 (1)	6	0	0	0
23 (8)	0	0	2	0
27 (6)	0	0	1	1
27 (7)	0	0	0	3
28 (9)	2	1	2	0
28 (10)	1	0	0	0
40 (12)	0	0	1	1
43 (13)	6	0	10	0
54 (17)	0	0	1	2
66 (20)	0	2	1	0
70 (21)	0	0	5	0
72 (22)	2	0	1	0
80 (25)	2	0	2	0
87 (31)	1	0	0	0

Table 15 Molluscs from flotation samples

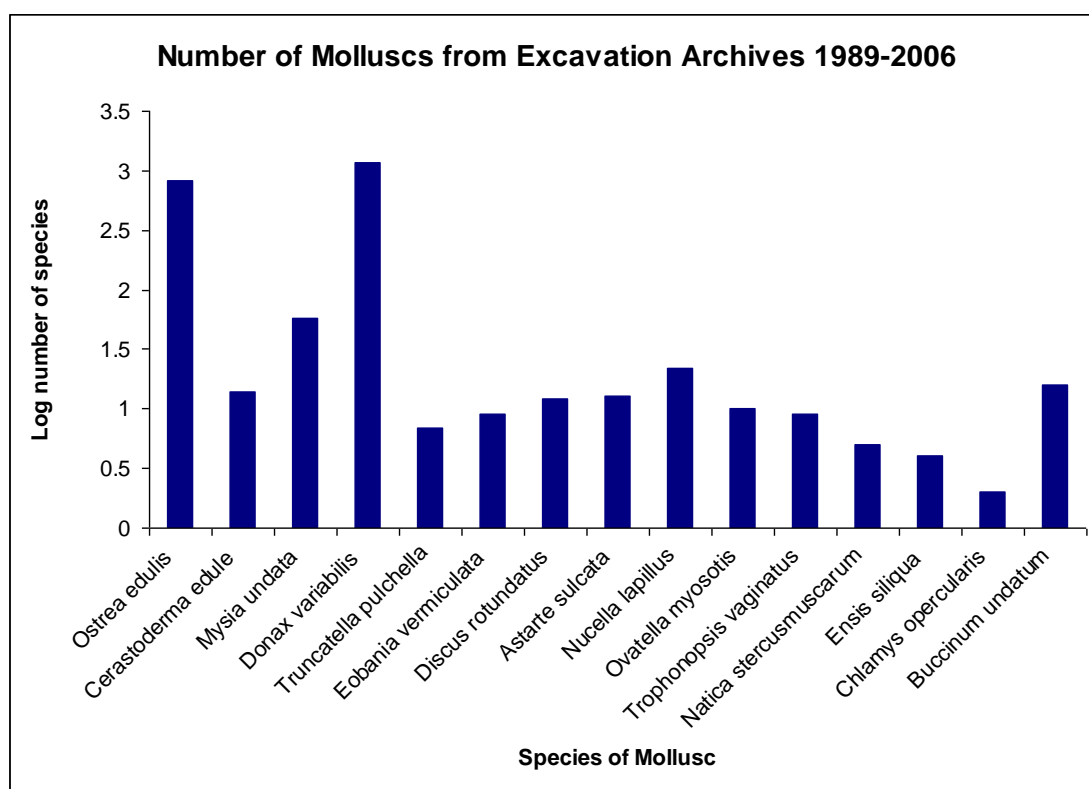


Figure 87 Log of individual species count from Excavation archives 1989-2006

Only two of the seven bulk sediment samples from D5 showed the presence of molluscs (Table 16), with context 9 showing the presence of *Zonitoides nitidus* and *Phenacolimax major* and context 10 only *Acroloxus lacustris* present. The presence of *Z. nitidus* and *P. major* show the local environment of D5 from context 9 to be wet woodland, as found at D6 (Core 1) and *Z. nitidus* was also found at Pozzo Napoliello (Core 7) during the post-Roman settlement. Whereas *A. lacustris* found in context 10

was also found in the Core 6 (D5), Core 1 (D6) and Core 7 (Pozzo Napoliello) during post-Roman settlement. They can be found marsh drains, which are wholly artificial in origin, and will silt up, eventually becoming marsh if not managed.

Trench 1/ D5 Context number	Zonitoides nitidus	Phenacolimax major	Acroloxus lacustris
9	5	3	0
10	0	0	6

Table 16 Molluscs from D5 bulk sediment

Archaeobotany

The results of the seeds, bryozoan statoblasts, *Daphnia magna ehippia* and stonewort oospores in the bulk sediments from D5 (Table 17) varied in presence within the context but show general agreement with the molluscs of contexts 9 and 10, in terms of local environment. Context 9 shows the presence of *Betula sp.* and *Carex sp.* which would support the interpretation of wet woodland. Whereas context 10 shows the presence of grasses and a specific form of grass, *Festuca*, which can be found in marshes, with the *Chara* oospores indicating the presence of freshwater, which, agrees with the findings in the molluscs of *A. lacustris*. The other contexts show the presence of seeds that would fit with a local wetland environment, i.e. wet woodland, similar to that found in context 9. Bryozoan statoblasts were absent, apart from at context 5, and *Daphnia magna ehippia* were absent from all contexts

Geochemistry

The geochemistry results from the bulk samples of D5 (Table 18) are harder to interpret without a scale; however on examination of the results with the excavation drawings some remarks can be made. Based on the previous results, of molluscs and plant macrofossils, alongside the excavation drawing (figure 87), context 1 is the modern top soil and context 10 is the bottom of the trench, which may indicate the pre-Roman level, when compared with the findings of Core 6. Context 9 is the context that may cover the Roman period, which shows high levels of phosphorous, and sulphur, which would agree with the with the absence *Daphnia magna ehippia* and bryozoan statoblasts. Context 7, although not shown on the excavation drawing, shows the same high levels of phosphorous and sulphur as context 9, and in core 3 *Juncus effusus* was also found with the absence of *Betula sp.*, which suggests this to

may be a Roman layer. This correlates with the finding in the cores 3 and 14 of eutrophication at the adjacent fish pond of D6, with the phosphorous and sulphur cycles associated with eutrophication, although dune slack groundwater has been found to have high levels of sulphate (Stuyfzand 1993). The levels of lead throughout the contexts is lower than found in other studies such as Settle and Paterson (1980), Hong *et al.* (1994) Shoytk *et al.* (1997), Renberg *et al.* (2009), which have suggested heavy pollution in the Roman period due the use of lead in this period. However, the source of lead in this context is more likely to be related to leaching from the lead pipework found during excavation, relating it to the Roman landuse (as there is no archaeological evidence to date of metal industry at Castelporziano).

Discussion

The results from the mollusc archives and flotation samples add to the picture of Roman life at Castelporziano, indicating aspects of diet, and the general environment at the Vicus Augustanus. The results from the analysis of samples taken during the excavation of the D5 fish pond are valuable for reconstructing the environment there, as the presence of macroremains in Core 6 did not extend to Roman period, but can related to the findings of neighbouring D6 from Core 3. Analysis of the bulk sediment shows evidence for eutrophication, with high levels of sulphur and phosphorous, potentially leading to the absence of the bryozoan *Plumatella repens* at both sites, and absence of *Chara* oospores, which could also be related to local fires as noted in Core 3 and context 7. The phosphorous levels may also be an indication of anthropogenic impact, which would further aid contexts 7 and 9 being of Roman date, and context 1 being the current top soil (as indicated in the excavation drawing/figure 86). General sources of anthropogenic phosphorus include: human waste; refuse, especially organic discard derived from bone, meat, fish, and plants; burials; and ash from fires (Holiday and Gartner 2007). The levels of chlorine in contexts 9 and 10 appear to be far higher than the other contexts, which may be related to the near shore position of the site at that time. The other elements relate to the minerals discussed in the pilot study in regard to core 1, and not directly to the environment, as noted there the local minerology was examined by Andy Bicket as part of the larger AHRC project and is beyond the scope of this study to examine in greater depth. The seeds suggest that the local environment of D5 changed from a fixed dune (similar to base of core 3), to a wet woodland.

Trench 1/ D5 Context number	<i>Quercus</i>	<i>Betula</i>	<i>Carex</i>	<i>Juncus</i>	<i>Eleocharis</i>	<i>Poaceae</i>	<i>Festuca</i>	<i>Chara</i> oospores	<i>Plumatella</i> <i>repens</i> statoblasts
1	5	0	0	0	0	0	0	0	0
5	0	17	0	0	0	0	0	4	2
6	0	17	4	0	7	0	0	2	0
7	0	0	0	1	0	0	0	0	0
8	0	4	0	5	0	0	0	5	0
9	0	19	1	0	0	0	0	3	0
10	0	0	0	0	0	23	5	3	0

Table 17 Archaeobotany results from D5 bulk sediment

Trench 1/ D5 Context number	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Ni	Hg	Pb
1	2.16	1.38	4.68	26.07	1092.0	42.4	194.2	1.52	2.66	0.1955	3.25	111.9	4.7	104.3
5	1.55	1.02	2.85	18.03	634.0	42.0	100.0	1.01	3.93	0.1568	2.15	69.8	5.0	209.0
6	2.18	2.80	2.32	24.21	419.0	27.0	99.7	1.07	1.05	0.1556	2.53	104.6	4.6	100.5
7	1.56	2.34	2.80	13.36	792.0	51.2	136.1	0.68	0.86	0.1234	2.34	49.3	5.0	125.5
8	1.95	1.22	2.34	23.61	419.0	20.0	82.9	1.08	1.06	0.1388	2.41	100.7	5.7	87.1
9	2.09	1.04	3.23	25.19	722.0	81.0	526.5	1.23	0.95	0.1206	2.15	82.9	6.7	72.9
10	2.02	1.13	3.11	16.29	686.0	47.4	540.3	1.61	0.84	0.1355	3.22	74.8	8.0	89.3

Table 18 Geochemistry from D5 bulk sediment

*Na, Mg, Al, Si, K, Fe and Ti are in %; P, S, Cl, Ni, Hg, Pb all in ppm (parts per million)

Synthesis of results for palaeoenvironmental reconstruction from Cores

Figure 89 shows the age/depth correlations for cores at D6, Pozzo Napoliello and Muraccioli (3, 7 and 9 respectively).

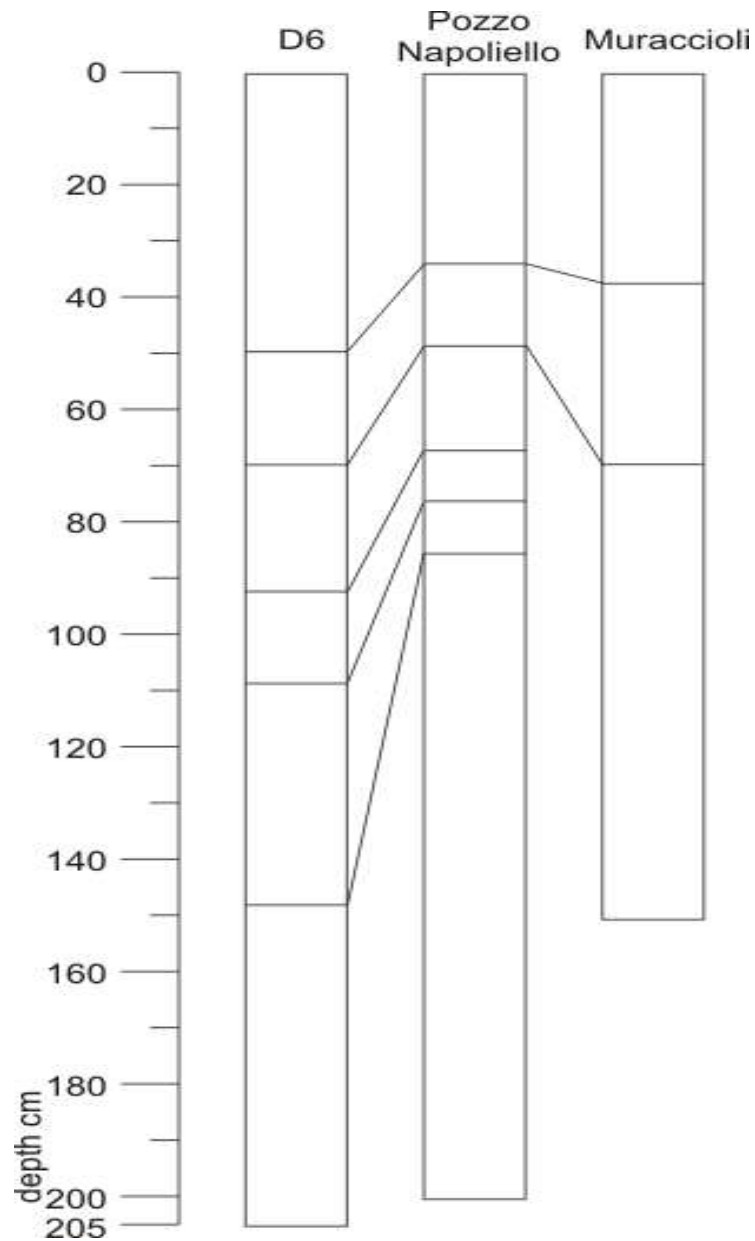


Figure 88 Depth comparison for main three areas in Castelporziano

	pre-Roman	Roman	post-Roman
LOI	D6: gradually increasing PN: Remains constant at 0.5% M: Low and constant (<1%)	D6: Increases and peaks at 25% at 134cm, then decreases to 5% at 122cm, and remains constant. PN: Gradually increasing throughout and peaking at 3% at 60cm M: Low and constant (<1%)	D6: Remains constant at 5% PN: Gradually increases from 2% to 5% at 20cm and remains constant M: Gradually increasing until 40cm, when it reaches 4%, and remains constant thereafter.
Plant Macrofossils	D6: Dominated by aquatic macrophytes and herbaceous PN: Potamogeton and Poaceae with mosses	D6: Betula present until 134cm, few aquatics except for Apium, no herbaceous and gradual increase in grasses and sedges particularly Eleocharis PN: Herbaceous with some Alnus, mosses and the non-pollen polymorph Glomus cf. fasciculatum	D6: No herbaceous and few grasses or sedges; aborealis show presence and few aquatic species PN: Wet woodland of Alnus with some herbaceous species and mosses M: Wet woodland of Betula and Quercus with some herbaceous species and mosses
Macrocharcoal	D6: Gradually increases and peaks at 70 pieces/cm ² /year at 200BC, before decreasing PN: Gradually increases and peaks at 29 pieces/cm ² /year at 650-550 BC before decreasing M: Peaks at 18 pieces/cm ² /year 1050 AD to 1150 AD	D6: Gradually increases and peaks at 129 pieces/cm ² /year at 0-50 AD before decreasing PN: Gradually increases to 8 pieces/cm ² /year at about 50 AD and then decreases to 3 pieces/cm ² /year at about 450 AD.	D6: Remains constant at 12 pieces/cm ² /year until 950 AD PN: Gradually increases to 10 pieces per cm ² 1950 AD and then decreases
Stonewort Oospores	D6: Chara present from 162 cm PN: Generally absent	D6: Chara present but decline from 130-115 cm PN: Chara and Nitella present	D6: Chara present throughout PN: Chara and Nitella both present until 40 cm then Chara only M: Present at 65 cm, then absent until 30 cm
Bryozoan Statoblasts	D6: Plumatella repens only	D6: Plumatella repens (absent 136-113 cm), Cristatella mucedo and Lophopus crystallinus (present 129 to 114 cm and 141 to 114 cm respectively)	D6: Absent until 70cm, then Plumatella repens only M: Plumatella repens 50 and 10 cm only
Other Proxies	Pollen (D6): AP: NAP increases in favour of AP throughout period from 50:50 to 60:40 Ostracods (D6): Cyclocypris serena only Molluscs (D6 and PN): Absent	Pollen (D6): AP:NAP begins as pre-Roman (60:40), then increase in NAP at 120-110 cm to 30: 70, before becoming 60:40 at the end of settlement. Ostracods (D6): Absent Molluscs (D6 and PN): Absent	Pollen (D6): AP:NAP 80:20 throughout most of the period, although decreasing to 70:30 in top 10cm. Molluscs (D6 and NP): Wet woodland Ostracods (D6): Cyclocypris serena, Potamocypris villosa Ilyocypris inermis and Limnocythere inopinata

Figure 89 Summary of results for proxies in the main three areas in Castelporziano

The summary of results shows the similarities and differences across the site (figure 89), in particular the similarities of Pozzo Napoliello (PN) and Muraccioli (M) in the post-Roman period (both being wet woodlands). D6 in the pre-Roman and Roman is markedly different to the other two areas, which may be connected to the Romans making it permanently wet, thus resulting in the presence of other potential proxies such as ostracods, branchiopod crustaceans, and beetles. However, in the post-Roman period D6 also becomes a wet woodland and therefore similar to Pozzo Napoliello and Muraccioli. Therefore in terms of the research questions it is clear that there is evidence of environmental changes, particularly in vegetation cover across the coastal zone of Castelporziano. As to whether the changes were natural or anthropogenic it is quite clear that the faunal richness of the cored sequences in D6 are related to the intervention of the Romans in this particular dune slack which resulted in modification of its hydrology with respect to adjacent, unmodified, slacks.

Chapter 5: Recent and Contemporary Environmental change at the Castelporziano estate

5.1 Introduction

This chapter aims to look at recent and contemporary environmental change within the Castelporziano estate (i.e. the last 50-100 years). Since 1948 the estate has been the property of the Republic of Italy, prior to this the newly established Kingdom of Italy bought the estate in 1872 for hunting (subsequently banned in 1978) (Manes *et al.* 1997). The current estate authorities claim that it is only relatively recently that the environment has been managed, and the current vegetation is perceived as of being “natural” (pers. Comm. Claridge 2006), making the site ideal to look at the legacies of past land use practices, which may continue to influence ecosystem structure and function after those activities have ceased. Consequently, recognition of these historical legacies adds explanatory power to the understanding of modern conditions. This leads on to the final two research questions set out in chapter one, which were as follows:

5. What is the current vegetation of the area and how has it been affected by estate management practices over the last 50-100 years?

6. What evidence is there of a legacy of past land-use practices from Roman times onwards?

This chapter analyses the current vegetation and environment using a series of measures: a baseline vegetation survey; soil chemistry; and Ellenberg indicators, showing the environment on different gradients and comparing them with the measured soil parameters. This analysis then leads on to a section on the known drivers of recent change (mostly anthropogenic in origin) and how these have affected the local environment through analysis of aerial photographs, excavation archives and recent vegetation surveys by other authors. The issue of the legacies of past land use within current vegetation will be examined. This chapter ends with a discussion of the factors that have influenced the patterns of contemporary vegetation at Castelporziano.

5.2 Current Vegetation

The current vegetation was analysed through baseline vegetation surveys, and the analysis of previous work on the vegetation (for example the surveys of Manes *et al.* 1997, Anzalone *et al.* 1990 and Bruno, 1980) and vegetation cover maps (Allegrini *et al.* 2006 and Della Rocca *et al.* 2003). In addition three other methods were used to determine factors (anthropogenic or natural) affecting the current vegetation: pollen rain was used to increase the understanding of the many processes affecting the production and transport of pollen within the Castelporziano estate; Ellenberg indicators were used to record and calculate the position of Castelporziano along several ecological gradients; and finally soil indicators were used to determine how they affect the current vegetation. This survey was limited to the coastal zone of the Castelporziano Estate, the area that included all of the archaeological remains associated with the Laurentine Shore, as this could then be related to the findings of the palaeoenvironmental reconstruction from the dune slack cores.

5.2.1 Baseline vegetation survey

A standard baseline vegetation survey was used to identify the extent and type of habitats and vegetation biomes, within the Castelporziano estate, and, as noted above, was confined to the coastal strip. The vegetation was surveyed by the author from west to east along a transect and surveyed at regular intervals of 100m, with quadrats 100m by 100m, following the main estate road (Via di Telefono) and from north to south at the Vicus Augustanus and Fishpond areas (Figure 91). The initial survey was undertaken during April-May 2007, in May 2008 further work was carried out to examine recent changes and was extended to include Castelfusano (the neighbouring estate) after a core was taken from there for the palaeoenvironmental reconstruction. Within each quadrat the vegetation was surveyed using the following criteria (based on the Canadian Forestry Commission's Form 6: Ground Vegetation Survey 1994) and identified using Touring Club Italiano (1958), Vedel and Rush (1978), Blamey-Grey-Wilson (2004) and Fletcher (2007) keys.

The ground vegetation was classified into broad types (i.e., mosses, ferns, herbs, etc.) and an association table was constructed using the traditional methods of Braun-Blanquet (1964).

- Identification of the ground vegetation to the family, genus, or species level where appropriate.

- An estimation of the percentage of the subplot covered by each ground vegetation type.
- Identification *in situ* of the main vegetation biomes.

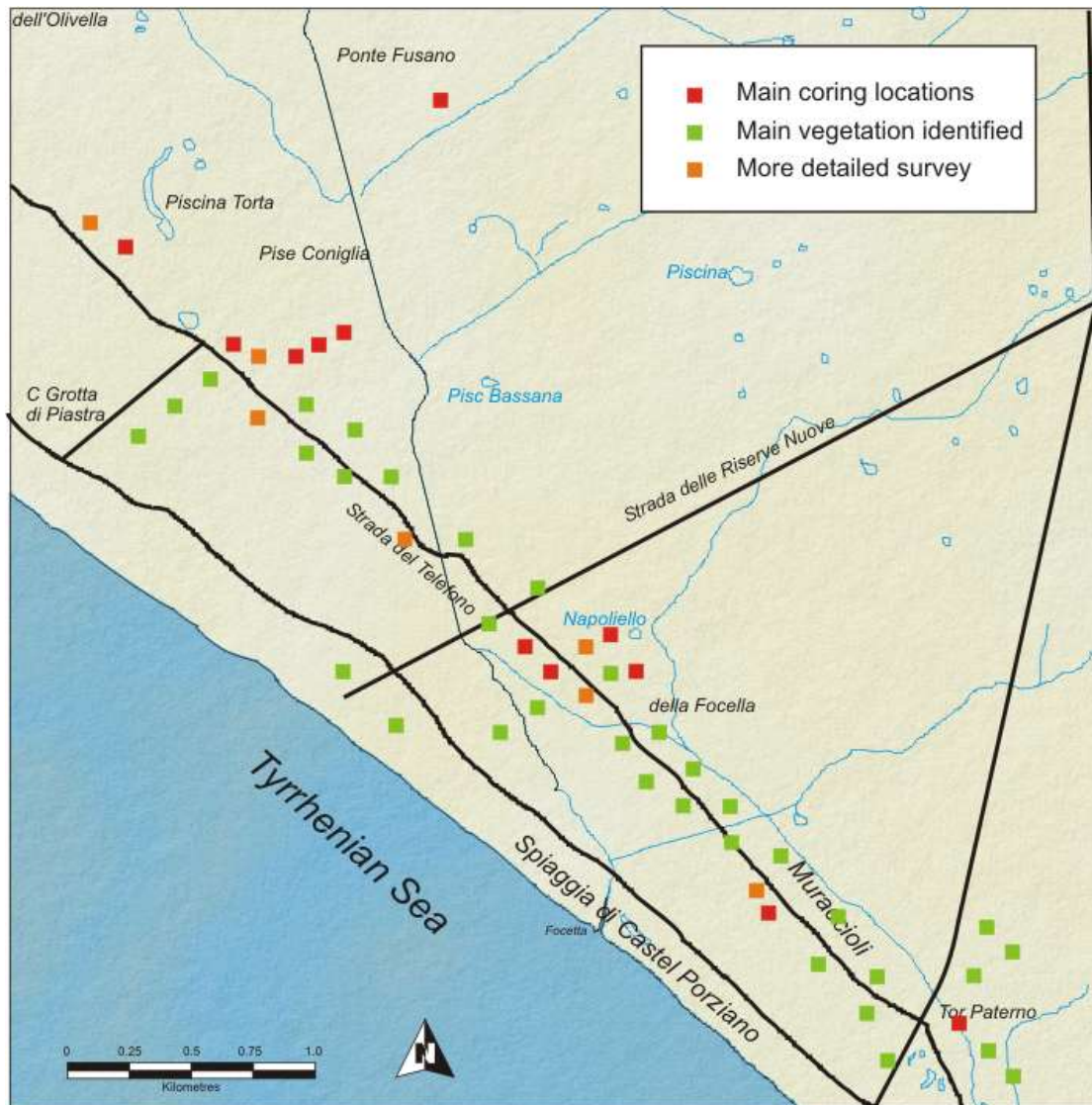


Figure 90 Location for vegetation survey in relation to coring locations

5.2.1.1 Results of the baseline vegetation survey

Between the two estates, Castelfusano and Castelporziano, lies an area of reforestation of *Pinus pinea* and *P. pinaster*, planted as part of one of the many reforestation schemes on these estates, the most recent of which commenced in the 1940s. The planting carries on south-eastwards into the Castelporziano estate and mixes with the macchia at the north-western edge of the Vicus Augustanus. At the Vicus Augustanus, in 2007, the macchia type was that associated with *Q. ilex*, on either side of the Via del Telefono. Dendrochronological examination of the trees in

this area showed them to be relatively young, at most 50 years old, which suggested that an event had resulted in older vegetation no longer being present. This event is thought to have been a large fire that had affected part of the coastal area in 1944, details of which are discussed section 5.3. By 2008, some of the *Q. ilex* had been coppiced or cut back by the estate to allow better transportation around the estate, i.e. “to allow double decker buses access to the nature reserve”, remarked one of the estate workers. This action has allowed *Asphodelus microcarpus* to colonise the areas around the archaeological remains. According to Le Houerou (1979, 1981) this species is very common in North Africa and expands extensively usually because of long-term grazing, likely to be due to *Dama dama*, and *Capreolus capreolus italicus* at Castelporziano, as they have no natural predator. Additionally, this species can serve as a sign of environmental degradation, i.e. reduction in soil nutrients (Touring Club Italia 1958) and may be an indicator of how sensitive the local environment is to change.

Immediately south of the Vicus Augustanus, the vegetation was dominated by macchia associated with the *Q. ilex*, each side of the Via del Telefono. However, a clearing 1km south of the Vicus Augustanus, at the junction of the Via del Telefono and one of the estate’s drainage canals (for water flowing to the sea), showed quite different vegetation. The vegetation here was sparse, consisting of *Ammophila* spp. and one *Q. ilex*. This is probably the result of deliberate removal of vegetation by the estate.

From Pozzo Napoliello to the south western corner, along the Via del Telefono, towards Tor Paterno, the denser the macchia with *Q. ilex* becomes. However, at Muraccioli, the reminder of the former marsh is still evidenced by the hygrophilous vegetation, in particular *Gymnocarpium dryopteris*, which dominates over the macchia scrub. This is also true on near the D5/D6 “fish ponds”, which had *G. dryopteris* growing along the edges of both structures, particularly D6. The fishponds varied in terms of vegetation, with D6 showing the presence of a central pond with the presence of *Potamogeton obtusifolius* and stoneworts of *Chara* and *Nitella* on the surface, whereas D5 were completely dry. Additionally both D5 and D6 showed the presence of at least one species of *Quercus*, *Fraxinus* and *Arbutus*, typical of a macchia with Holm oak.

At Tor Paterno the contemporary vegetation is a mixture of afforested *Pinus pinea* and *Q. ilex* with macchia, with *Asphodelus aestivus* at the junction of the roads, behind Tor Paterno’s medieval chapel and Roman bath house lies a different type of

macchia, associated with *Arborescent matorral* with *Juniperus spp.* Other species in this area included *Laurus nobilis*, which is why the area was known as Laurentum by the Romans.

The vegetation towards the coast (from north to south) is more dense macchia with *Q. ilex* alongside *Sphagnum subsecundum* and *Hedera helix* covering the standing archaeological remains, particularly at the north western end of the Vicus Augustanus, which gradually disappears leaving just the macchia with *Q. ilex* beyond the Vicus Augustanus that becomes higher in both macchia and Garigue closer to the sea.

At the modern seafront, the vegetation was typical of Mediterranean beach and/or dune vegetation, with 95% being *Ammophila spp.*, *Silene colorata* and *Ononis variegata*.

The Castelfusano estate for the last 30 years has not been subjected to the same management as the Castelporziano. For this reason, Castelfusano may have shown differences c.f. Castelporziano, but was subject of a fire in 2000. The survey showed an under-storey of sclerophyllous species, which were being replaced by pine trees, thereby contributing to establish natural climax vegetation, mainly represented by holm oak woods, i.e. a macchia associated with *Q. ilex*.

5.2.2 Pollen rain studies

The pollen rain associated with the modern vegetation was also investigated, as discussed in chapter 4. The overall findings show that the pollen spectra of moss cushions are dominated by high pine and oak pollen percentage values. However, some areas like Vicus Augustanus, D6 and Muraccioli did show the presence of pollen from other vegetation types, some of which were found in the baseline vegetation, but none were macchia species. This may have been due to most macchia species being insect pollinated, and therefore producing much less pollen. *Ericaceae* and *Cyperaceae* were both found in the contemporary vegetation growing at D6, *Acer* and *Alnus* found at the Vicus Augustanus and Muraccioli. The ground flora elements of the contemporary vegetation were not represented in the pollen record.

The next two sections presents work carried out by others on Ellenberg Indicators and soil indicators. To carry out the detail needed for such work would be a study in itself; however, the results are important and need to be considered when looking at the recent environmental changes and for understanding the contemporary environment.

5.2.3 Ellenberg indicators

Vegetation is not only the essential component of most terrestrial ecosystems, but it is also important to use the plant species themselves, as they carry information about the changes in environmental conditions in which they grow (Hill *et al.* 1999). Ellenberg's indicator values (Ellenberg *et al.* 1992) provide tabular data about habitat requirements of nearly all Central European vascular plant species. By calculating the mean Ellenberg value of all plants recorded in a study site/plot, the position of a site/plot along particular ecological gradients can be calculated (Jones *et al.* 2007) or changes in vegetation communities over time can be assessed (van der Maarel *et al.* 1985). This is done by expressing the average niche along gradients related to light (**L**), temperature (**T**), continentality of the climate (**K**), soil moisture (**F**), soil pH (**R**) and Nitrogen (**N**). These numbers constitute a relative scale, one that cannot be directly linked to 'real' pH or nitrogen availability. The Ellenberg system has enjoyed widespread application in plant ecology studies in Europe (e.g. Hill and Carey 1997, Chytrý *et al.* 2003). Although most studies fall within central Europe, Pignatti *et al.* (2001) have calculated values for Italy using Castelporziano as the location for the baseline, and these values were calibrated using algorithms from Fanelli *et al.* (2007). These values were then correlated with edaphic and microclimatic parameters measured within the Castelporziano Estate (Table 19).

The edaphic and microclimatic parameters measured were:

- N (%) - Nitrogen is the element responsible for growing foliage, resisting disease, and promotes photosynthesis.
- Organic C (%) - The organic carbon content relates to the soil organic matter, which is material in the soil derived from living species. This can be compared with the LOI results from the palaeoenvironmental work, which is an indirect measure for organic matter, which can then be converted to organic carbon.
- P (%) - In soil, the element phosphorus (P) exists mostly in organic and inorganic form, both of which are important sources of P for plant and microbial uptake. The organic form exists mostly in humus and other organic

materials. The inorganic form occurs in combination with various forms of Al, Fe, Mg, Ca and other elements most of which are not soluble and therefore not available for both plant and microbial uptake.

- Sand (%) – Sandy soils are light and typically very free draining, usually holding water very poorly due to very low organic content. Given the coastal location of Castelporziano, this would be expected to be a major constituent of the soil.
- Clay (%) – Clay soils are nutrient rich, but the structure of clay soils does not allow for easy movement of air and water through the soil.
- Slime (%) - Slime molds normally live on or close to the soil surface where they feed on decaying organic matter, thus are related to the organic carbon content.
- pH – A measure of how acidic or alkaline a soil is.
- AWC (mm) – AWC or Available Water Capacity is the amount of water that a soil can store that is available for use by plants
- Air Temperature at soil level (°C) - Soil temperature varies from month to month as a function of incident solar radiation, rainfall, seasonal variations in air temperature, local vegetation cover, type of soil, and depth in the earth.
- Air humidity at soil level (%) - Widespread temperate woodland herb species depends on high air humidity, and certain sensitive species do not occur at sites with reduced air humidity even though soil moisture is high.
- Air Temperature at 1.5 m above soil level (°C) – See Air Temperature at soil level (°C)
- Air humidity at 1.5 m above soil level (%) – See Air humidity at soil level
- PAR at soil level – PAR or Photosynthetically Active Radiation is measure of radiant power is important in evaluating the effect of light. It is measure at both soil and 1.5 m above.
- PAR at 1.5 m above soil level - see PAR at soil temperature.
- Soil Temperature at 25 cm (°C) - Soil temperature is an important indicator of frozen ground status, driven at least partly by air temperature variability.

The vegetation biomes used are from the study by Fanelli *et al.* (2007): (A) *Quercus ilex* woodland (*Viburno-Quercetum ilicis*) on recent dunes; (B) *Quercus suber* woodland (*Viburno-Quercetum ilicis suberetosum: Stipa bromoides* xeric facies) on old dunes; (C) *Quercus suber* woodland (*Viburno-Quercetum ilicis suberetosum: Quercus cerris* mixed mesic facies) on old dunes; (D) *Quercus cerris* woodland (*Echinopo-Quercetum frainetto* Blasi et Paura 1993: *Erica arborea* silvofacies), on old

dunes; (E) *Quercus cerris* woodland (*Echinopo-Quercetum frainetto* Blasi et Paura 1993: *Carpinus orientalis* silvofacies), on old dunes; (F) *Quercus cerris* woodland (*Echinopo-Quercetum frainetto* Blasi et Paura 1993: *Carpinus betulus* silvofacies), on old dunes; (G) *Fraxinus angustifolia* subsp. *oxycarpa* woodland (*Carici remotae-Fraxinetum oxycarpae* Koch ex Faber 1936) in interdunary depressions; (H) *Carpinus betulus* and *Laurus nobilis* woodland (*Lauro-Carpinetum*) on tuffs and ravines.

5.2.3.1 Results of the Ellenberg Indicators

Environmental variables measured on site are taken from Pignatti *et al.* (2001) (as noted on Table 19), when both were taken by the author and Pignatti *et al.* (2001) an average was taken but the final values reported are by Pignatti *et al.* (2001) only. These were then compared with the Ellenberg indicator values from Pignatti *et al.* (2005) (Table 20) for the vegetation biomes using the Pearson correlation coefficient (Table 21). The letters used in the tables reflect the Ellenberg nomenclature and defined in the previous section.

The results show good correlation (positive) for the **N** values with the measured nitrogen, organic carbon, phosphorous, slime and air temperature at 1.5 m above soil level. Whereas negative correlations were found for variables such as sand content, temperature at soil level, humidity at soil level and humidity at 1.5 m above soil level. With the **L** value correlations were found with the measured nitrogen, organic carbon, pH and available water capacity. **T** values showed only one positive correlation with the measured humidity at 1.5 m above soil level, whereas negative correlations were found with nitrogen, organic carbon, humidity at 1.5 m above soil level, radiation at both soil and at 1.5 m above soil level, and soil temperature. The **K** values only correlated with the humidity at soil level, with **F** and **R** showing no moderate or strong correlations.

This analysis was then repeated with the (re)predicted Ellenberg indicator values of Fanelli *et al.* (2007) (Table 22) and the environmental variables, with the Pearson correlation coefficient used (Table 23) again for noting correlations. The (re)prediction was needed as the original Ellenberg indicators were based on British flora, and not Italian thus did not allow for Mediterranean species to be taken into account. Fanelli *et al.* (2007) used an algorithm that used a Gaussian-logit model, which was used to test the amplitude of plant species responses and to test the internal consistency of the Ellenberg indicators. The estimation of indicator values is fundamentally a regression problem. Indicator values and ecological amplitudes can

be estimated from presence-absence data by logistic regression, with a second-order polynomial in the environmental variable as linear predictor. This procedure, termed Gaussian-logit model, or Gaussian logistic regression, fits a curve related to the Gaussian species response curve (Austin, 1980) but adapted for presence-absence data.

The (re)predicted Ellenberg indicator values were much better correlated to environmental measurements. The most striking difference between the results of the two is the correlations between **K** and **F** values, with correlations high for nitrogen, organic carbon, phosphorous, slime, clay and available water capacity (AWC), as well as a negative correlation with sand content.

How do these correlations relate to the contemporary ecology of the Castelporziano estate? One of the highest correlations found was the **F** value (related to soil moisture) and the AWC, which focuses on the close relationship existing between the amount of available water in the soil and the water requirement of the species along a gradient of communities. Furthermore, AWC shows significant correlations with **K** and **N** indicator values when the reprediction algorithm is used, which emphasizes the occurrence, within a Mediterranean area, of habitats with Central-European affinity, where high quantity of organic matter and large water availability in soil play an important role.

Chiti (2007) showed that the Castelporziano woodland has a turnover time of 35 years, which is due to the low soil C content and the comparatively fast decomposition rate occurring in this soil, due to differences in soil, climate, vegetation and management, which can be seen in the **K**, **L** and **N** values correlation with organic carbon in the reprediction algorithm was used. Among the broad leaf trees, nitrogen fixing species seems to enhance soil carbon sequestration, which would explain the correlation of organic carbon and the **N** value. Resh *et al.* (2002) found that nitrogen fixing plantations sequestered more soil carbon than eucalyptus plantations, which can be noted at other parts of the Castelporziano estate. Soils from Mediterranean ecosystems have been relatively little investigated in terms of carbon sequestration and quality of soil organic matter, perhaps because they are often considered very poor in organic carbon. As a consequence, information is information scarce on the quantity, chemical composition and age of the carbon stored in Mediterranean soils (Chiti 2007).

Other significant correlations were found with clay content and **F** and **N** values. The clay content enhances a large stock of species with high requirement for water and organic matter in the soils. This represents an additional edaphic factor integrating the complexity and the strength of the interactions between plant species/communities and soil-measured variables.

The low correlations with the **R** values suggest that the woodlands of Castelporziano are not determined by pH, which given the average measured pH for the 8 areas measured is 6.26 this is not surprising as typical macchia Mediterranean species grow on nutrient poor acid soils. However, most of the palaeoenvironmental cores were taken in an area where the current vegetation belongs to the *Viburno-Quercetum ilicis* (macchia with Holm oak prevailing) and had an average pH of 8.1.

5.2.4. Soil Indicators

As well as the soil measurements, other soil factors were found to play a role in the modern ecology. The Recalcitrance Index (RI) provided information on the distribution of soil organic matter in recalcitrant and labile pools. At Castelporziano (41° 42'19" N, 12° 22' 34" E; North of Pozzo Napoliello), RI ranges around 35% up to a depth of 70 cm, except in the 30-50 cm soil layer where it amounts to 44.1% of total carbon. The distribution of the RI confirms the fast decomposition occurring at these sites compared to the other areas within Italy. Chiti (2007) found that in Castelporziano soils the recalcitrant compounds represent only a minor part of total carbon and were affected by decomposition already at the surface, thus only a small amount of carbon can accumulate in soil, as evidenced from the low concentrations of this element in the soil (both modern and as determined within the cores from the loss on ignition). Chiti (2007) also found that the degree of humification at Castelporziano was low, but higher than at San Rossore (a coastal park near Pisa), which shows degree of decomposition is high, as well as the sandy texture of the soils. The fast decomposition occurring in the Castelporziano soil is also noticeable by the soil organic matter turnover time in the 0-10 cm soil layer that contains half of the total carbon and the fast recycling rate suggests that only a small quantity of carbon is accumulating in soil, which may have led to low organic matter in some cores.

Vegetation biomes	N (%)	Organic C (%)	P (%)	Sand (%)	Clay (%)	Slime (%)	pH	AWC (mm)	Air T at soil level (°C)	Air humidity at soil level (%)	Air T at 1.5 m above soil level (°C)	Air humidity at 1.5 m above soil level (%)	PAR at soil level	PAR at 1.5 m above soil level	Soil T at 25 cm (°C)
Viburno-Quercetum ilicis	0.3	3.1	7.2	64.4	6.8	28.7	8.1	187.0	23.5	66.2	23.0	67.5	20.5	18.5	17.7
Quercetum ilicis suberetosum: Stipa bromoides facies	0.1	1.5	1.3	83.2	7.8	9.0	6.0	167.5	24.9	62.0	24.5	61.9	24.1	24.7	18.0
Quercetum ilicis suberetosum: Quercus cerris mixed facies	0.1	0.9	2.8	80.3	12.2	7.6	5.5	165.2	26.1	57.3	25.8	57.3	45.6	36.9	18.1
Echinopo-Q.frainetto: Erica arborea silvofacies (1)	0.1	1.0	0.8	78.0	11.5	10.5	6.1	157.1	21.4	65.5	21.1	64.8	23.2	41.9	15.9
Echinopo-Q.frainetto: Erica arborea silvofacies (2)	0.1	2.3	4.7	72.0	14.8	13.2	5.8	174.4	23.9	61.7	24.2	58.9	65.3	102.5	16.6
Echinopo-Q.frainetto: Carpinus orientalis silvofacies (1)	0.2	1.5	2.6	74.4	12.0	13.6	5.8	170.5	22.3	67.3	22.3	65.8	43.1	50.6	16.8
Echinopo-Q.frainetto: Carpinus orientalis silvofacies (2)	0.1	1.3	4.4	75.8	14.6	9.6	6.0	171.7	24.6	62.8	24.2	62.0	18.8	41.6	18.0
Echinopo-Q.frainetto: Carpinus betulus silvofacies (1)	0.2	2.0	3.2	67.8	18.0	14.3	6.3	171.0	23.9	66.0	23.5	65.6	20.5	28.1	17.2
Echinopo-Q.frainetto: Carpinus betulus silvofacies (2)	0.1	1.2	4.1	78.4	10.7	10.8	5.9	163.3	24.5	66.5	24.1	66.4	15.4	30.7	17.9
Carici remotae-	1.1	9.1	12.4	38.2	20.7	41.1	7.3	332.4	19.9	65.5	20.2	58.2	30.5	35.7	21.6

Vegetation biomes	N (%)	Organic C (%)	P (%)	Sand (%)	Clay (%)	Slime (%)	pH	AWC (mm)	Air T at soil level (°C)	Air humidity at soil level (%)	Air T at 1.5 m above soil level (°C)	Air humidity at 1.5 m above soil level (%)	PAR at soil level	PAR at 1.5 m above soil level	Soil T at 25 cm (°C)
Fraxinetum oxycarpae															
Lauro-Carpinetum	0.2	3.0	5.9	49.2	26.2	24.6	6.1	181.1	21.3	67.5	21.0	68.4	29.5	12.4	15.5

Table 19 Values of edaphic and microclimatic parameters (*Pignatti et al. (2001)).

	L	T	K	F	R	N
Viburno-Quercetum ilicis	6.50	8.00	3.06	2.89	3.61	3.78
Quercetum ilicis suberetosum: Stipa bromoides facies	6.15	7.80	2.90	3.60	4.85	3.75
Quercetum ilicis suberetosum: Quercus cerris mixed facies	5.69	6.92	2.23	4.15	4.54	2.92
Echinopo-Q.frainetto: Erica arborea silvofacies (1)	6.00	7.18	2.82	3.73	4.05	3.91
Echinopo-Q.frainetto: Erica arborea silvofacies (2)	5.77	6.70	2.97	3.80	4.20	4.20
Echinopo-Q.frainetto: Carpinus orientalis silvofacies (1)	5.71	7.24	3.19	3.24	3.90	4.10
Echinopo-Q.frainetto: Carpinus orientalis silvofacies (2)	5.25	7.38	3.38	3.88	3.13	3.63
Echinopo-Q.frainetto: Carpinus betulus silvofacies (1)	5.22	7.09	3.00	4.13	4.13	4.17
Echinopo-Q.frainetto; Carpinus betulus silvofacies (2)	4.86	7.00	3.29	4.21	4.29	4.36
Carici remotae-Fraxinetum oxycarpae	6.46	6.18	3.18	4.79	4.04	4.82
Lauro-Carpinetum	5.26	7.68	2.79	3.89	4.68	4.16

Table 20 Average Ellenberg indicator values calculated with the values in Pignatti et al. (2005) for Castelporziano

	L	T	K	F	R	N
*Correlation is significant at the 0.05 level (2-tailed).						
N (%)	0.52	-0.51	0.27	0.45	-0.11	0.63
Organic C (%)	0.50	-0.49	0.23	0.47	-0.06	0.64*
P (%)	0.36	-0.39	0.30	0.38	-0.23	0.55
Sand (%)	-0.26	0.30	-0.16	-0.38	0.03	-0.63*
Clay (%)	-0.29	-0.34	-0.02	0.56	0.16	0.44
Slime (%)	0.51	-0.21	0.23	0.20	-0.12	0.60
pH	0.61*	0.16	0.31	-0.20	-0.36	0.33
AWC (mm)	0.49	-0.57	0.23	0.54	-0.10	0.59
Air T at soil level (°C)	-0.34	0.26	-0.27	-0.17	0.08	-0.71*
Humidity at soil level (%)	-0.11	0.18	0.60	-0.17	-0.20	0.70*
Air T at 1.5 m. above soil level (°C)	-0.30	0.15	-0.27	-0.12	0.08	-0.67*
Humidity at 1.5 m. above soil level (%)	-0.30	0.64*	0.31	-0.50	-0.08	0.20
Radiation at soil level (PAR)	0.18	-0.53	-0.38	-0.02	0.22	-0.11
Radiation at 1.5 m. above soil level (PAR)	0.05	-0.69	0.08	0.05	-0.15	0.15
Soil T (°C)	0.39	-0.53	0.24	0.54	-0.15	0.27

Table 21 Correlation coefficients between a few environmental variables and Ellenberg indicator values based on Pignatti et al. (2005)

	L	T	K	F	R	N
Viburno-Quercetum ilicis	4.93	7.44	2.11	4.15	6.78	3.44
Quercetum ilicis suberetosum: Stipa bromoides facies	5.37	7.54	2.02	3.89	7.07	3.77
Quercetum ilicis suberetosum: Quercus cerris mixed facies	4.59	7.26	1.64	4.32	6.91	4.06
Echinopo-Q.frainetto: Erica arborea silvofacies (1)	4.53	7.17	1.67	4.42	6.81	3.92
Echinopo-Q.frainetto: Erica arborea silvofacies (2)	5.08	7.00	2.22	4.73	6.86	4.32
Echinopo-Q.frainetto: Carpinus orientalis silvofacies (1)	4.88	6.75	2.00	4.75	7.28	4.47
Echinopo-Q.frainetto: Carpinus orientalis silvofacies (2)	4.00	7.00	1.67	4.81	7.10	4.05
Echinopo-Q.frainetto: Carpinus betulus silvofacies (1)	4.15	6.49	1.67	4.95	7.18	4.95
Echinopo-Q.frainetto; Carpinus betulus silvofacies (2)	4.07	6.41	1.70	5.07	7.30	5.00
Carici remotae-Fraxinetum oxycarpae	5.50	6.16	2.44	5.97	7.19	5.91
Lauro-Carpinetum	4.33	6.74	1.93	4.77	6.96	4.51

Table 22 Average Ellenberg indicator values calculated with the reprediction algorithm (Fanelli et al. 2007)

	L	T	K	F	R	N
N (%)	0.55	-0.54	0.74**	0.72*	0.21	0.67*
Organic C (%)	0.55	-0.53	0.77*	0.71*	0.14	0.66*
P (%)	0.36	-0.51	0.70*	0.69*	0.09	0.57
Sand (%)	-0.27	0.57	-0.62	-0.68*	-0.06	-0.61*
Clay (%)	-0.16	-0.63	0.16	0.62*	0.16	0.61*
Slime (%)	0.45	-0.42	0.73**	0.56	-0.01	0.48
pH	0.35	-0.03	0.53	0.16	-0.21	0.04
AWC (mm)	0.55	-0.54	0.71*	0.74**	0.22	0.69*
Air T at soil level (°C)	-0.29	0.49	-0.51	-0.56	-0.04	-0.47
Humidity at soil level (%)	-0.15	-0.49	0.16	0.35	0.33	0.32
Air T at 1.5 m. above soil level (°C)	-0.21	0.46	-0.42	-0.50	-0.04	-0.42
Humidity at 1.5 m. above soil level (%)	-0.45	-0.05	-0.25	-0.18	0.08	-0.19
Radiation at soil level (PAR)	0.49	0.11	0.49	-0.01	-0.25	0.00
Radiation at 1.5 m. above soil level (PAR)	0.29	-0.03	0.36	0.21	-0.12	0.08
Soil T (°C)	0.45	-0.36	0.46	0.56	0.38	0.54

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed)

Table 23 Correlation coefficients between a few environmental variables and Ellenberg indicator values estimated with the reprediction algorithm of Fanelli et al. In bold the new correlations arising in comparison with Table 21

5.3 Recent changes

When studying vegetation changes over the time period of 10-50 years, it is important to understand the ecological processes that may have occurred. Of these, the most noteworthy are: temporal patterns of vegetation change (i.e. what is happening?), ecological succession in response to certain events (why is it happening?), and interactions contributing to successional change (how is it happening?). Vegetation studies over 10 to 50 years may facilitate the description of the external causes of change (e.g. low rainfall) and the generation of hypotheses concerning internal causes and mechanisms of change (e.g. species competition, allelopathy) (Bakker *et al.* 1996).

The Castelporziano Estate has remained free from intense anthropogenic exploitation for hundreds of years, unlike like the surrounding coastline, apart from grazing by deer and wild boar, hunting and agricultural-forestry, which has been very active. The arrangement of the estate has remained essentially unaltered over the last century, which has allowed for the lack of disturbance of the vegetation and the development of forest cover. Safeguarding the forest is important and, as such as the Italian Presidential Estate access is restricted to a limited number of guided tours and to scholarly research.

To assess recent changes in vegetation a variety of sources were used. These included: excavation records from the Vicus Augustanus, aerial photographs, published literature, and unpublished estate records.

5.3.1 Aerial photographs

Historical aerial photographs are an important source for data on medium- to long-term (10-50 years) vegetation changes (Yohay and Ronen 1998). Early investigations using aerial photographs in other locations for vegetation changes have typically employed manual interpretation of aerial photographs to extract vegetation data. The labour-intensive nature of manual interpretation may limit the spatial extent of vegetation databases (Woien 1995). Manually interpreted maps usually have coarse spatial resolution, and classification accuracy, which is a critical parameter for studies of vegetation change, is not readily assessed in this method (Biging *et al.* 1991). Manual interpretation of aerial photos is assumed to be 100% correct, which is not true (Biging *et al.* 1991; Congalton and Green 1993).

For the present research three sets of aerial photographs from 1954, 1983 and 2003 (see Appendix 4 for copies of some of the images analysed) were analysed using a stereoscopic viewer for noting changes in vegetation. As there appeared to be little difference between the 1983 and 2003 coverage, the changes occurring between 1954 and 2003 were focused on.

5.3.1.1 Methodology

A map of the area (the coastal strip of the Castelporziano estate) was made into a grid of 12 zones, which were then counted for the major biomes for 1954 and 2003. The biomes were identified by examining for key species, e.g. *Quercus ilex*, *Q. Suber*, *Pinus pinea*, *Poaceae*, *Carpinus orientalis* Miller, *Laurus nobilis*, and *macchia* species. This enabled the changes to be quantified (Tables 24 and 25), and thus changes in frequency, total cover, average cover, relative cover, relative frequency and importance were calculated for 1954 and 2003. To give a more general picture of the overall changes in vegetation, a second grid was created of cm squares, and the major biome in that square noted and then plotted on a map of the area (figure 91), with the colour coding used being the same as that use by Allegrini *et al.* (2006).

5.3.1.2 Results of Aerial Photographic interpretation

In 1954 only 3 major biomes existed (figure 92), sparsely vegetated (grey), hygrophilous vegetation (navy) and *Q. ilex* (red), whereas by 2003 most of the sparsely vegetated areas had gone (apart from at the modern beach). In place of the sparsely vegetated areas *macchia* and Garigue (pink) or high *macchia* (dark red) are to be found and a limited portion of natural grassland, with some *Q. ilex* and hygrophilous biomes left. The hygrophilous vegetation was noted on the areas of former marsh, which correlates with the baseline vegetation survey. The reason for the comparatively sparse vegetation on parts of the 1954 photographs, especially near the Vicus Augustanus, may relate to the fire of 1944.

From the 12 zones (Tables 24 and 25), overall the greatest changes in vegetation biomes has been in *macchia* and garigue, which in 1954 covered on average 10% of the total vegetation per quadrat, by 2003 that has risen to 39%, an increase of over 287%. The expanse of tall *macchia* has been negligible and still accounts for an average of 7% of the total vegetation per quadrat. The expansion of *macchia* and garigue was most noticeable in those zones previously dominated by the sparsely vegetation biomes, i.e. at Grotta di Piastra, Muraccioli, and Tor Paterno. This change

was most likely due to two different succession scenarios, which may be viewed as alternative responses to the main human impacts in the Mediterranean regions, i.e. grazing and fires.

Other vegetation growth on the formerly sparse vegetation included: reforestation with *Pinus pinea*, which increased from 5% to 7% of the total vegetation per zone; natural grasslands increasing from 4% to 11% % of the total vegetation per zone. Both vegetation types have also been found on the former marsh areas, which have seen a 20% decline in hygrophilous vegetation (4% to 3%).

The highest decrease in vegetation biome was that of the Holm Oak and Pine by 92% (10.00%-1%), the only zone which still had this biome is Tor Paterno. This decline has been primarily due to anthropogenic impact of activities such as coppicing, grazing and fires. However, the loss of pine has been compensated with the reforestation of *P. pinea* in some parts, especially at the Muraccioli. There were still Holm Oaks forming the sclerophyllous woodland biome, which increased from 12% to 21% of the total vegetation per zone (i.e. a 73% increase). This was particularly true at Piscina Bassa and Grotta di Piastra at the north-western end of the area that is much denser in Holm Oaks than 1954, whereas nearer the Via Littoranea, macchia and garigue have superseded this. These results agree with the baseline vegetation survey which suggested the Holm Oak in these zones and around Fosso di Murracioli was around thirty to fifty years old.

5.3.2 Excavation archives of the Vicus Augustanus

Archaeological excavation of the Vicus Augustanus has been carried out by Amanda Claridge *et al.* for the last twenty five years, and there are detailed records from their excavations. The archives contained some references to vegetation, which was used to trace the vegetation history within the archaeological remains of the Vicus Augustanus over this period. In 1983 when excavation commenced, the vegetation record was that of macchia with large-berried juniper. This type of macchia with juniper colonizes sand dunes and is therefore found only along beaches, as is found near the modern beach, by the Via Littoranea. It is a form of transitional vegetation between the pioneering phytocenoses of sandy areas and the forest ones of holm oak. Kovačić *et al.* (2001, p73) noted that in “*areas where the Phoenician juniper (Juniperus phoenicea) is very abundant, as well as communities in which this species*

is dominant, represent a special form of forest community, commonly developed as xerothermic macchia known as Pistacio lentisci – Juniperetum phoeniceae and included in the Oleo-Ceratonion alliance. This association represents an important progressive stage in the succession towards evergreen vegetation, developed mostly after forest fires". However, often the plants that make up macchia are not thought to be the climax stage in succession, but represent stages of degradation or regeneration (Clements 1936), according to changes occurring in the environment. This suggests that this form of macchia possibly resulted from the fire of 1944 and changed either by succession or adaptive cycles to form the present form. However, is macchia as seen today a non-climax vegetation stage, or can succession truly explain the change of one form of macchia to another? Therefore the question is whether there was a change in succession or change in stable state, and this will be discussed further in chapter 6.

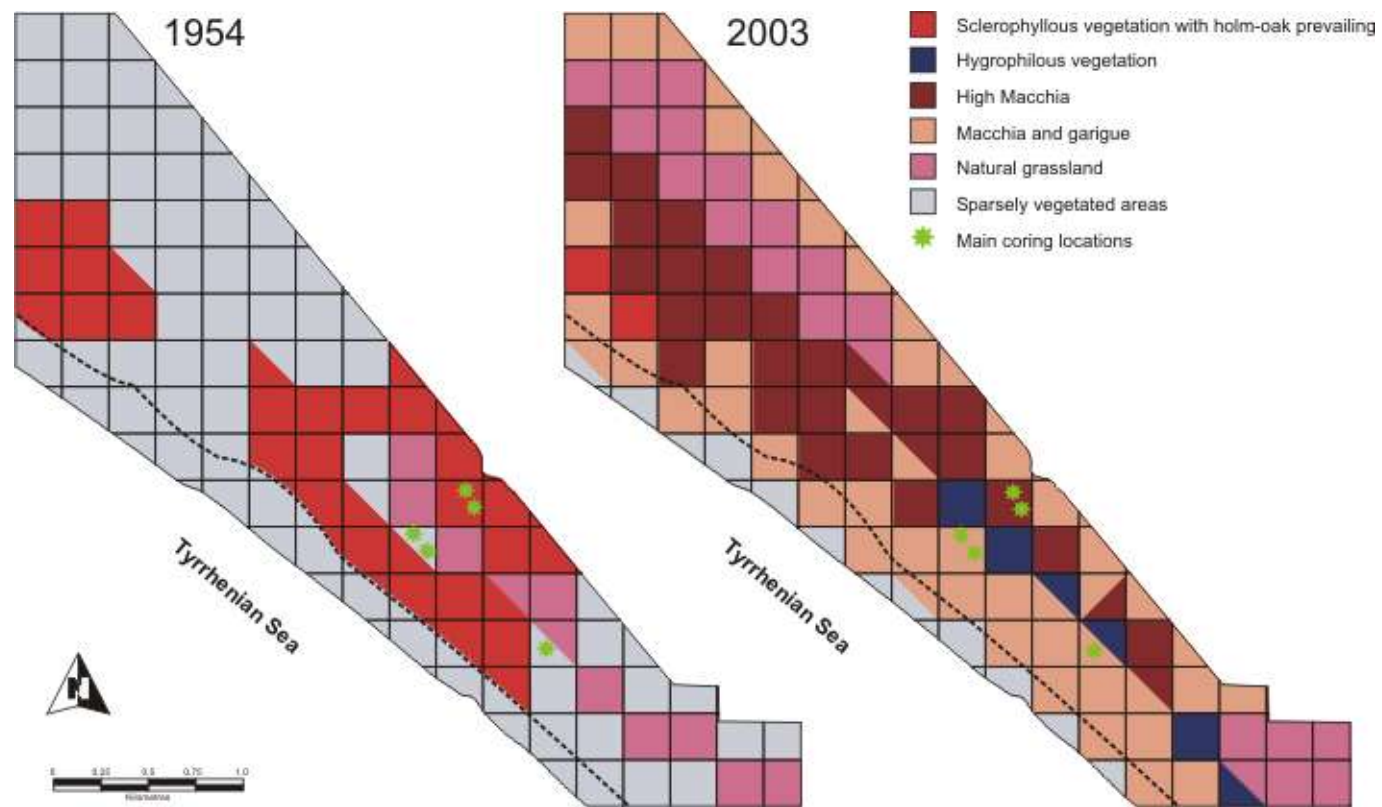


Figure 91 Results of the aerial photograph interpretation of vegetation changes (1954 and 2003).

Vegetation Biome	Zones Occurred (out of 12)	% Frequency	Total cover %	Average Cover %	Relative frequency %	Relative cover %	Importance value
Sparsely vegetated areas	8	66.66	360	30.00	18.61	35.47	54.08
Sclerophyllous vegetation with Holm-oak prevailing	8	66.66	145	12.08	18.61	14.29	32.90
Macchia and garigue	6	50.00	120	10.00	13.96	11.82	25.78
Mixed woods (Holm-oak and pine)	5	41.66	120	10.00	11.63	11.82	23.45
High Macchia	5	41.66	80	6.67	11.63	7.88	19.51
Reforestation of Pinus pinea	4	33.33	60	5.00	9.30	5.91	15.21
Hygrophilous vegetation	3	25.00	50	4.17	6.98	4.92	11.90
Natural grassland	2	16.66	50	4.17	4.65	4.92	9.57
Deciduous oak forest with evergreen shrubs	1	8.33	20	1.67	2.32	1.97	4.29
Deciduous oak forest with Carpinus orientalis Miller	1	8.33	10	0.83	2.32	0.98	3.30

Table 24 Absolute and relative values of plant typology importance in 1954

Vegetation Biome	Zones Occurred (out of 12)	% Frequency	Total cover %	Average Cover %	Relative frequency %	Relative cover %	Importance value
Macchia and garigue	8	66.66	465	38.75	18.61	37.50	56.11
Sclerophyllous vegetation with Holm-oak prevailing	8	66.66	250	20.83	18.61	20.16	38.77
High Macchia	8	66.66	80	6.67	18.61	6.45	25.06
Natural grassland	6	50.00	130	10.83	13.96	10.48	24.44
Sparsely vegetated areas	5	41.66	125	10.42	11.63	10.08	21.71
Reforestation of Pinus pinea	4	33.33	80	6.67	9.30	6.45	15.75
Hygrophilous vegetation	2	16.66	40	3.33	4.65	3.23	7.88
Deciduous oak forest with evergreen shrubs	2	16.66	30	2.50	4.65	2.42	7.07
Deciduous oak forest with <i>Carpinus orientalis</i> Miller	1	8.33	30	2.50	2.32	2.42	4.74
Mixed woods (Holm-oak and pine)	1	8.33	10	0.83	2.32	0.81	3.13

Table 25 Absolute and relative values of plant typology importance in 2003

5.3.3 Other changes within the Castelporziano estate

Alongside the changes noted in vegetation from the aerial photographs; there have been other drivers of change within the estate itself, which are mostly anthropogenic in origin. The estate as a whole (not the coastal strip studied) has changed from grazing land from the 1950s, thus leading to an increase in macchia growth, especially where vegetation was sparse previously and within the oak woods. Where felling of the oak trees has occurred along the coastal strip and elsewhere in the estate, more mature macchia has formed mixed woodland with the oak. As noted during the baseline vegetation survey the landscape is still responding to anthropogenic impact.

Fire remains a major hazard at Castelporziano, as with any Mediterranean type environment. A large fire occurred in the coastal area in 1944 during the American Army's occupation of the estate, the impact of which could be seen at the Vicus Augustanus, Grotta di Piastra and Muraccioli on the 1954 aerial photographs. In the mid-1980s, Castelporziano estate staff started noticing symptoms of infection in the stone pines (*P. pinaster*), eventually leading to the death of several hundred trees and to *P. pinaster* being cut down throughout the estate (Gonthier *et al.* 2004). There is a gap in the forest of about 100 meters from where trees were cut down (figure 92), particularly at the area north of Muraccioli. Gonthier *et al.* (2004) found the cause was a pathogen, the fungus *Heterobasidion annosum*, non-native to Europe, and its presence on the estate was initially a mystery. This type of fungus does not move easily through soil, and its airborne spores are short-lived. Gonthier *et al.* deduced that the fungus arrived at Castelporziano through untreated lumber from infected trees through transport crates, pallets or other military equipment belonging to the American Army.

Chapter one highlighted the potential impact of atmospheric pollutants upon the Castelporziano estate (page 16). Some species absorb ozone through their stomata, and thus are more affected by this pollutant, which may trigger future changes in ecosystem composition. This is what was found by Gerosa *et al.* (2009) for the *Arbutus unedo*, *Quercus ilex*, and *Erica arborea*, which is important as ozone damage reduces the rate of photosynthesis in the plant and cripples its ability to grow. This may lead to biochemical and physiological changes that may lead to have adverse effects through an alteration in sensitivity to other biotic or abiotic stresses, which may lead to long term damages in the vegetation, and thus the local environment.

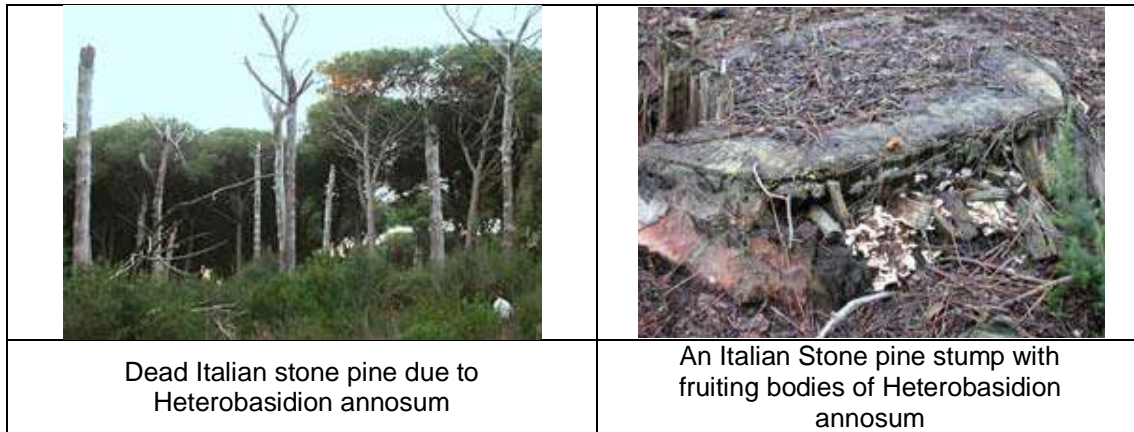


Figure 92 The effects of *Heterobasidion annosum* on the stone pine (Mazzaglia 2004)

5.4 Legacies of Past Land Use

Periodic interruption is one of the defining characteristics of Mediterranean ecosystems. These are best seen as a mosaic of closely interwoven environmental and cultural processes; thus the semi-natural and agricultural vegetation of open forest, shrublands, grasslands and terraces comprise a dynamic degradation and regeneration on regime in time and space (Naveh 1987). Importantly, this evolutionary sequence does not fit any preconceived deterministic, classic successional sequence and thus the term perturbation-dependence is appropriate (Vogl 1980). The crucial point is the fundamental role of perturbation in contributing to evolutionary structure, but as a necessary component in the maintenance of ecological diversity and system integrity. The persistence of such regimes is explicable if the role of seasonal climatic fluctuations is considered in generating fluctuations in productivity, which in turn act to regulate the frequency of grazing. In addition, disastrous fires and the over-exploitation of woodland are prevented by the natural periodicity of fire events which act to regulate the exploitable level of natural resources. In fact, if the perturbation occurs on a sufficiently regular schedule it gives a competitive advantage to species whose life-spans match the intervals between perturbation events (Horn 1981). Structural changes will only occur provided sufficient time has elapsed for the process of regeneration to occur.

Knowing the site history of an ecosystem is often crucial for understanding current ecological processes. Anthropogenic disturbances of forest ecosystems are increasingly recognized as fundamental ecological processes with important long-term implications for biogeochemical cycles and vegetation patterns (Gimmi and Burghi 2007). The lasting effects of past human actions (termed “land-use legacies”) include changes in species composition, successional dynamics, soils, water, topography, and nutrient cycling. Many seemingly natural areas have

a cultural past that is part of their ecological history; and their conservation today requires knowledge of that past and an assessment of the value of continuing or replicating past cultural practices. In considering anthropogenic landscapes, it is important to emphasize that not all human disturbance is the same, and different practices can have very different effects.

The legacies of past land use interact with natural disturbance processes and may confound the interpretation of disturbance regimes in many landscapes. Vegetation structure and composition strongly control landscape susceptibility and ecosystem response to fire and wind, and consequently vegetation modification by past land use can alter these responses. Of equal significance is the persistence of landuse legacies through several episodes of disturbance. This finding is critical, because scientists who are investigating disturbance-prone landscapes often incorrectly describe post-disturbance responses and conditions as “natural” in the sense that natural processes were the proximate cause of the pattern of disturbance and ecosystem response (Eberhardt *et al.* 2003). The longevity of land-use legacies also belies a common assumption that natural processes and conditions may be restored on human-modified landscapes simply by applying historically relevant disturbances like prescribed fire (Stephenson 1999).

The imprints of past land use on soil properties are equally enduring and may have important ramifications for the function and dynamics of ecosystems ranging from forests to grasslands (Trimble 1999). Many persistent physical, chemical, and biological changes are imposed on soils by agriculture, burning, and grazing (Haas *et al.* 1957, Burke *et al.* 1989, Davidson and Ackerman 1993, Compton *et al.* 1998, Pouyat and Effland 1999).

Historical land use has also been increasingly recognized as an important factor determining modern vegetation patterns. These include the vegetation response to the type and intensity of previous agricultural land use (Koerner *et al.* 1997; Prevosto *et al.* 2003; Wulf 2003), the timing of agricultural abandonment (Graae *et al.* 2003; Chauchard *et al.* 2007), logging history (McCay 2000), and combined effects of different land-use types (Foster 1992). Dupouey *et al.* (2002) for example, showed that two centuries of farming during Roman times induced gradients in soil nutrient availability and plant diversity that are still measurable almost 2000 years later and suggested that effects of past agricultural land use on forest biodiversity may be irreversible on an historical time scale.

In the case of Mediterranean vegetation, fire, drought, herbivory and agrosilvicultural systems provide recruitment opportunities at very different spatial and temporal scales to the

the forest gaps that typically occur in temperate forests. This difference is critical because the most widespread type of forest simulators have a built-in gap dynamics structure (Shugart 1984). Eberhardt *et al.* (2003) conclude that the understanding of past land use should be integrated into the ecological models used in the management of biological reserves. For central European forests, Wohlgemuth *et al.* (2002) proposed management principles integrating information on natural as well as anthropogenic disturbances, their regimes, and historical range within.

Plant communities that develop after afforestation of abandoned lands differ from ancient forests in relation to the modification of soil properties (Glatzel 1991, Compton and Boone, 2000) and to the relative colonization rates of species into new forests (Brunet and Oheimb 1998). These after-effects have been shown to control vegetation diversity in forests (Foster 1992, Hemy 1993, Koerner *et al.* 1997) even 300 years after afforestation, and it has been suggested that they could persist indefinitely (Peterken and Game 1984). The assumption that forest plant communities modified by agriculture revert to their former state has been seldom tested (Plue *et al.* 2008). The effects of former human occupation or agricultural land use in forests may be visible both in the soil and vegetation. It is well documented that agricultural land use modifies geochemical soil properties and that these alterations may last for centuries (e.g. Sandor *et al.* 1990; Sandor and Eash 1995; Verheyen *et al.* 1999; Dupouey *et al.* 2002; Dambrine *et al.* 2007).

In relation to the Roman land-use at the Castelporziano estate, it is possible that it may have effects on the current vegetation, both in regard to plant species and at the community level. Vanwalleghem *et al.* (2003) found that the vegetation on formerly cultivated and fertilised sites had a more eutrophic character, and therefore, contained more typical forest species. In many regions of the world, successive episodes of woodland clearance and cultivation has led to impoverishment of soil fertility by erosion, leaching of nutrients, and acidification, usually associated with loss of biodiversity in reforested areas compared with native vegetation. However, Roman landuse does not appear to have left its mark on Castelporziano for three reasons: limited evidence for local Roman agriculture was found in the palaeo record thus may not have left as indelible a mark as other areas of the Roman empire; the abandonment of the site by the Romans allowed the landscape time to recover, which also links with the post-Roman occasional settlements, with those of the later settlement at Tor Paterno during the 9-12th centuries AD and 17th-20th centuries more likely to have had an impact. Evidence for eutrophication today (as was found in the palaeoenvironmental reconstruction at D6) is in the small temporary ponds found scattered around the estate, which are mostly artificially excavated for wild boar, other animals and

birds. These are more likely to result in modern anthropogenic impacts and natural eutrophication than a long term impact from the Romans.

Unlike other studies, the Roman settlement may not have led to significant geochemical alterations at the occupied sites as previously indicated by Dupouey *et al.* (2002) and Dambrine *et al.* (2007), as noted from the geochemistry of the bulk sediment of D5 and cores from the Roman fishponds (D6/D5). However, the minerogenic nature of the site this may also have masked the signal. Verheyen *et al.* (1999) found significant modifications of the chemical soil environment on a similar timescale, although considering only agriculture, not occupation, which may have been of more relevance for Castelporziano. Dambrine *et al.* (2007) suggest that the weathering of the calcareous sandstone, used as construction material, continually provides the soil with fresh nutrients, keeping pH at an elevated level, but at Castelporziano due to its coastal location the high pH is equally due to calcareous remains of shell fragments in the sandy soil.

There is little evidence of Roman agriculture at Castelporziano, apart from possible grazing of animals, which may have been for pasture or for a game reserve. Different types of agricultural management practices lead to different outcomes for soil organic carbon (SOC) and nutrients thus have been reflected in the LOI at the sites, but this may be low at Castelporziano due to the high mineralisation rate. Tillage and harvesting tend to decrease concentrations of SOC and nutrients, whereas fertilization tends to increase these concentrations (McLauchlan 2007). Grazing can affect the soils properties in different ways, which depend on the prescribed stocking rate and grazing periods (Sanjari *et al.* 2008), with continual grazing increasing the SOC.

The discontinuous human settlement following the Roman period allowed the growth and preservation of the holm oak forest with macchia at Castelporziano. As the palaeo record shows, the effects of fire within the estate, as within the last twenty five years are comparatively low. Between 1984 and 1998 there were 48 fires, which broke out with and contained at the borders of the estate, with only four spreading within the estate and which were put out immediately (Castelporziano Estate pers. comm.).

As to the overall “naturalness” of the current vegetation, it has clearly been managed far longer than the estate gives credit for as Lanciani (1909 p308-309) noted that “*the Vicus Augustanus and Laurentum (Torre Paterna), runs through the pine forest planted by the Sacchetti in the seventeenth century, the area of which has been trebled since*

1875...any thousand pines are planted every year and great care is taken to keep the older ones in a healthy state". Thus the current macchia growth may be as a result of far earlier anthropogenic impact and management of the area, which a study as noted above may help elucidate.

5.5 Discussion and Conclusions

This chapter set out to find the answers to these questions:

- What is the current vegetation of the area and how has it been affected by estate management practices over the last 50-100 years?
- What evidence is there of a legacy of past land use practices from Roman times onwards?

The baseline vegetation survey together with the analysis of the aerial photographs from 1954, 1983 and 2003 showed changes in vegetation at different timescales. The current vegetation shows a high proportion of *Quercus ilex*. There is debate about the apparent naturalness of this macchia; however, most appears to conform to the primary macchia. However, the fire of 1944 left marked changes within the macchia, as noted by the presence of the bare patches from the 1954 aerial photographs. This led to the formation of secondary macchia within these sites, which appears to have undergone a succession type change from the pioneering *Juniperus* type macchia to that found at Napoliello and Muraccioli, the *Viburno-Quercetum ilicis* type. The *Viburno-Quercetum ilicis* macchia although has shown its resilience to fire, if no more fires occur, after 8-10 years, the shrubby layer returns to its previous state, as regards ground cover and height. However, this replacement macchia is not as resilient as the original macchia, as the Vicus Augustanus already shows signs of degradation and is beginning to be populated by *Asphodelus*, which with continual removal of the *Quercus ilex* and other vegetation will lead to the spread of garigue. The issue of the sensitivity of the local environment to change will be examined in greater detail in the following chapter.

Historical changes in land-use following the Roman period reflect both 'unmanaged' changes associated with abandonment (e.g. in the Vicus Augustanus area) and 'managed' changes (e.g. in the Tor Paterno area). The emergence of holm oak forest with macchia contrasts with the (documented) plantation of pines.

Chapter 6: Discussion

6.1 Introduction

This chapter discusses the findings of the thesis in four sections: The first section places the results within the broader context of Late Holocene environmental change in Italy and the northern Mediterranean, with an examination of anthropogenic impacts upon the landscape. The second section scrutinises the use of palaeoenvironmental reconstructions for typical Mediterranean species (macchia and garigue). The third section examines the importance of parallel studies of past and contemporary environmental change and the final section examines the role of succession vs. resilience as informed by the results of the palaeoenvironmental reconstruction.

6.2 Late Holocene environmental change in Italy

Chapter one showed that the majority of palaeoenvironmental reconstructions for Italy came from long pollen sequences from crater lakes, which highlighted the vulnerability of the Italy (as well as the greater Mediterranean) to the combined effects of climate and human activities. Few papers looked at central and southern Italy, particularly during the time frame for this thesis (the last 3-2000 years specifically), and fewer still were done in relation to known archaeological sites or within archaeological contexts to give an anthropogenic baseline. The main problem for those studies that did cover the time period was disentangling the climate from the anthropogenic signal for these often long sequences stretching back up to 250,000 years, with *“abrupt climate changes generally suspected to be the overriding factor”* (Sadori and Giardini 2005). Sadori and Giardini (2005) acknowledge that *“the best potential to detect the cause of the landscape change comes from combining continuous records of proxy vegetation and climate change such as from lake cores obtained as close as possible to archaeological sites, which are the direct link to cultural history”*. Landscape change could be done using plant macrofossils, yet their work and others still neglect use of this proxy, thus not using pollen as the lone indicator. Another issue often neglected is what the pollen signal actually looks like from the taxa that are likely to have been dominant, i.e. which species form part of the typical Mediterranean signal, and which do not. This is particularly important as most Mediterranean macchia species are insect pollinated and produce less pollen than wind pollinated species, as discussed later in this chapter, and this should be factored into the analysis. Therefore, the use of a multiproxy study like the one carried out for this thesis may help in the search for other appropriate proxies that may aid future work in this area.

6.2.1 Changes at Castelporziano in relation to changes in Italy in the Late Holocene

6.2.1.1 In relation to non-crater lake studies

At Castelporziano, the earliest known settlement lies some 300 m further inland from the fish ponds of D5 and D6. The excavation of this site showed a group of low mounds containing shell middens and potsherds of late Bronze Age/early Iron age date (900-700 BC), close to Pozzo Napoliello (Claridge pers. comm. 2008). This discovery contrasts with the views of Forni (1990) who assumes that Bronze Age farmers avoided wet areas like Castelporziano, because drainage systems were not common during this period. Any impact of this Bronze-Iron Age settlement is perhaps best reflected in the results from Core 7 from Pozzo Napoliello, which is in close spatial proximity to D1 (<1 km) and potentially at the fish ponds of D5/D6. Although an age depth model was created for Core 7, it was only based on two dates. However, using this model and the CHAR results, the highest influx is around 530 BC (± 40), but this maybe an artefact of limited age depth model. The results from Core 7 show an increase in CHAR in the pre-Roman sequence, which represent an increase in local fires, as well as an absence in the stonewort chara (oospores), whose absence has been correlated with an increase in CHAR (Hallett 2003). The plant macrofossils record show the absence of arboreal species below 85 cm in core 7 (using the age depth model to be dated to around 220 BC (± 40)). Also in the plant macrofossil record was the presence of *Poaceae*, which could be correlated with the sequence in pollen found by di Rita *et al.* (2009) further up the Tyrrhenian coast that shows a major decrease in arboreal pollen over the period ca. 1000 BC – 0 AD, which the authors link to the development of new marshlands. They also noted an increase in microcharcoal, c.f. the previous period (3150–950 cal. BC), which may also be showing a similar story to the macrocharcoal found in Core 7. The reasons for the increase in charcoal could be climatic or anthropogenic or both.

The anthropogenic impact of the Romans is often ascribed by a decline in arboreal pollen (see 6.2.1.5), and related to deforestation. By contrast, di Rita *et al.*'s (2009) work shows an increase in arboreal pollen (40–86%), during the Roman period, mostly represented by evergreen taxa, in particular *Quercus* evergreen type (47%), *Erica* (6%) and *Olea* (3%). This is comparable with Castelporziano's pollen data with an increase from 50% to 75% of arboreal taxa. These changes are accompanied by high percentages of deciduous taxa, mainly deciduous *Quercus*, *Ostrya/Carpinus* and *Fagus*, and conifers, mostly represented by *Pinus* and *Juniperus*. In relation to the findings at Castelporziano, the plant macrofossils

from Core 3 at D6 showed an absence of arboreal species during the use of the site as a fish pond with *Betula* and *Alnus* gradually returning to the sequence at 90 cm (ca. 469 AD \pm 40). However, *Betula* plant macrofossils were found at 101-99 cm (ca. 191-242 AD \pm 40), along with the *Arbutus unedo* wood fragments at 112-100 cm (ca. 52-217 AD \pm 40). Also worthy of note is the arboreal pollen presence (despite a decline in some species (e.g. *Quercus* and *Alnus*) between 120-110 cm (ca. 7-63 AD \pm 40). There were also significant negative correlations of *Alder*, *Salix* and the aquatic pollen with the increased CHAR throughout the core. The presence of *Betula* plant macrofossils as the CHAR decreases is significant because its pollen frequencies have been shown in other studies (e.g. Simmons 1996) to rise sharply during post-fire regeneration, thus suggest the area is recovering from major fire(s), which in turn may be related to the known fire at the Vicus Augustanus. The absence during the Roman period and presence in the post-Roman period of *Betula* in the sequence may not be the result of deforestation but may have been due to the results of storms and wildfires, both of which would have removed established trees and allowed succession to begin in which *Betula* could flourish briefly. This may be particularly true in the post-Roman period, which the presence of *Quercus* reduced the available habitats for *Betula* as the macchia the area is known for today with *Quercus ilex* began to grow.

6.2.1.2 In relation to Crater Lake studies

Anthropogenic impact

Studies from the Italian crater lakes appear to show anthropogenic impact starting around the same period as settlement first occurred at D1, for example ca. 3000 years ago at lakes Albano and Nemi, and Valle di Castiglione, which are comparatively close (ca. 33 km) to the Castelporziano Estate, in the Alban Hills near Rome. However, most of these sequences have used Pollen as their marker for anthropogenic impact, due to the poor preservation, the pollen record from the site as whole; other proxies were used for this, see 6.2.1.4 for a more detailed discussion of evidence for anthropogenic impact at Castelporziano. In addition, Core 7 was taken relatively close to D1 (<1 km), but with only two AMS radiocarbon dates the age depth model is not robust as that for Cores 3 or 14 for D6 to constrain the record from this period. However, early anthropogenic impact maybe noted in core 14 from 193-143 cm (ca. 730-78 BC \pm 40), which showed an increase in nitrogen during this period (from C/N ratio), as dune slacks are primarily nitrogen poor environments, this increase is significant. Other anthropogenic impacts were noticeable in the sequence from Core 3 during the Roman period, with the localised eutrophication at D6, which was noted in the absence of proxies such as bryozoan statoblast and aquatic plant macrofossils.

Methodological issues

Distinguishing between climatic and anthropogenic signals in pollen records from the crater lakes is not just a question of identification; it is also a methodological question with regard to temporal resolution. For example, Drescher-Schneider *et al.* (2007) sampled for pollen every 9-20 cm at Lago dell'Accesa, and Kelly and Huntley (1991) sampled every 7-8 cm at Lago di Martignano, thus leading to one sample being taken every 300-500 years or so. Sampling at such relatively low frequencies leads to only general trends being established and makes any sudden or abrupt changes difficult to resolve. The results from the analyses of Cores 3 and 7 highlight the differences that resolution can make even with plant macrofossils. As Core 7 from Pozzo Napoliello had fewer macrofossils present it was only counted every 5 cm, whereas core 3 from D6 had more remains it was sampled at a finer resolution (every cm). In so doing more detailed changes could be established for Core 3, whereas more general trends were possible with core 7.

6.2.1.3 Changes at Castelporziano in relation to changes in the Mediterranean in the Late Holocene

Chapter one highlighted the changes in the Mediterranean during the Late Holocene, particularly the recognised changes in climate, i.e. the Sub Atlantic Period, the Roman Warm Period, and the Dark Ages Cold Period. However, the sequence reconstructed at Castelporziano is a local record. Some of the changes may be related to changes due to climate with Ostracods in the post-Roman period suggesting a colder climate than today (possibly the Dark Ages Cold Period).

6.2.1.4 European landscape change during the Holocene

The word 'landscape' is often ill defined, representing the totality of topographic components for some and the individual components for others (cf. Muir 1999). In addition, the sensitivity of landscapes to natural and anthropogenic inputs (assuming, for the moment, that people exert unnatural pressures on environment) is clearly demonstrable over timescales extending for millennia (Edwards and Whittington 2001).

Changing histories of the climate, soils, vegetation, flora, fauna and humans, their interactions and varied responses, will collectively result in impacts upon pedogenesis, vegetation history, and their appearance in the dune slack reconstruction. Dearing (1991)

suggested that evidence from temperate zones indicates that the 'natural' trend for sediment yield through the Holocene is decreasing or stationary, implying a reduction in sediment supply or in the transport capacity of fluvial systems as equilibrium systems are attained by ecological, pedological and hydrological controls (cf. Engstrom and Hansen, 1985). At sites subject to human impact, there are 'stepwise reversals' in the trend from the mid to late Holocene (Dearing 1991).

The Mediterranean is a complex landscape, and as Grove and Rackham (2001) contend, it is far too simplistic to view it now solely in terms of anthropogenic impact. Rackham is an opponent of "pseudohistory" who notes that: "*One should not assert that goats eat everything without having (first) watched goats*" (1997, p111-116), and that: "*deforestation is not the landmark catastrophe in environmental history that so many have made it*" (1997, p128-319). Indeed, Naveh and Carmel (2004, p339) go further in discussing the "*natural and cultural processes and patterns* contributing to the *ecological heterogeneity, biological diversity and its adaptive resilience*". Castelporziano provides an interesting source of comparison with this literature because of its discontinuous post-Roman settlements, and post-Roman vegetation history.

The Mediterranean is a complex landscape, and as Grove and Rackham (2001) contend, it is far too simplistic to view it now solely in terms of anthropogenic impact. Rackham is an opponent of "pseudohistory" who notes that: "*One should not assert that goats eat everything without having (first) watched goats*" (1997), and that: "*deforestation is not the landmark catastrophe in environmental history that so many have made it*". Indeed, Naveh and Carmel (2004) go further in expanding anthropogenic impact in the Mediterranean as a co-evolution interweaving the "*natural and cultural processes and patterns*" contributing to the "*ecological heterogeneity, biological diversity and its adaptive resilience*". Castelporziano provides an interesting source of comparison with this literature because of its discontinuous post-Roman settlements, and post-Roman vegetation history.

Use of pollen as an indicator of anthropogenic impact during Holocene

Understanding of the Holocene history of European cultural landscapes is largely based on vegetation histories derived from pollen data from lakes or bogs (e.g. Berglund 1991 and Gaillard 2000). The use of pollen diagrams to detect and define anthropogenic impact has a long history in temperate northern Europe. Two main approaches are noted for identifying human impacts in pollen studies; the first is to evaluate the changes in forest composition (Amman 1988) and the second to study indicator species (Behre 1981). The former are

established in terms of land use types or degree of vegetation openness around a site which are inferred qualitatively or semi-quantitatively, while reconstructions are based largely on the occurrence of anthropogenic indicator taxa, similarity with assemblages from 'modern analogue environments' (p21/table 1 and/or variations in overall percentages of non-woodland pollen types (Non Arboreal Pollen, NAP) (e.g. Behre 1988). The actual area represented by the pollen signal is often not addressed explicitly, or is defined loosely following the broad definitions of the pollen source area of e.g. Tauber (1965), Janssen (1973), and Jacobson and Bradshaw (1981). This is different to indicator species, which are plant species (for example knapweed, barley and chestnut) that occur only in the context of, or are at least highly correlated with, human activity (Behre 1986). Kelly *et al.* (1991) describe (groups of) species or specific situations, which may prove human influence upon the vegetation development:

- Firstly, the occurrence of cereal pollen generally provides evidence for human activity. Pollen of *Secale cereale* (rye), *Triticum/Avena* (wheat/oats) and *Hordeum* (barley) can be recognised, however it is difficult to distinguish the domesticated varieties from the wild ones. Kelly *et al.* (1991) indicate that the natural habit of many wild members of the cereal genera is a park land with a discontinuous canopy.
- Arrival and increased abundance of *Castanea sativa* (chestnut), *Juglans regia* (walnut) and *Vitis vinifera* (vine) are generally considered to reflect human activity in the pollen record (Kelly *et al.* 1991). However, an early arrival of these species in the Holocene may be a result of natural migration when environmental conditions changed. A later increase may reflect human influence or further progressive environmental change.
- Finally, indications for forest decline are supposed to be anthropogenic as a result of clearance, but environmental alterations must be considered as well.

Pollen based models for anthropogenic impact

Several models have been developed to examine the effect of humans on the environment in terms of pollen dispersal and spatial representation of settlement (Edwards 1979; 1982), but ultimately, the detection of anthropogenic change remains problematic. Many of these problems may result from the over-dependence on the indicator species approach which is highly problematic, e.g. in south-east Europe (Bottema 1982). Birks *et al.* (1988) note the followings shortcomings as problems in pollen taxonomy from pollen-morphological limitations; representational bias due to differential pollen production and dispersal; differences in human exploitation of certain crops and environments and the problems of finding modern analogues for past floral assemblages – a fundamental point also raised by

Berglund (1985) and Birks (1993). Therefore, other methods need to be used alongside pollen for monitoring anthropogenic impact.

Other methods of monitoring of anthropogenic impact during the late Holocene

Plant Macrofossils

Questions arising from the literature review of late Holocene environmental change centred on the ways of deciphering the influence of various effects on woodlands; i.e. how can human impact be separated from climatic change effects? Can autogenic succession be identified in woods interfered with by humans? What distinguishes human impact from natural forest succession? To answer these questions other indicators of anthropogenic impact have to be considered alongside pollen data. One means of testing pollen results is to use plant macrofossils from the same sites or areas. Being relatively large and heavy, macrofossils are usually not transported far from their sources (Birks 1973; Birks 2001) compared with many wind-dispersed pollen types. Therefore, if they are found in sediments, it is probable that the parent plants were growing locally at the site. There are several situations in which pollen assemblages can give a false impression of local vegetation and vegetation change (Birks 2001; Birks and Birks 2006). Thus the use of plant macrofossils alongside that of pollen may be used to understand better the changes at a local level and thus changes in the landscape and landscape interactions may be established (i.e. interspecies competition, and human elements e.g. selective cultivation of wheat types).

Geochemical indicators

Another indicator of anthropogenic activity is phosphorus (P). Many elements are left in the soil by humans but few are as ubiquitous, as sensitive, and as persistent an indicator of human activity as phosphorus. General sources of anthropogenic phosphorus include: human waste; refuse, especially organic discard derived from bone, meat, fish, and plants; burials; and ash from fires (Holiday and Gartner 2006). This can be measured directly using geochemistry from sediment (be it a lake or peat bog or archaeological site), or indirectly using diatoms with transfer functions as per Lake Albano (Guilizzoni and Oldfield 1996). Variation in the amount and composition of organic material in lake sediments gives valuable information about palaeoenvironmental changes, either caused by natural factors or human impact. The ratio of total organic carbon (TOC) to total nitrogen (TN), i.e. C/N, is frequently used as a parameter to describe the origin of organic matter (Meyers and Ishiwatari 1993). Organic matter from terrestrial sources shows C/N ratios that typically exceed an atomic ratio of 20, whereas algal organic matter is characterized by C/N ratios below 10 (Meyers 1994). Enters *et al.* (2006) found that two opposing processes, depending on the intensity

and type of human impact, appear to influence the C/N ratios: (1) Increased runoff following deforestation leads to higher C/N ratios through an increased flux of terrestrial organic matter into the lake. In some cases this effect is compensated or exceeded by (2) a higher lacustrine productivity caused by an enhanced mobilization of nutrients.

Methods used for monitoring anthropogenic impact in thesis

For this thesis plant macrofossils were used as the primary indicator of human impact with pollen being used as a secondary indicator owing to its poor preservation. The presence or absence of other proxies was used to infer human impact, for example the presence of *Lophopus crystallinus* statoblasts were used to infer a change in the levels of phosphorous and nitrogen based on its contemporary ecology.

Roman impact upon the landscape

As mentioned numerous times throughout this thesis, it has been suggested the Romans caused deforestation throughout the Empire. This section looks at the evidence for this in palaeoenvironmental and the textual evidence for this in different parts of the Empire from studies that have been directly focused on the subject of deforestation.

Northern England

It has been suggested by authors such as Dumayne and Barber (1994), Barber (1998), Dark (2005) and others that the Roman land use and clearance around Hadrian's Wall in Northern England led to deforestation. Large tracts of land have been shown, via pollen sequences, to have undergone exceptionally abrupt and unusual phases of forest clearance, which led to a dramatic impact upon the woodlands from c. 500 BC onwards (i.e. late Iron Age) (Manning *et al.* 1997). Dumayne with Barber (1994) and *et al.* (1995) has hypothesised that the forest clearance was not for agricultural expansion but primarily generated by the needs of the troops themselves, for defensive purposes as well as wall construction, metal work and accommodation. Tipping (1995 and 1997) argues that the proportions of palynological indicators of increased pasture and arable as sites on Hadrian's Wall are as important as sites away from it, where a native expansion of agriculture was shown by van der Veen in 1992. On a methodological note: when using pollen, it is important to remember the source, for which the catchment area can vary in size depending what was sampled. If the evidence from several pollen catchments indicates a consistent pattern of vegetation or vegetational change during a particular period, it may be thought, albeit with caution, that these change(s) are typical of the region as a whole. In the case of Northern England and

Hadrian's Wall, the late Iron Age and Roman periods it is possible that the Romans did clear the land as Dumayne notes, but other factors still need to be considered as the cause of the decline, including disease, fire and succession. For example, a well documented decline in Elm in North Western Europe during the Mid-Holocene, in which recent research on palaeoclimatic change and the nature of the transition from the Mesolithic to Neolithic in the British Isles implicates both climatic change and human activities. It was probably the interplay between these factors, rather than any one in isolation, that catalyzed the widespread, catastrophic decline of elm population (Parker *et al.* 2002). Therefore, the decline of trees during the Roman period could also be an interplay between climate and human activities.

Central Europe

Küster (1994) noted a decline in *Abies* during the Roman period in the Alps, which he acknowledges that other authors have found throughout central Europe (e.g. Janssen *et al.*, 1975 for France, Welten 1982 for Switzerland, Küster 1988 for Germany, Heitz 1975 for Austria, and Seiwald 1980 for Italy); as well for other sites, but no Roman Age *Abies* decline was found in areas which were not settled by the Romans, such as the Bayerischer Wald and northern Bavaria (Küster 1994). If climate had been a factor, this would have affected all the *Abies* in the Alps, but it is cited by Küster as clear evidence of deforestation due to the Romans favour for using it a building material (Hollstein 1980). In some areas plant macrofossils were found too, but the majority of examples where the decline was noticed were without the plant macrofossil record, thus the pollen could be seen as local and regional, therefore could be from elsewhere (based on the distribution of locations highlighted in Küster's figure 2). It is not known whether the Romans had temporary settlements in the Alps, as there is no archaeological evidence. Furthermore, they may have had their residences in the valleys and plains, and only went to the hills for wood-cutting. Therefore, the use of *Abies* as an indicator species for deforestation in these areas is made in the absence of information on any other reason for the decline. Within the same part of Europe as Küster's sites, the Jura Mountains of Switzerland, Soepboer *et al.* (2007) calculated the pollen productivities of key pollen species including *Abies*. Using pollen productivity values for *Abies* together with Küster's results to ascertain if the pollen signal was from temporary Roman camps in the mountains, shows that the *Abies* could be local to the sites where the pollen was counted but there is a long distance 'tail', so single grains could come from anywhere in the region (pers. comm. Bunting 2009). As such with counting the pollen with high temporal resolution and adjusting the count to reflect the productivity of each species, the results can only indicate a possible pattern but not necessarily one of deforestation. The results of the pollen count from core 3 at Castelporziano were normalised

by taking the logarithm of the count, thereby allowing those trees that produced fewer grains, such as *Salix*, not to be overwhelmed by those have greater productivity, such as *Quercus* or *Pinus*. Pollen productivity values were not factored in because they do not yet exist for Mediterranean taxa.

Italy

Few palaeoenvironmental studies have looked directly at the deforestation during the Roman period in Italy; most studies simply rely on the classical writers of the time.

Written Evidence

On looking at the written record of the Romans, it is worth noting that Pliny the Elder commented that Tiber at Rome flooded frequently in the first centuries BC and AD, with major crises recorded for 54 BC, 23 BC, and 15 AD (cited by Lamb 1977). Pliny the Younger (his nephew) confirmed the existence of a high water table in the coastal area, noting that it was possible to strike water when digging anywhere at his Laurentine villas (Radice 2003). A lack of comparative data precludes any real assessment of the scale of changes over time, but taking in the writings of both Plinys with archaeological evidence from the Forum in Roman of the Imperial Period is separated from the stratum of the archaic period by several meters of alluvial deposits (Quilici 1979), suggesting a period rather wetter than that of today. However, as the next section shows, the written records of Classical authors have been used by environmental historians have been implied to show deforestation (e.g. Hughes (1975, 1983, 2001 and 2005), which authors such as Rackham and Grove (2001) and Blondell (2006) oppose as they keep the theory of “the ruined landscape” going.

Environmental historians on deforestation

Donald Hughes (e.g. 1975, 1983, 2001 and 2005) has written extensively on “*how the Romans viewed deforestation*”, without disclaiming any discussion of what deforestation there was at the time. Shipbuilding and military exploitation, linked closely to political and economic forces are frequently cited as primary causes. Hughes (1975 and 1994) cites metallurgy and the ceramic industry in particular as demanding large amounts of wood and charcoal as fuel, thus worsening deforestation. Homer-Dixon (2007) attempted to calculate the energy consumption of the Romans using Energy Returned on Energy Invested (EROEI), which is the ratio of the amount of usable energy acquired from a particular energy resource to the amount of energy expended to obtain that energy resource (Dadeby 2008). Homer-Dixon (2007) proposed that a falling EROEI in the Later Roman Empire was one of the reasons for the collapse of the Western Empire in the fifth century AD. In “*The Upside of Down: catastrophe, creativity, and the renewal of civilization*” he suggests that EROEI

analysis provides a basis for the analysis of the rise and fall of civilisations. Looking at the maximum population extent of the Roman Empire (60 million) and its technological base the agrarian base of Rome was about 1:12 per hectare for wheat and 1:27 for alfalfa (giving a 1:2.7 production for oxen). From this Homer-Dixon calculated the population of the Roman Empire required at its peak, on the basis of about 2,500-3,000 calories per day per person, which is roughly equal to the area of food production at its peak. At the beginning in the 2nd century AD, the EROEI began to fall, which he cites being due ecological damage, falling to 1084 calories per day per person when Rome's population, which had peaked under Trajan at 1.5 million, was only 15,000 (Tainter 1990; Diamond 2004).

Another environmental historian, Sing Chew in his work "*World ecological degradation: accumulation, urbanization, and deforestation*" (2000), states that Roman "*deforestation . . . caused a tremendous amount of soil erosion,*" and that "*soil erosion was the order of the day*" (2000:95), this is his evaluation and interpretation of the classical texts but it is difficult to evaluate for the whole of the Roman Empire. In addition, although he gives occasional references to species extinctions, but the reason for all the events cited remains, in his view, deforestation.

Finally, there are frequent rather vague references to resource demands, which Hughes (1975 and 1994) also use as evidence for deforestation. Chew (2000:92) states that "*Shipbuilding for the Roman navy also required a lot of wood*", which they undoubtedly did but these imply trends but are difficult to evaluate using palynological evidence. Giachi *et al.* (2003) examined Roman ships found in the ancient harbour at Pisa (Tuscany, less than 300 km from Castelporziano) which found for the most part, that the timber utilised for the ships' construction was available in the surrounding area of Pisa. The absence of any plant in the pollen record, i.e. *Fraxinus excelsior* or *Picea Abies*, does not necessarily attest to the disappearance of these plants from the area. For example, the absence of *Ficus carica* pollen grains maybe expected because its pollen is not generally detected in the sediments even if the plant is growing near the sampling site, due to its particular pollination mechanism (Gail and Eisikovitch 1974). *Olea europaea*, which was found sporadically, is known to be widespread all around the Mediterranean Basin (Giachi *et al.* 2003). The availability of the wood for ships' construction in the surrounding area does not exclude the possibility of a foreign origin of the timber or a different provenance of the ship. Some of the plants involved were, and are widely spread, i.e. *Populus alba*, *Olea europaea* or *Quercus ilex*, or cultivated, i.e. *Juglans regia*, in the Mediterranean area. However, other plants indicate a more restricted provenance (Huntley 1988). The ecologist Oliver Rackman (2001) points out that the environmental historians such as Hughes (e.g. 1975, 1983, 1994, 2001

and 2005) and Chew (2000) confuse what the original context for these texts was, i.e. they are things people have **said** about nature, not a **history of changes** in nature, which are two very different things. Additionally, as fellow ecologist Jacques Blondell (2006) also notes, there is evidence from the Roman writers such as Paulinus and Virgil that some landscapes were more intentionally managed using empirical knowledge and observation specifically with the intent of making them more durable, which were then maintained with the use of traditional land use practises for centuries. Furthermore, other forms of ecological disturbance may result in the loss of woodland, such as wildfires and changes in the fallow cycle and the introduction of new plant and animal species (Thornes 2009). If an area is continually exploited, it can exacerbate its recovery and lead to degradation. At Castelporziano, the comparative absence of anthropogenic impact in the post-Roman period prevented wide spread disturbance throughout the site.

The Roman Wilderness

As discussed in chapter one, the area in which the Castelporziano estate lies in the Roman world has often been referred to as a “wilderness”. Three strands of thought on the meaning of “wilderness” in the Roman context were formulated, which were: a) The wilderness relates to a distinctive landscape; b) There are wild beings living there; c) A barren landscape. The findings from the palaeoenvironmental reconstruction are limited, due to the preservation of remains and issues of limited excavation means only tentative conclusions can be drawn. The archaeological record at Castelporziano has recovered inscriptions suggesting a game reserve, perhaps for the amphitheatre at Ostia Antica, thus fitting with Neudecker’s work on other *Vici Augusti*. However, this description does not match the textual evidence from Pliny the Younger who suggests a tranquil place for relaxation during the winter months, with no mention of hunting for game. Other places called *Vicus Augusti* or *Augustanus* are known in the Roman world, none in Italy, but several in North Africa, where they are all apparently attached to Imperial estates. One in particular, *Vicus Augustorum Verecundensis*, near Lambaesis (in Algeria), is interesting because it was originally called only *Vicus Verecundensis*, acquiring the imperial title in the early AD 160s. Similarly, the *Vicus Laurentium Augustanorum* of Castelporziano could have started life as plain *Vicus Laurentium* - the Vicus of the Laurentines - who then became the “imperial Laurentines” or “emperors’ Laurentines” in the later 2nd century AD, in connection with developments taking place on an adjacent imperial estate (Claridge 2009). The villa at Tor Paterno, 3 km to the south of the Vicus Augustanus, is probably the '*Laurentum*' to which the emperor Commodus withdrew when plague struck Rome in AD 191 (Herodian). An estate of that name had been in imperial hands since the 1st century AD, when an imperial procurator

of elephants was based there (*CIL* VI, 8583) and may have been first acquired by Augustus, one of whose slaves was honoured with a tomb on the Via Laurentina (Gellius), perhaps taking over a property which earlier belonged to the orator Quintus Hortensius (Varro). Archaeological excavation at Castelporziano has shown that the coastal villa was the focus of major re-development under the Antonine emperors (AD 138-180), possibly during the joint reign of Marcus Aurelius and Lucius Verus (AD 161-9), who could also have invested in the Laurentine forests and their management as a hunting park. One of the other inscriptions found in the Vicus Augustanus refers to a gallery of imperial portraits set up there in a building belonging to the '*saltuarii Caesaris*' - the emperor's gamekeepers. In 1938 bones of an elephant were found to the south of Ostia, beyond the Canale dello Stagno (figure 94) at Infernetto, which was cored (core 17) but contained no macroremains. It is possible that in this area wild animals were kept, to be transported to the amphitheatre at Ostia, as well as a small harbour, where the animals were unloaded, near a swamp. In 1990 poles were found for tying up ships, which were found on private property and subsequently destroyed by the owners. Does this then suggest the decline in arboreal plant macrofossils and pollen at D6 (core 3), and absence at Muraccioli (Core 7) be due to elephants!? Other animals that potentially kept at Castelporziano include leopards, as depicted on a mosaic found at building C of the Vicus Augustanus. Building C was a residential building originating in the first century AD, but by the mid-late 2nd century AD it was substantially enlarged with the addition of peristyle garden, whose porticoes were paved with black-and-white mosaics showing wild animals being trained for the amphitheatre, which include a Venator (hunter) chasing a leopard, and mythical marine monsters and sea creatures. The building was later divided up into smaller units in the 3rd and 4th century AD (Claridge 2009). The palaeoenvironmental reconstruction is limited to representing very local conditions particularly at D6 that if animal damage was responsible for the change in vegetation due to their impact it be hard to be noted with such work. However, there does appear to be a shift after D6 ceased to be used as a fishpond 1st century AD, which may explain the differences between Pliny's sedate place to relax and a "wilderness, before the re-development under the Antonine emperors. The next chapter will look more in depth at the Roman-environment interactions, and what can be taken from the palaeoenvironmental record as demonstrating anthropogenic impact.



A – Via Calcaterra, villa rustica (*piscina*)



B – Fosso dei Bastioni: elephant's bones

Figure 93 Elephant bone findings near Castelporziano

6.3 *Macchia* vegetation

Chapter one gave a detailed description of *macchia* vegetation within a Mediterranean environment, and it is typically shrubby, stiff-leaved, evergreen vegetation and adapted to the Mediterranean climate. Chapter five highlighted the presence of *macchia* in the current vegetation and the increased presence of *Asphodelus*, with considerations of what this may mean in terms of future environmental change. This section will look at how well this type of environment is represented in palaeoenvironmental studies (via selected case studies), how this could be improved, and how well the reconstruction from Castelporziano represents/shows the presence of *macchia* in the past.

6.3.1 *Macchia* vegetation: Representations in palaeoenvironmental reconstructions

The typical Mediterranean *macchia* community is often under-represented in pollen diagrams. Therefore, a definitive interpretation of vegetation cover in terms of *macchia* is

difficult, which is an important consideration given that macchia is often considered as part of a degraded, anthropogenically enhanced landscape (Rodrigue 2005; Allen 2009). It can be argued that, given large variations in time and space, it is difficult, on the basis of the limited number of pollen sites, to reach meaningful conclusions on vegetation cover.

6.3.2 The pollen signal from macchia species in palaeoenvironmental reconstructions

As noted above, the typical macchia species are often under-represented in pollen diagrams due to their being insect pollinated, thus producing less pollen than their wind pollinated rivals. Another problem can be for species like the kermes oak (*Quercus coccifera*), which can grow as a tree or a shrub, and both produce the same seeds and pollen. The only way in modern ecology to tell which form it is by the influence of grazing and browsing, with grazing making it grow as a shrub and browsing as a tree. However, this difference would not be noted in a pollen diagram, as the pollen would be the same whether it was a tree or a shrub. Liu *et al.* (2007) suggest plant macrofossils show a clear distinction between deciduous and evergreen oaks can be made but it is not clear on what basis as the seeds are the same.

6.3.3 Macchia pollen from palaeoenvironmental reconstructions

The next couple of sections look at case studies from countries within the Mediterranean basin and out with in which the authors claim to have found the typical macchia species such as *Phillyrea*, *Pistacia*, *Cistus* etc and examine their claims.

Italy

An important study by di Rita *et al.* (2009) from an artificially drained coastal basin north of the Tiber delta now occupied by the Fiumicino Airport, the other side of the Tiber delta from the Castelporziano Estate, shows the presence of find typical macchia species, particularly *Erica* in depths dating back 8300 years ago (ca. 9% of the total pollen count) and in the plant macrofossil record, dating to 2000 years ago, alongside *Pistacia* and *Phillyrea* thus suggesting macchia has long been found along this part of the Tyrrhenian coastline.

Spain

Carrión *et al.* (1995) report that their pollen from a cave in south eastern Spain shows “numerous taxa which can be assumed to represent Mediterranean vegetation similar to that found today near the coast: *Olea*, *Phillyrea*, *Pistacia*, *Cistus* etc”. Without examining the

modern pollen rain, there is no way to know whether the pollen found within their cave is representative of these species or not. Additionally, as cave pollen frequently has low counts, thus how representative their count was remains unknown.

Portugal

Fletcher (pers. comm. 2009) suggested the presence of macchia pollen in his samples from wetlands in Portugal may be due to the estuaries receiving a lot of water-transported pollen, i.e. probably washed directly into the core site from the low hills surrounding the coring area, which is a feasible explanation as his modern surface pollen samples showed a macchia pollen signal (including *Cistus*, *Phillyrea*, *Genista* types), which was strong immediately in the area of macchia development, but the signal was not found in the more distal portions of the floodplain (Fletcher 2007). The signal would not be expected to travel far due to the nature of the pollination of these species (i.e. insect pollinated), thus it is highly likely that in this case the samples were representative of past macchia in the area.

These case studies highlight the need to understand the contemporary pollen signal from the typical macchia species, as Carrión *et al.* (1995) assume they have it without examining the contemporary vegetation and Lopez *et al.* (2003) don't offer an explanation for which species of *Asphodelus* they mean, however Fletcher (2007) does show that these species can be preserved under certain conditions (as well as di Rita's work also showing this is true in Italian climates) and can be linked to the contemporary pollen rain.

6.3.4 Other methods for examining macchia in palaeoenvironmental reconstructions

The above section highlights the issues involved in isolating the pollen signal from typical macchia species, and that it can be found in small quantities given the right conditions. In addition to pollen, what other proxies could be used to highlight the presence of macchia in palaeoenvironmental reconstructions?

Plant macrofossils

As noted throughout this thesis, the use of plant macrofossils is important for ascertaining changes in the local environment, however few studies within Italy have used them. However, as noted above, di Rita *et al.* (2009) highlighted the potential of finding and using plant macrofossils. Additionally, few studies look directly use palaeoenvironmental combined with archaeological studies. A recent study by Tereso (2009) recently reported the presence of *Arbutus unedo*, *Fraxinus angustifolia*, *Cistus* sp. and *Erica* spp. amongst the species

present from a study of a Roman settlement at Terronha de Pinhovel, northwest Iberia (Spain) from taken from well-delimited domestic hearths (not a traditional palaeoecological archive).

Phytoliths

Some species of *Fraxinus* have known phytoliths, e.g. *F. Americana* and *F. pennsylvanica* both of which are both registered with Colonial Williamsburg' Foundation's database. Therefore, this could potentially be expanded to include other European species of *Fraxinus* and other Mediterranean species, thus expanding proxies that could potentially used for palaeoenvironmental reconstructions.

6.3.5 Presence of macchia inferred from the Castelporziano reconstruction

The pollen record showed the absence of macchia species, which may be due to poor preservation of any pollen grains.

The plant macrofossils on the other hand show an early presence of macchia with the presence of *Thymus vulgaris* in core 7 from Pozzo Napoliello during the post-Roman period, at depth of 50-40 cm, which using the time/depth model fits with the resettlement at Tor Paterno (9th to 12th centuries AD). The occurrence of macchia at this time is also shown in di Rita *et al.*'s (2009) pollen record, with the highest counts for *Erica* and *Olea*, thus indicating the presence of macchia elsewhere on the coastline at this time. As a species *T. vulgaris* has deemed to be less dynamic and less evolved than other types of macchia, as well as in areas where fire has been used to clear areas for grazing (Paola and Peccenini 2003), which may be explained by the increased CHAR at Pozzo Napoliello and Muraccioli (found in cores 7 and 9 respectively).

Other evidence for macchia at Castelporziano came from the wood fragments, which were noted but not counted, which included *Arbutus unedo* (identifiable by its red bark) at 100-112 cm of core 3 (ca. 52-217 AD \pm 40). *A. Unedo* tends to be found on siliceous soils rich in humus (Paola and Peccenini 2003), and is a common species within the contemporary vegetation throughout the coastal belt of the Castelporziano estate. Additionally, it has been found to regenerate rapidly after a fire (Paola and Peccenini 2003), their prevalence may be due to wild fires or after the larger fire noted in both the archaeological and palaeoenvironmental record. This type of macchia is believed to succeed towards holm oak, in the absence of any further disturbance (Paola and Peccenini 2003), which is indicated in

the plant macrofossil record by the presence of oak at 95 cm in core 1 and 96 cm in core 3, which is near the end of settlement at 92 cm (419 AD \pm 40). This again can be linked with the presence of *A. Unedo* pollen found by di Rita *et al.* (2009) over a similar time period.

This section has shown the palaeoenvironmental reconstruction showed traces of the presence of macchia growth during and post-Roman settlement, and shows a similar pattern to that found along the coast in the northern part of the Tiber delta by di Rita *et al.* (2009).

6.4 Parallel studies

Within the last few years examining long-term ecological changes have been examined with regard to understanding the functioning of modern ecosystems and landscapes (Dearing 2008). Examples of this include: Messerli *et al.* (2000) who show how both palaeoecological and environmental records could provide insight into “vulnerable” environments, whereas Homer-Dixon (2006) show how the past influences the present and Bradshaw *et al.* (2006) use the palaeoecological record to inform future conservation or restoration ecology.

6.4.1 Why undertake parallel studies?

Parallel studies examining both the modern ecology and palaeoecology allow a modern baseline to be constructed and inform future management strategies. Also, long term forest dynamics can be reconstructed using palaeoecological techniques enabling better management and aiding biodiversity and conservation schemes. Problems may also be highlighted if, as is the case with macchia, the palaeo-assemblage fails to preserve all of the elements of the original vegetation cover and in the correct proportions. Therefore, understanding the past succession, resilience and sustainability of ecosystems and landscapes can be considered empirical and theoretical studies of environmental system dynamics. Dearing (2006) states that there is no single accepted methodology to achieve this, therefore more work must be done to understand modern ecological change and future landscape sustainability.

6.4.2 How does this fit with the findings at Castelporziano?

By examining both palaeoenvironmental and more recent environmental change at Castelporziano, the changes due to anthropogenic impact may be examined in detail at different spatial and temporal scales. The sensitivity of the local environment to change (i.e.

how it has coped with stresses upon it be they natural, anthropogenic or a mixture in origin) and the “naturalness” of the current vegetation (i.e. is the macchia present purely due to past anthropogenic action) can be explored. Examples from the palaeoenvironmental record are at D6, which was changed by the Romans into a fish pond from a dune slack and made permanently wet. The local environment at D6 recovered from being eutrophic to returning to an oligotrophic environment, which in part may be due to the lower anthropogenic impact after its abandonment. The study of contemporary change in the environment demonstrates how rapidly the environment can respond to disturbances. The aerial photographs showed the impact of a fire in 1944 was still prevalent around the Vicus Augustanus, Muraccioli and Grotto di Piastra in 1954, as these areas were sparsely vegetated. However, in the 1983 aerial and excavation photographs these areas were almost covered in macchia, and by 2003 the area was completely dominated by holm oak with macchia. By studying the palaeoenvironmental and the contemporary changes in environment gives a baseline indicator of anthropogenic impact at Castelporziano, which can be used in future planning.

6.5 Succession vs. resilience with adaptive cycles

Chapter two highlighted the potential errors in the succession model for dune vegetation traditionally used for showing changes from bare sediment via pioneer and intermediate stages to a climax forest stage. However, this only allows for single pathway leading towards the climax forest, i.e. it is unidirectional. This does not account for disturbance events, such as fire, that are prevalent in a Mediterranean type of environment such as that at Castelporziano and the typical macchia species are seen as subclimax.

6.5.1 Fire and succession theory

In the Mediterranean basin, different plant communities have demonstrated their resistance to fire and vegetation regeneration has been traditionally described as an autosuccessional process where, after a fire, the vegetation generally recovers without any great changes in the species composition (Hanes, 1971; Zedler *et al.*, 1983; Keeley, 1986; Trabaud, 1992). The re-establishment of communities post-fire is a comparatively quick phenomenon (as noted earlier with regard to Castelporziano), and with maturity comes the return to a state similar to that of the unburned system. This change in vegetation does not follow a classic succession model, instead the herbaceous layer that dominates in the early post-fire stages declines with the replacement being shrubs and trees. This is because the species present pre-fire and post-fire are effectively the same, and not invaders from unburned areas (Allen 2001). It is important to note though that in the context of fire, species have evolved different survival

strategies that allow them to continue growing and the communities they are part of despite the impact of fire (Trabaud 1994), these survival strategies are discussed further below in section 6.5.2.

6.5.2 Resilience and Adaptive cycles

Another theory, other than succession, that may be suitable for explaining changes in both the palaeoenvironmental reconstruction and recent changes is that of resilience, which in the ecological sense refers to “the ability of an adaptive system to undergo changes and reorganisation while maintaining its fundamental functions, processes and structures” (Holling 1973, p2). Unlike succession there is no single equilibrium state, but potentially stable state systems are seen as moving through various stages of an adaptive cycle, which necessarily involves both changes and stability at different temporal and spatial scales (Gunderson and Holling 2002; Redman 2005). This adaptive cycle is represented by a figure of eight (figure 95), which is divided into four major phases: exploitation (r), conservation (K), release (Ω) and reorganisation (α).

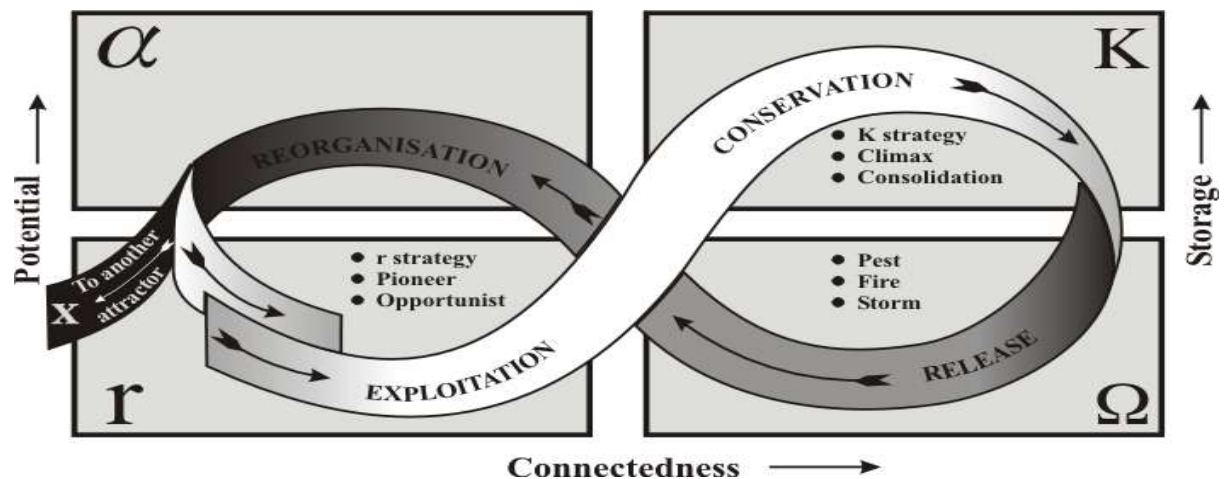


Figure 94 A stylized representation of the four ecosystem functions (r , K , Ω , and α) organized into an adaptive cycle. Adapted from Holling and Gunderson (2002)

6.5.2.1 How do Resilience and Adaptive cycles differ from Succession?

Succession normally starts with Ω phase, representing the accumulated biomass due to external perturbations, e.g. for a Mediterranean ecosystem such as Castelporziano an example would be fire. This is followed by the r phase, representing the exploitation or colonization of reproducing plants and animals, i.e. R strategists (pest and weed species), within the Mediterranean context such species include *Poa annua* *Juncus bufonius* and

Funaria hygrometrica. The **K** phase represents conservation, the slow accumulation of biomass as more slowly growing and reproducing plants or animals animals, i.e. K strategists that replace the initial colonizers, examples include *Quercus sp*, and humans. In Mediterranean ecosystems, such as at Castelporziano, macchia type plants in mature communities have slow energy release, whereas garigue type pioneer stages in disturbed sites can follow r strategists (Terradas 1991), which succession does not take into account. As previously noted succession ends with a climax community, which eventually may be subject to disturbance and release to start the succession process again. However, the adaptive cycle adds the α step, or reorganisation phase emphasising that succession will not necessarily lead to a climax community. In the α phase, resources are reorganised, or transformed, potentially in novel ways creating a new system that may or may not differ fundamentally from its predecessors. Additionally, this theory acknowledges that events or processes triggering a Ω release may include those internal to the system rather than external factors (Redman and Kinzig, 2003).

6.5.2.2 How does resilience and adaptive cycles fit with other studies within the Mediterranean?

Most studies within the Mediterranean have concentrated in proving the autosuccessional theory (e.g. Trabaud, Bonet 2003) rather than look for an alternative hypothesis as this fits with their theories with fire. However, this does not explain the presence of macchia growth in the first place as it's regarded as sub-climax.

Another problem is within the Mediterranean the use of the word "resilience" can be confusing in literature, as some use "resilience" to mean a specific adaption that certain species have to inputs such as fire, and not "resilience with adaptive cycles" to show changes within the ecosystem.

Ecological Resilience to Fire

As well as resilience meaning "*the ability of an adaptive system to undergo changes and reorganisation while maintaining its fundamental functions, processes and structures*" (Holling 1973 p2), it can also be used to describe the components themselves within the ecosystem. In Mediterranean ecosystems, rapid recovery from fire, soil disturbance and grazing have been attributed to two complementary causes. Firstly, disturbances often modify species relative abundances rather than composition, and recovery only involves the return to initial abundances. Secondly, life histories of dominant life forms in Mediterranean communities include efficient regeneration strategies that allow for recovery from dormant seeds or buds (Lavorel 1999). Thus they have been found to be of *high diversity and reputed*

high resilience" (Lavorel 2003), which has been demonstrated in terms of palaeoenvironmental reconstructions, archaeological and historical records, and from modern studies within the Mediterranean.

A good example of a survival strategy or adaptation is the response to fire, which is believed to have been induced by humans in the Mediterranean landscape since at least the Neolithic (Naveh 1975), and is still a major determinant within the landscape (Allen 2001). Fire is a disturbance process that propagates *within* the same cover type as well as *between* different cover types (Turner *et al.* 1989). The rate of fire spread depends on the fuel *characteristics* of the cover types. It also can play an important role in changing landscape heterogeneity and connectivity (Miller and Urban 2000). In a coastal study in France, Lemauviel and Roze (2003) used indices of resistance and resilience to compare three typical plant communities belonging to the various landscape units: mobile dune, semi-fixed dune, and fixed dune. The mobile dune and semi-fixed dune with their low resistance contrasted with the fixed dune. Only the vegetation cover of the semi-fixed dune apparently benefited from long-term trampling and had a very high resilience, with a balance of two opposite factors: soil compaction increasing soil stability and moisture content, and vegetation destruction. Dune vegetation can be destroyed by natural causes such as storms or fire, or by human interference such as clearing, grazing, vehicles use or excessive foot traffic

It is not just the plant species that show this resilience. Mediterranean land snails, for example, have also been found to show high resilience to fire disturbance in the long-term because they are greatly diversified whatever the fire regime, and even whatever the number of fires. However, the time lapse between successive fires seems to influence snail community composition (Kiss and Magnin 2003). Indeed, communities from the sites burned with fire intervals of 10 years or less have the least species richness and the lowest diversity indexes. In addition, closed and successive fires induce change in community composition, which includes more species living in open, sunny and dry habitats, i.e. stony areas, grassland and garrigue. Communities are greatly resilient to fire provided that the time elapsed between fires is over 5 years, i.e. the time needed for land snails to recover equilibrium with their habitat (Kiss and Magnin 2006). However, this does not relate to succession, rather something that has occurred as an adaptation to the Mediterranean environment.

Therefore, this autosuccessional pattern with fire may be due to this inherent adaptation and as noted above does not explain the growth of macchia, whereas resilience within adaptive cycles may offer an explanation as to what causes its growth, but this has yet to be explored

in the literature. There is a third theory which builds upon the potential of resilience and adaptive cycles, that of Panarchy, which is examined in the next section.

Panarchy

As noted previously, the model for succession although simplistic provides a good introduction to ecosystem functioning. Succession theory did not allow for growth of macchia species, where as the resilience theory and adaptive cycles allowed for alternative steady states, accounting for variations in local topography and climatic variability. However, these ideas can be further explored with regard to panarchy, which is the conceptual term given to a nested set of adaptive cycles that covers multiple spatial and temporal scales. Its essence is the need to understand different scales of change in order to explain causation in the modern states for geomorphology (Schumm and Lichty 1965). Although used regularly since the 1970s, it is only recently been considered with regard to palaeoenvironmental sequences (e.g. Dearing 2008).

A fundamental factor is the linking of “slow” processes that operate over large spatial areas (slow-large) and “fast” processes that operate over small spatial area (fast-small). Gunderson and Holling (2002) showed that within resilience theory, it is the slow-large processes that dominate in the forward part of the adaptive cycle. Natural ecological systems tend to re-organise through fast to slow processes, working within constraints imposed by the slow-large processes, with human activities often shifting from fast processes (high frequency) to slow processes (low frequency) but higher magnitude regimes (e.g. forest fires) (Dearing 2008). Carpenter and Brock (2006) suggested a role for palaeoenvironmental reconstructions in understanding the interaction between these processes for assessing current environmental system behaviour and resilience, thus highlighting the importance of palaeoenvironmental work for understanding current ecosystem functioning and future conservation.

6.5.3 Discussion of Succession, Resilience and Adaptive cycles, and Panarchy inferred from the Palaeoenvironmental reconstruction

The results from core 3 at D6 show a change from a bare grey dune to a freshwater lagoon to a dune slack, which was modified by the Romans to be permanently wet. The act of making the dune slack permanently wet alongside the Roman activities resulted in eutrophication, with the aquatic plant macrofossils from Core 3 showing the presence of more eutrophic tolerant species. As D6 was abandoned as a fish pond it continued to be a wet forest. Whereas the area around Pozzo Napoliello was a dune slack fen in the pre-

Roman period, developing into a fen during the Roman period and into a wet forest in the post-Roman period. However, these scenarios do not explain the presence of macchia or garigue which may be due to grazing of animals at the site, together with the effects of fires, which were not necessarily anthropogenic in origin. The presence of *Betula* at infrequent periods throughout the D6 core record could be the result of storms and/or wildfires, both of which would have removed established trees and allowed this species to grow. The presence of Macchia within the later Roman settlement was established by the presence of *Arbutus Unedo* fragments in the plant macrofossils, which is a species that grows a few weeks after a fire (Paola and Peccenini 2003). di Rita *et al.* (2009) found the presence of *A. unedo* pollen around 100 AD, which at Castelporziano is a period of low fires, which could suggest there had been a period of regional fires prior to this. In addition to the wood fragments, seeds of *Thymus vulgaris* were found at 50-40 cm of core 7, which using the limited age depth model for that core suggests the period of resettlement at Castelporziano (in the Tor Paterno area) in the ca. 9th to 12th centuries AD. The presence of *T. vulgaris* has deemed to be less dynamic and less evolved than other types of macchia, which with low anthropogenic impact in the previous four centuries and less fires (anthropogenic and/or natural) may have led to its growth. These changes do not fit with a classic succession model, as factors such as fires may have led to alternative paths being formed within the succession pathway.

As for the use of resilience and adaptive cycles as descriptors of changes in the environment and vegetation, these concepts were found to be most applicable to the recent environmental changes and palaeoenvironmental changes regarding fire, i.e. the 50-75 AD and 1944 AD fires. This led to the Ω and r phases, with the k phase perhaps explaining the presence of macchia and garigue in the current environment on the formerly bare areas as seen in the aerial photographs. Furthermore, the change in the palaeoenvironmental reconstruction of fire followed by growth of *Betula* followed by growth of *Quercus* alone could be seen as succession, but the presence of macchia species shows another process occurring alongside this. Indeed the question arises as to whether macchia and garigue could be better thought of as alternative steady states due to the co-evolution of anthropogenic activities and effects of the Mediterranean climate? With the recent changes in environment, the macchia at Castelporziano has been shown to change types or are they changes in a steady state? The 1954 aerial photographs showed sparse vegetation at the Vicus Augustanus, by 1983 macchia scrub can be seen to have covered the majority of the area. Excavation started the next year, and excavation records showed the presence of Macchia with large-berried juniper and lentisk (*Pistacio-Juniperetum macrocarpae*), which was not present in the baseline vegetation survey at the Vicus Augustanus in 2007, and had

been replaced by high macchia with prevailing holm oak (*Quercus ilex*). This change cannot be explained by succession, as macchia is deemed “sub climax” vegetation as it does not “represent a type of vegetation in equilibrium with the climate and the soil” (Tomaselli 1977, p356). The presence of the Juniper based macchia maybe the same as was present before the 1944 fire, which has been found to colonise dunes elsewhere in Italy (Paola and Peccenini 2003). The macchia with large-berried juniper was possibly the long-term vegetation at the Vicus Augustanus, as this type of macchia grows on both active and fossil dunes on sandy coasts. It may have taken over from the *Thymus vulgaris* type macchia found in the palaeoenvironmental reconstruction, as this was found a few km north from the Vicus Augustanus in the vegetation today in association with *Eucalyptus globules*. The macchia with large-berried juniper may no longer be present at the Vicus Augustanus today with increased anthropogenic activity and/or climatic changes, a different form of macchia has developed, typical High macchia (macchia with holm oak). The changes in different forms of macchia could be seen as a switch in steady states, rather than a successional change, adapting to the environment at that time. The reason the large-berried juniper macchia grew back quickly after the 1944 is the underlying ecological resilience found in Mediterranean ecosystem, as shown in the palaeoenvironmental reconstruction with the increased CHAR and eventual fire at the Vicus Augustanus, the proxies initially all declined or became absent in core 3 record, but gradually each one returned to its pre-fire state. This provides evidence that Mediterranean ecosystems can be thought of as resilient, due this co-evolution or synergy that exists between anthropogenic actions and the Mediterranean environment, which adaptive cycles may go some way to explain. Adaptive cycles take account of the importance of episodic change, which in succession is seen as agent for the process restarting and is not necessarily true in all environments. The concept of the adaptive cycle is beneficial because it emphasizes the multiple possible trajectories for growth and development. However, resilience theory has its own assumptions that events are circular, and does not take account of places like Castelporziano that have had relative low anthropogenic impact for centuries, thus the low macchia with large-berried juniper and lentisk prevailed upon the dunes in some areas like the Vicus Augustanus and others like D6, Pozzo Napoliello and Muraccioli wet forests formed, similar to a “climax” scenario.

6.6 Summary

- The results of the palaeoenvironmental reconstruction relate to the local environment but similar patterns are shown in the northern part of the Tiber delta (di Rita *et al.* 2009) in terms of both the range of species found and their periods of presence and absence.

- As for the ruined landscape theory, it is likely the synergy between anthropogenic impact and the Mediterranean environment pre-dates the periods of Greek and Roman dominance, areas that are marginal or poor today may well have been marginal or poor in the past. This can be noted in terms of the poor quality of soils at Castelporziano today which show low levels of organic matter due to high mineralisation. Therefore, the process of soil degradation, and thus presence of plants such as asphodels, is more likely to occur with the combination inter-annual climate variability, grazing of animals (particularly the deer in modern times at the estate owing to their lack of natural predator), and the estate pollarding of trees.
- Additionally, the presence of a Roman “wilderness” at Castelporziano and surrounding area may have varied with time. Archaeological evidence from the mid-late 1st century AD onwards suggesting the presence of a game park for animals for the amphitheatres at nearby Ostia, but this could not be proved using the palaeoenvironmental reconstruction.
- Dearing (2008) promotes the use of the palaeo record to assess the current environment and future developments. It is clearly important to study both contemporary anthropogenic impact and climate-forced impacts on ecosystems and environments, and not just in the Mediterranean, to develop an understanding of the mechanisms of change. By understanding the past synergy within the Mediterranean ecosystems, future planning and conservation of environments like dune slacks maybe better informed.
- The presence of macchia can be noted in palaeoenvironmental samples by use of pollen or plant macrofossils, but care must be taken to understand what the pollen signal looks like in the contemporary environment before it is applied to palaeoenvironmental reconstruction.
- Succession has been shown to be too simplistic a concept for describing changes within Mediterranean environments. Within Mediterranean ecosystems species (plants and animals) having adapted to the anthropogenic impact (a different type of resilience), thus macchia and Garigue are more steady states than degraded forms of climax vegetation. These ecosystems are dependent, in time and space, on resource gradients (moisture and light), disturbance type and frequency, previous land-use/cover, and the vegetation of adjacent land areas (via seed dispersal).

- Therefore, the model for changes in the Mediterranean lies between both systems, and neither theory alone can explain the changes, but the ideas of adaptive cycles may go some way to providing a better understanding of the complexities.
- The results from Castelporziano have shown resilience of the local landscape to anthropogenic and natural changes both during the period of Roman settlement and afterwards due to a mixture of the inherent synergy with the climate and the discontinuous human impacts in the post-Roman period. The forms of macchia that grow vary according to the type or level of anthropogenic impact, as can be seen from the results of the recent changes at the Vicus Augustanus.

Chapter 7: Synthesis of Roman human-environment interactions

7.1 Introduction

This chapter presents a synthesis of the human-environmental interactions deduced from the palaeoenvironmental reconstruction for the last 2500 years at Castelporziano. First, the results are compared with the archaeological evidence, with the differences examined and explained; second, the sensitivity of various environmental indicators to climate and human drivers of change are examined; and finally the implications for modern system functioning and future sustainability are discussed.

7.2 Archaeological and palaeoenvironmental interactions

Interactions between humans and their surrounding environments have been discussed in anthropological and archaeological literature over the past fifty years (e.g. Baker 1962, and Dincauze, 2000). Until the 1970s, the development of this subject was guided by a deterministic approach, thus suggesting that human ways of life were determined by environmental factors and local resource availability (see review in Trigger 1971). The current view assumes that climatic and ecological conditions provide the context within which all human decisions are made (Jones *et al.* 1999 and Sandweiss *et al.* 1999). However, the environment does not determine the social organisation of human societies, but instead sets the frame within which they must adapt, establishing boundaries for the range of social strategies that can be selected and applied (Dearing 2006; Leroy 2006). One possible long-term historical trajectory is that adverse climatic conditions and/or maladaptive human behaviour drive some societies, or parts thereof, to crisis or collapse, eventually leading to local extinction (Brenner *et al.* 2001 and Morales *et al.* 2009). For these reasons, palaeoenvironmental reconstructions are becoming increasingly important within archaeology, particularly in the consideration of cultural change and adaptation. Such patterns have been compared with regional archaeological information, and have demonstrated agreement between palaeoecological and archaeological data (e.g. Berglund 1991; Molloy and O'Connell 1991 and Molloy and O'Connell 1995; Andersen 1992–93; Rösch 1992; Behre and Kucan 1994). Therefore, this section compares changes in the palaeoenvironmental reconstruction at Castelporziano with the archaeological record.

7.2.1 Castelporziano's history

A time line showing the known events in the history of the Castelporziano estate is given in figure 3 (chapter 1, p 4), based on pottery dates and coinage from the excavations, as well as on written records. A synthesis of the key findings of the palaeoenvironmental work is presented at the end of Chapter 4.

7.2.1.1 Pre-Roman impact

As noted in the previous chapter, the earliest known settlement at the Castelporziano estate lies some 300 m further inland from the “fish farms” D5 and D6, where there is a series of three swamps or shallow lakes, associated with site D1. The excavation of this site revealed a group of low mounds containing shell middens and potsherds of late Bronze Age/early Iron Age date (900-700 BC), close to Pozzo Napoliello (see figure 4) (Claridge pers. comm. 2009).

The results from cores taken from this area (Cores 7 & 8) show an increase in CHAR, an indicator of local fires, and the absence of stonewort oospores. The increase in CHAR and presence of charcoal during excavation of D1 (Pers. Comm. Claridge 2009), may be related to ignicoltura (akin to *Slash and Burn* agriculture), as previously noted, in this practise fire is often used to clear land for pasture (van Joolen 2003). In addition, the analysis of cores from D6 showed strong correlations between the presence of *Betula* and increased CHAR, which, as noted earlier, may be related to post-fire regeneration at this time. The pollen record from D6 shows the presence of trees within the Castelporziano area, with the AP: NAP (Arboreal to Non-Arboreal Pollen) ratio of 18:82 at ca. 330 BC, with the AP: NAP ratio changing to 66:34 by early in the period of Roman settlement ca. 50 BC. The low AP in the pre-Roman period is not necessarily a sign of local deforestation since the plant macrofossil record shows the presence of *Betula*. It is possible that the area was more a grassland which, with the presence of frequent fires, would have allowed this species to colonise the bare or unused ground. In addition, the plant macrofossils from core 7 (Pozzo Napoliello) show an absence of any arboreal species during this pre-Roman period. The macrofossils record showed a dominance of grasses, which can equally be cleared or rejuvenated by fire. The mosses found in Core 7, *Lycopodiella inundata* and *Polytrichum commune* are also often found in a disturbed ecosystem with frequent fires.

Thus the pre-Roman shows evidence of fire and a limited presence of tree species.

7.2.1.2 Roman impact

During most of the Roman period the plant macrofossil record from D6 shows a continued presence of *Betula* until ca. 59 BC and then from 191 AD it is present sporadically until the end of settlement. The pollen record also shows the absence of *Betula* over the same time period. The presence of *Betula* during the early Roman settlement continues to show a strong correlation with the CHAR record, and, as the latter declines, *Betula* becomes absent in both the macrofossil and pollen records. *Salix*, although typical of a dune slack, is also absent. The decline and subsequent absence of these species could be as a result of fewer fires giving less opportunity for species like *Betula* to grow on the bare ground. Additionally, it is vulnerable, when young, to browsing by cattle, sheep, deer and large herbivores. Thus if the Romans had been using the area for browsing animals, particularly for use as a game park this may provide a reason for its absence. *Arbutus unedo* wood fragments were found in Core 3 (D6) ca. 52-217 AD \pm 40, and these may be associated with post-fire regeneration (Paola and Peccenini 2003).

One of the most notable events discovered during the archaeological excavations of the Vicus Augustanus was evidence for a fire between 50 and 75 AD that was followed by extensive rebuilding. Close examination of the CHAR from Core 3 (D6) shows a peak at ca. 7-18 AD \pm 40, and is followed by a notable decline or absence in the majority of proxies, from pollen, plant macrofossils, bryozoan statoblasts and organic matter. This peak in CHAR may correlate with the fire at the Vicus Augustanus; the age depth model puts the peak at 13 AD (\pm 40), with the subsequent decline and absence of other proxies dating to 20-50 AD (\pm 40). The archaeological excavation of D6 found a deposit of burnt material in the topsoil in the northern sector of trench nine, which produced several pieces of finewares ranging in date from 2nd century BC to c. AD 30-50, thus related in time to the fire event in Core 3.

The end of settlement was discussed in the previous chapter, which showed that climatic changes, with possible increased storminess, alongside the socioeconomic fallout from the sacking of Rome in 410 AD may have led to the abandonment of the Castelporziano “Laurentine Shore” by the Romans in 420 AD.

7.2.1.3 Post-Roman impact

The immediate post-Roman period showed a change to more arboreal conditions than during those during the Roman settlement. This is particularly the case at D6, with the presence of *Betula* and *Alnus glutinosa*. *A. glutinosa* was also found in Core 7 (Pozzo Napoliello), which suggests the presence of alder birch fen-woods, i.e. wet woodland. The

return of *Salix* pollen in Core 3 (D6) also shows the presence of wet woodland, as together with *Betula* and *Alnus*, *Salix* is dominant in this type of woodland, with *Quercus* growing on drier areas. Thus evidence points to a cool and wet climate, and the presence of ostracods in Core 3 (D6) also suggests a cooler temperature than at present. The presence of fen-woods suggests the water table within the slacks is at ground level or rarely varying more than 1m (Ellenberg 1988). As there was no human settlement until the re-occupation of Tor Paterno (9th to 12th centuries AD) these changes are not directly reflected in the archaeological record.

7.3 The sensitivity of the Castelporziano environment to change

This next section looks at the sensitivity of the environment to change with regard to the Roman-environment interactions. This provides a basis for defining the nature of human pressure, its interaction with natural variability and the sensitivity of the system under study, which, in turn, may form the basis for classifying the sensitivity to future impacts.

7.3.1 Ecosystem processes

In reconstructing the past, it is worth remembering that although each proxy is considered individually, in reality they would have interacted, as components within an ecosystem (Lowe and Walker 1997). Rutledge (1974) identifies three different properties of ecosystems, all of which could be encompassed under a heading of "*ecological stability*." The first is the greater the sensitivity of the components of the ecosystem to perturbation, the larger the overall sensitivity, the less the stability. The second is the persistence of the ecosystem over time. The longer it has survived the more stable it is. The final property is the ability of the ecosystem to return to its equilibrium state after being disturbed (Kay 1991).

Kay (1991) found ecosystems can take one of three paths after being stressed: (1) the ecosystem does not change from its original path; (2) the ecosystem changes from its original path but returns to it; and (3) it moves from its original path permanently, establishing a new but similar pathway to the original, or setting a completely new set of structures. The recovery of the ecosystem depends on a number of factors, the severity and nature of the stress, its duration and timing, subsequent disturbances, and sensitivity of key species or processes (Kelly and Harwell 1990; Cairns 1999).

7.3.2 Sensitivity of Castelporziano deduced from the palaeoenvironmental reconstruction

Given the Roman impact at Castelporziano, this section will examine how sensitive the environment is to change (i.e. natural variability), what has driven the changes, whether the environment recovered from these changes and, after the agent of change had gone, which pathway the environment followed. It is important to consider this in light of the findings of more recent (rapid) change, which showed that during the baseline vegetation survey areas full of *Quercus ilex* in 2007 which were coppiced for improvement of transportation had led to the spread of *Asphodelus sp.* in the 2008 survey. Therefore, the coppicing combined with the grazing of animals, organically poor soils and Mediterranean winter rains promoted this growth. The *Asphodelus sp.* is an indicator species for Garigue, the poorer form of Macchia, which forms due to overgrazing and nutrient poor soil (Huxley 1987). The species of Asphodel found, *A. microcarpus* is found in the least degraded stage of systems (Pantis and Margaris 1987), and continued overgrazing of animals may change the environment here. As the Romans appear to have used the site for grazing their animals, it is important to look at how it responded to change, which may in turn help future planning at Castelporziano.

7.3.2.1 Eutrophication

The action of the of the Romans in making D6 permanently wet led to changes in the local environment (only at D6 and not elsewhere) in particular eutrophication of its water, which resulted in changes in flora and fauna as found in Core 3, which showed the presence of more eutropic tolerant species, while more oligotrophic tolerant species were absent. For example within the bryozoans statoblasts, *Plumatella repens* became absent whilst *Lophopus crystallinus* and *Cristatella Mucedo* were present, the latter have been found in contemporary lakes that are high in nitrogen and phosphorous. The absence of *P. Repens* may also be explained by the absence of its food source, i.e. macrophytes. As previously noted, Core 3 showed an absence of arboreal plant macrofossils from ca. 59 BC to 217 AD \pm 40, alongside the increase in CHAR and decline in stonewort oospores. As well as eutrophication, these changes could also indicate acidification, as the number of *Daphnia ephippia* declined and they are sensitive to decreasing pH. This may be a sign of the temporary onset of acidification, changing the water body due to the settling out of decaying organic matter, which was also increasing as can be seen in the loss on ignition results, whilst the total amount of living matter may remain largely unchanged, the diversity of different species may drop considerably. This in turn may explain the absence of the ostracods and molluscs, as the ostracod species found were alkaliphiles and acidic conditions are unsuitable for mollusc preservation. However, acidic conditions should have

led to improved pollen preservation. Additionally, this change to more acidic conditions was only temporary and both molluscs and ostracods became present again by 420 AD (when the site was abandoned). Overall the results show that the environment is sensitive to change and that it adapted to changes in the use of the site, alongside increased eutrophication and acidification. Thus the changes appear to have followed the second of Kelly's pathways, i.e. the environment changed but then returned to its previous path (the seasonally wet environment). These types of changes are neglected in succession models as they assume change is unidirectional, whereas the alternative steady states suggested by resilience and adaptive cycles may be a better way to describe the changes noted.

7.3.2.2 Fire

Another aspect of the environment during Roman times was high charcoal influx (CHAR) in D6 suggesting local fires. This was examined in earlier sections, which highlighted the presence of *Betula* plant macrofossils and pollen with a strong correlation to the CHAR, which was shown to be frequently a pioneer species after fires. *Arbutus Unedo* wood fragments were found as *Betula* became absent in the plant macrofossil record and in the pollen, and this is also a pioneering species immediately after a fire. In a Mediterranean type environment such as Castleporziano, fire has evolutionary impact on plants as manifested by feedback responses, in which the fire, and its after-effects, affects selected plants for physiological and other mechanisms that enable direct fire tolerance or permits avoidance followed by vegetative and reproductive regeneration. Fire has thus been important in the evolution of more xeric grasslands and woodlands and more mesic macchia and shrubland communities (Naveh 1975). Fire as a driver of change, and thus ecosystem function, is a short-term event that moves the system well away from its optimum operating point. However, the forest regenerates back to the original system. That is to say single "fire events" may not excessively change the existing vegetation structure and floristic composition - or, rather, the more or less accentuated variations which may be caused by the passage of fire are cancelled in a short, sometimes a very short, period of time (Paola and Peccenini 2003). Therefore, although the palaeoenvironmental record showed increased CHAR during the Roman period, it was not driven to change from its original pathway because the plants themselves were adapted to fire. However, the CHAR from Core 3 (D6) shows a peak at ca. 7-18 AD \pm 40, and is followed by a notable decline or absence in the majority of proxies, from pollen, plant macrofossils, bryozoan statoblasts and organic matter, which correlate with a fire in the archaeological record at the Vicus Augustanus. This fire led to changes in the environment, with a change in the plant macrofossils in D6 with the presence of *Eleocharis palustris* which tolerates pioneer

conditions (Shay and Shay 1986), such as burnt sites (Millar 1973). High-severity fires in coastal marshes result in either root burns or peat burns. Root burns kill dense climax vegetation in marshes and allow earlier successional plants such as *Eleocharis sp.* to colonize the site (Lynch 1941).

7.3.3 Summary

Although there were changes within the local environment at D6 due to anthropogenic (eutrophication) and fires, the environment has a built in adaption to change that is temporary before returning to the previous pathway, like the second of the pathways suggested by Kay (1991).

7.4 Modern system functioning at Castelporziano

The section looks at modern system functioning at Castelporziano and how this fits with human-environment interactions. Human activities over long time periods may gradually transform ecosystems while in others, initial impacts can be critical in switching ecosystems into different functional modes (Oldfield and Dearing 2003). The functioning of the majority of modern ecosystems is contingent upon a significant history of human impact, demanding that integrated strategies for preservation, conservation or sustainable management of ecosystems incorporate an understanding of long-term responses to both climate and human activities (Dearing *et al.* 2006). Therefore, in a location where certain human activities have been suppressed for centuries, the question arises of the extent, if any, of the legacy of Roman activities in contemporary Castelporziano.

7.4.1 Castelporziano – the modern situation

In terms of modern system functioning, as noted previously, access to the Castelporziano estate had been limited for centuries, thus knowing how the environment previously linked with anthropogenic inputs is important not only for management of the estate but also for future planning. System functioning is strongly dependent on how these changes occur. Therefore, changes today may not only be characterised by processes with long time scales, but may also respond to impacts according to the changes that took place within those timescales. The growth of macchia, for example, is believed to be a result of such processes.

The palaeo record may be used to develop generalisations regarding the nature of system dynamics, ecological thresholds and non-linear thresholds (Dearing 2002). For future climate scenarios at Castelporziano, the draining of the swamps in the early 20th century may have led to changes which continue have impacts now. Impacts include peat shrinkage and, importantly, the oxidation of organic matter. With regard to survival and persistence of species, some seasonal Mediterranean ponds still exist in the relatively poor sandy soils and the fossil interdunes within the estate; therefore the findings with regard to eutropication in the palaeo record are important. Both the intensity and the frequency of local fires, particularly in a Mediterranean context, are likely to increase with an increase in temperature, and an increase in convectional storms and associated lightning strikes, presenting similar scenario as to the Roman record (although lightning is natural and it is not possible to say all the fires in the Roman period were anthropogenic in origin). Therefore, the palaeo record gives some partial historical analogues for extreme events, abrupt impacts and human-environment interactions; potentially quantifying natural variability and defining threshold limits.

7.4.2 Castelporziano – What is natural?

A problem with using history to identify “natural” conditions is the fact that humans were an important cause of past variability in most ecosystems (Swetnam *et al.* 1999). The Roman influence at Castelporziano was notable at least at a localized level, particularly at D6, due in part to the good preservation of proxies at this site. There seems to be a tendency to over generalize the impacts of the Romans in other areas by environmental historians, prescribing deforestation as the cause of everything, without examining any other possible causes such as disease or climatic variability. Some landscapes were managed and manipulated during Greek and Roman times in the Mediterranean, while it is likely that some regions and ecosystems were not substantially altered by humans after this period until the 20th or 21st centuries, like Castelporziano. However, the current environment and vegetation at Castelporziano is taken by many, including some of the Estate Administrators, as being “natural”, simply because it has not been disturbed for centuries. This is not actually true as Lanciani (1909, p308) stated that the pines between the Vicus Augustanus and Tor Paterno were planted “*by the Sacchetti in the seventeenth century, the area of which has been trebled since it was joined to the royal shooting preserves in 1875. Many thousand pines are planted every year and great care is taken to keep the older ones in a healthy state*”, thereby suggesting the environment has been managed far longer than the estate foresters are prepared to concede. Additionally, this research has shown there is a synergy between anthropogenic impact and climate in Mediterranean ecosystems, whether

the change is due to fire or, as in the Roman period, localized eutrophication at D6, this built-in synergy allows the environment to return to a previous path.

Thus, what aspects of the current environment and vegetation can be described as “natural” irrespective of anthropogenic inputs? The *Quercus ilex* found throughout the area of the estate investigated may be in part the result of the draining of the swamps, since, as fens dry out, *Quercus* often dominates. Another reason for the dominance of *Quercus* is its adaption to the Mediterranean climate, i.e. it is sclerophyllous (Reille and Pons 1992).

7.4.2.1 Macchia growth – origins and what drives it at Castelporziano

As for the macchia, human activities, overgrazing and events such as fires are often cited as causes of its growth (e.g. Camarda *et al.* 2004). The macchia at the Castelporziano estate is at least 200 years old, as Louis Petit-Radel noted in 1796 “*the presence of myrtle, rosemary, juniper, laurel, terebinth, erica, viburnum, and two species of daphne*” (Lanciani 1909, p309) near Tor Paterno and are all typical macchia species. In addition in the palaeoenvironmental reconstruction, traces were found of macchia: e.g. the presence of *Arbutus unedo* bark, perhaps attested to the frequent fires; and the presence of *Thymus vulgaris* plant macrofossils.

The macchia growth at Castelporziano is old but was it anthropogenically induced? Plant–herbivore relationships in Mediterranean ecosystems are poorly documented even for the simplest aspects of dietary choice of ungulates and the impact of grazing on vegetation, but paleoecological evidence (reviewed by Grove and Rackham, 2001) suggests that Mediterranean plants evolved under conditions of heavy grazing and are hence likely to exhibit compensatory re-growth. Castelporziano may well have been used as a game park during the period of Roman settlement, and the subsequent (infrequent) settlements have allowed the natural fauna to graze with little predation.

7.4.3 Castelporziano – the future?

Contemporary human use of the Castelporziano estate may alter the structure and functioning of the ecosystems, and alter how the ecosystems interact with the atmosphere, with aquatic systems, and with surrounding land. Thus, future anthropogenic activity needs to consider the highly sensitive nature of the environment, particularly as it is a “valued” ecosystem and nature reserve. Additionally, the nature reserve and management need to consider the flora, not just the fauna being impacted by their actions and the actions of the

fauna upon the flora. With limited anthropogenic impact at the Castelporziano estate, it may not show the same long term resilience to change as elsewhere in Italy or the Mediterranean as it has not been subject to the same anthropogenic stresses, therefore may not return to its original pathway once disturbed. However, a fire in August 1982 damaged an area of the estate but all the typical macchia species survived the fire and reconstituted a community similar to that unburned in a relatively short time span (Gratani and Amadori 1991). Contemporary vegetation changes, with *Asphodelus sp.* covering the open ground left after the pollarding of *Quercus ilex* allowing grazing and leading to the growth of Garigue, appear to be following a different path. Therefore, careful management of the animals within the estate is necessary for the protection of the flora.

7.5 Summary

This chapter showed that some aspects of the Romans' interaction with their environment can be elucidated from the palaeoenvironmental reconstruction. The local environment is sensitive to changes from inputs, but shows a specific adaption to the change, and soon returns to its original pathway. However, the overgrazing, particularly by deer, is notable in the current environment, in areas where trees have been coppiced and without sufficient recovery periods to allow the environment to recover.

Chapter 8: Conclusions, future work and context of findings

In this final chapter the research questions set out in chapter one are reviewed; with the key findings and conclusions for each question are summarised and, where appropriate, suggestions for future work are noted. The findings will then be examined in the wider context of Central Italy and the Mediterranean.

Introduction

This thesis investigated the potential of dune slacks as archives for palaeoenvironmental change within a Mediterranean environment using a multiproxy approach and examined the changes in relation to the archaeological evidence for human-environment interactions at the Presidential Estate of Castelporziano, central Italy. Ancillary work was done by examining the record of the last 50-100 years in terms of recent environmental changes using vegetation surveys, aerial photographs and contemporary ecological data.

Chapter 1

In chapter one, six research questions were set out which were:

1. Are dune slacks suitable archives for palaeoenvironmental reconstructions? As few palaeoenvironmental reconstructions had been carried out previously using dune slacks, their full potential as an archive needed to be explored. Dune slacks represent the only sinks for sediment and organic remains within the confines of the Castelporziano estate.
2. Which palaeoenvironmental proxies can be used to reconstruct past changes in the dune slacks? If dune slacks were to be suitable archives for palaeoenvironmental reconstructions, would classical proxies of pollen and diatoms prove just as successful for the reconstruction as they are in peat bogs and lakes, or would other proxies such as molluscs and ostracods be of more use? The taphonomy of potential proxies within dune slacks, let alone Mediterranean ones, is beyond the scope of the present work.
3. What environmental changes are apparent from the palaeoecological and chemical proxies? When did they occur and why? Do the proxies do show any changes with time, or all factors all constant with time? If there are changes, are these related to

changes in the environment? Can these be correlated with any known events, by use of a ^{14}C dating age-depth model?

4. To what extent were these changes anthropogenic and/or natural? If the proxies do show any changes, can the anthropogenic signal be disentangled from the climatic one? Additionally, do the changes relate to a succession type scenario or other “natural” changes within the environment?
5. What is the current vegetation of the area and how has it been affected by estate management practices over the last 50-100 years? As the site has been acknowledged to have been managed in terms of reforestation schemes, road building, banning of hunting etc, how have these activities impacted on the current vegetation and has there been any change due to these activities on the vegetation?
6. What evidence is there of a legacy of past land use practices from Roman times? Vanwalleghem *et al.* (2004) looked at possible effects of Roman agricultural land-use on the present-day vegetation in the Meerdaal Forest (Belgium), also a nature reserve with limited access to protect its diversity, thus parallels with Castelporziano and found that the vegetation on formerly cultivated and fertilised sites still had a more eutrophic character and hence, contained more typical forest species. Therefore, a pilot study to look at possible impacts on the current vegetation given the restricted access to the site for centuries.

These questions will now be addressed in relation to the findings presented in each chapter.

Chapter one set the scene by showing the context of the research within the larger AHRC project, the history of the site from Pliny the Younger and archaeological excavations, and what is known of the surrounding area during the time period of settlement by the Romans. This highlighted the issue of the Roman “wilderness” and its contested meanings: (a) the wilderness relates to a distinctive (wooded) landscape; (b) it is a wilderness because there are wild beings living there; (c) it is a desolate, barren, sandy landscape. These issues and meanings were then examined in relation to the palaeoenvironmental reconstruction in chapter 6. This contemporary “wilderness” is also placed within a theory that prevails in the Mediterranean of a “ruined landscape” and the long-term impact of anthropogenic upon the Mediterranean. The current vegetation at Castelporziano, in the coastal area examined in this thesis, is dominated by that of

macchia and is believed to be one of the few places in Italy with high or primary macchia, thus highlighting its ecological importance of the study site. The chapter then looked at the Late Holocene within Italy and the Mediterranean. In the case of Italy it highlighted the use of pollen records from crater lakes in Italian palaeoenvironmental reconstructions, the problems associated with the use of pollen as a primary proxy for such studies (the disentanglement of anthropogenic from climatic signals), the abundance of literature centring on Northern Italian Crater Lakes with Central and Southern Italian ones hardly covered, and the focus on the Pleistocene-Holocene boundary, with few studies specifically highlighting the last 3000-2000 years of record. Within the Mediterranean, work has centred climatic changes; e.g. the work of Desprat *et al.* (2003) from North Eastern Spain which demonstrated the existence of a warm period, “The *Roman Warm Period*” from 250 BC to 450 AD. The chapter concluded with the research questions and the aims and objectives of the thesis.

Chapter 2

Chapter two demonstrated that the current understanding of dune slacks has a northern European bias, particularly the Netherlands and United Kingdom, with knowledge of Italian and Mediterranean slacks comparatively poor. Within Mediterranean there are known to be 42 areas known to have dune slacks, 25 of these are in Italy. One site in nearby Lazio identified two different communities: one dominated by *Schoenus nigricans* and *Erianthus avennae*, and the other comprises evergreen woodland, dominated by *Quercus ilex*, which is found at the Castelporziano estate. The rest of the chapter examined in more depth the features of dune slacks: for example the model of succession within dunes and potential errors associated with this model, which is special interest at Castelporziano because Lancisi in 1714 first described succession using the area around Castelporziano for his work; the hydrology of slacks that showed the maintenance of dune slack ecosystems depends on both the amount of precipitation and the groundwater discharge; and as with other dune habitats, are generally nutrient-poor and therefore associated with low levels of nitrogen and phosphorus in the soil but anoxia tolerance is one of the dominant factors responsible for a stable vegetation zonation between dune slack and dune top. The impacts of factors such as water abstraction and drainage and climate change were examined. The chapter finishes looking at the limited work that has used dune slacks as a palaeo archive, with the work of Fontana from Buenos Aries Province (Argentina) highlighting potential for remains to be preserved, such as ostracods, but also potential problems with traditional proxies such as pollen. The chapter ends by questioning the extent to which the northern European dune slacks are appropriate analogues for the Mediterranean slack environments.

Chapter 3

Chapter 3 addressed the first two research questions: Are dune slacks suitable archives for palaeoenvironmental reconstructions and which palaeoenvironmental proxies can be used to reconstruct past changes in the dune slacks? To answer these questions a series of literature reviews and laboratory pilot studies were undertaken to narrow down the list of potential proxies. In answering whether the two questions on the suitability of dune slacks as an archive for palaeoenvironmental reconstructions and which proxies were suitable for reconstructing environments, cores 1 and 6 from D6 and D5 respectively showed preservation of proxies such as plant macrofossils, molluscs, bryozoan statoblasts (in particular *Plumatella repens*) and *Daphnia magna* Ehippia. Geochemical analysis was carried out on the core from D6 but due to the minerogenic nature of the samples, the geochemistry reflected mineral composition of the sand and was not suitable for palaeoenvironmental reconstructions for environmental change. Other proxies tested and then eliminated included diatoms, due to their poor preservation at sites other than D6 (e.g. D5, Muraccioli, and the lower 150 cm at Pozzo Napoliello), which may have been due to desiccation as a result of drainage or could be absent due to the high levels of carbonate at these sites. Of the proxies that were preserved, plant macrofossil preservation was generally good and were best to record changes within the local environment, particularly the vegetation history. However, further work needs to be done in the following areas: to illustrate what drives the record, i.e. allogenic and autogenic processes; whether the differences in hydrology of the slack alter preservation of proxies; and to improve contemporary knowledge of Mediterranean dune slacks and how they differ from those at the Wadden Sea.

Chapter 4

This chapter built on the findings of chapter 3 and focused on the changing environment at D6 on a ^{14}C constrained timeframe, as well as expanding the study to cores taken from other areas within and outside the estate. From the view of potential proxies (and further answering question two), pollen was found to be degraded in Core 3 from D6, which may be due to local (alkaline) pH conditions and possibly the seasonality of wetness. Plant macrofossils, on the other hand, were found in almost all of the cores examined, with the exception of Infernetto (Core 17). The presence of plant macrofossils enabled reconstruction of changes of the local vegetation, which aided interpretation of the limited pollen results in terms of distinguishing between local, extra local and regional sources. The loss on ignition proved valuable to estimate the percentage of organic matter in the cores, thus giving an indication of likely preservation within the core, as well as optimum locations for ^{14}C dating and allowing multiple cores from one location to be correlated. The macrocharcoal gave a

good record of fire history. Ostracods were found at D6 both before and post Roman settlement; all were alkali tolerant species and all freshwater species. Molluscs were found in the post Roman part of Core 7 from Pozzo Napoliello and proved to be useful indicators of the local environment and good agreement with the plant macrofossils interpretation of wet woodland. Other proxies present included bryozoan statoblasts, stonewort oospores and daphnia ephippia, which were important for distinguishing more subtle changes in the environment. These findings highlight that there are many potential proxies that can be used for reconstructing environments from dune slacks.

The results of the proxies helped answer the third question concerning what environmental changes are apparent from the palaeoecological and chemical proxies, when did they occur and why? Environmental changes due to eutrophication were found at D6 resulting from making of the site permanently wet. This led to absence of the most aquatic macrofossils (mostly macrophytes), ostracods and *Plumatella repens* statoblasts, on the other hand this led to an increase of organic matter, and presence of other proxies including the bryozoans *Cristatella mucedo* and *Lophopus crystallinus*. *C. mucedo* are found in contemporary clear lakes, they do not thrive in lakes with plenty of clay and silt in the water, which are high in phosphorus and nitrogen as well as having high water temperatures.

Another change in the local environment at D6 as the organic matter declined was an increase in the charcoal influx, which is associated with absences or declines in all proxies at around the time of the fire at the Vicus Augustanus, but within a decade (based on the age depth model) the proxies had returned. To answer question four as to whether the changes were natural or anthropogenic, fire could have been used to improve pasture and clear ground for grazing, however, it is more likely to be due to wildfires that are common in Mediterranean type environments. The plant macrofossil record for Pozzo Napoliello and D6 (Cores 7 and 3 respectively) shows the presence of disturbed ground taxa, e.g. *Apium graveolens*, and *Poaceae*, as well as mosses *Lycopodiella inundata* and *Polytrichum commune* both during the Roman and post Roman settlement, alongside the non-pollen palynomorph *glomus* c.f. *fasciculatum* chlamydospores, which are commonly found in fire-prone areas. Thus the ground may have been disturbed due to frequent fires, or due to the presence of wild boar as described by the classical authors, which grew to a large size, but were considered by epicures to be of inferior flavour on account of the marshy character of the ground in which they fed (as noted by Vergil, Horace and Martial). Varro also tells us that the orator Hortensius had a farm or villa in the Laurentine district, with a park stocked with wild-boars, deer, and other game. This might explain why, as the charcoal influx declines, the plant macrofossil remains continue to show the presence of disturbed ground taxa.

Further archaeological work at some of the other coring sites may help elucidate which animals were at Castelporziano at this time, as to date only limited excavation has occurred within the site with Amanda Claridge *et al.* concentrating on the Vicus Augustanus. However, although elephant bones were found south of Ostia in 1938 at Infernetto, no large animals remains have yet been found at Castelporziano.

Chapter 5

This chapter focused on the more recent changes to the environment (50-100 years), the extent to which these were driven by the management of the estate, and also what “natural” means in the context of Castelporziano and whether there were any legacies of past land use on the current environment.

The current vegetation along the Via del Telefono of the Castelporziano Estate, alongside the archaeological remains is macchia associated with *Quercus ilex*. A ground vegetation survey found at most areas, e.g. Vicus, Pozzo Napoliello, and Muraccioli. In some areas hygrophilous vegetation is evident, particularly at Muraccioli close to the Via del Telefono and the edges of D5 and D6 which have ferns (*Pteridophyta*) as remnants of the wet forest noted in the palaeoenvironmental reconstruction. Other vegetation currently mapped includes the reforestation of *Pinus pinea*, which is apparent along the main estate road. The reforestation scheme was thought to originate from a fire in 1944, but earlier schemes are also documented. Another impact upon the environment has been the fungus (*Heterobasidion annosum*) currently affecting growth of the *P. pinea* in the afforested areas, which came to Castelporziano with the American soldiers in 1944. The current estate practise of coppicing of the *Q. ilex* has allowed *Asphodelus sp.* to grow and this change together with the contemporary ban on hunting has lead to some areas being overgrazed by deer and wild boar. The long term effects of this clearance and overgrazing will require further monitoring by the estate. The *Q. ilex* woodland has a turnover time of 35 years, which was due to the low soil carbon content and the fast decomposition occurring in the soil owing to differences in soil, climate, vegetation and management, which was also indicated in the Ellenberg indicator values of **K** (climate), **L** (light) and **N** (nitrogen) and their correlation with organic carbon in the re-prediction algorithm. Further work could be done surveying the current vegetation and examining further the macchia and garigue as to differences in types varying within the site as this was found to be more dynamic than is commonly assumed in the literature. It has changed due to anthropogenic impact and the fire of 1944, although the vegetation returned to pre-fire levels soon after the fire, the macchia at the Vicus Augustanus was shown to change from macchia with large juniper to that associated with *Q. ilex*.

The final research question was examined in chapter six, concerned the evidence of a legacy of past land use practices from Roman times. There does not appear to be any legacy of past Roman land at Castelporziano, which may have been due to the limited agriculture practised at Castelporziano (little palaeo evidence was found for agriculture) and the discontinuous anthropogenic impact since the Romans abandoned the site has allowed the land to recover from this. For example from Core 3 the proxies showed an eutrophication signal during the Roman period, recovered during the post-Roman period. Dambrine *et al.* (2007) suggested that the weathering of the calcareous sandstone, used as construction material, continually provided the soil with fresh nutrients, keeping pH at an elevated level, but at D6 due to its coastal location the high pH is almost certainly due to shell content in the sand. Dupouey *et al.* (2002) suggested that geochemical signals were altered in Roman sites but this was not substantiated at D5 or D6, as the geochemistry related to the mineralogical components of the sandy substrate. Further work could be done in this area with a detailed study of the vegetation at the archaeological remains c.f. elsewhere on the estate, including the recently annexed Capacotta area, which was known to be used for agriculture prior to becoming part of the estate.

Chapter 6

This chapter was divided into four sections: first, the results were reviewed within the broader context of Late Holocene environmental change in Italy and the northern Mediterranean, with an examination of anthropogenic impact upon the landscape; second, the use of palaeoenvironmental reconstructions for reconstructing typical Mediterranean species (macchia and garigue) was discussed; third, the importance of parallel studies for examining past and contemporary environmental change was reviewed; and, finally, the role of succession vs. resilience, as informed by the results of the palaeoenvironmental reconstruction, was discussed.

Anthropogenic impact noted at Lakes Albano and Nemi ca. 3000 years ago fits with the archaeological record from Castelporziano of 900-700 BC. The use of pollen in the studies, made comparing direct sequences with an extremely localised sequence from Castelporziano very difficult. The study by di Rita *et al.* (2009) at the northern end of the Tiber delta plain shows similarities in terms of both vegetation and environmental changes, both areas show an increase in AP:NAP with di Rita's showing an increase from 40-80% in arboreal pollen during the Roman period, at Castelporziano it increased from 50-75% over the same time, thereby suggesting the increase in tree cover was regional as well as extremely local to Castelporziano. There have been many studies (particularly in Northern England) that suggest Roman impact lead to declining arboreal species in the pollen

records, which many interpret as a sign of deforestation and purposeful clearance. However, it is possible this change was due to disease, fire or succession and these possibilities provide. D6 ceased to be used as a fishpond in the 1st century AD, after this there was a change to more herbaceous species present, which suggests a change which may have been driven by the fire at the Vicus Augustanus. As to the “wilderness” as the area is often called, it is possible it was a sedate place that was only used as a winter retreat during the time of Pliny the younger.

Macchia vegetation is common throughout the Mediterranean today, including at Castelporziano. The palaeoenvironmental reconstruction showed limited remains of its presence from the wood fragments of *Arbutus unedo* at D6 during the Roman period and *Thymus vulgaris* at Pozzo Napoliello in the post-Roman period. Other studies claim to have found typical macchia vegetation but it is very hard to detect from pollen records. Other methods may help in pinpointing when macchia was first established within the Mediterranean and whether it was the results of anthropogenic or climatic forcings or a mixture of both.

The parallel study with the modern environment and the palaeoenvironmental reconstruction provides a baseline for future planning, particularly given the speed with which the Mediterranean environment responds to change from fire. However, at Castelporziano the grazing management may need to be addressed in the context of future planning.

The final section looked at succession and climax vs. resilience and adaptive cycles. As noted previously, fire is frequently a driver for change within the Mediterranean type environments, and often thought of as autosuccessional as the vegetation generally recovers without any great changes in the species composition. The herbaceous layer that dominates in the early post-fire stages declines, with the replacement being shrubs and trees. This is because the species present pre-fire and post-fire are effectively the same, and not invaders from unburned areas, which is not explained by succession theory alone. Resilience, as in “*the ability of an adaptive system to undergo changes and reorganisation while maintaining its fundamental functions, processes and structures*” (Holling 1973, p2). with adaptive cycles has no single equilibrium state, but potentially stable state systems are seen as moving through various stages of an adaptive cycle, which necessarily involves both changes and stability at different temporal and spatial scales. Within Mediterranean ecosystems species (plants and animals) having adapted to the anthropogenic impact (a different type of resilience), thus macchia and garigue are more steady states than degraded forms of climax vegetation. These ecosystems are dependent, in time and space, on

resource gradients (moisture and light), disturbance type and frequency, previous land-use/cover, and the vegetation of adjacent land areas (via seed dispersal). Indeed macchia and garigue could be better thought of as alternative steady states due to the co-evolution of anthropogenic activities and effects of the Mediterranean climate. Changes in the recent environment cannot be explained by succession either. The excavation records showed the presence of macchia with large-berried juniper and lentisk (*Pistacio-Juniperetum macrocarpae*) in 1983, which was not present in the baseline vegetation survey at the Vicus Augustanus in 2007, and had been replaced by High macchia with prevailing holm oak (*Quercus ilex*). The change driven by anthropogenic action or changes in the climate cannot be explained using succession. Therefore, within the Mediterranean type environments the use of resilience and adaptive cycles may be a better explanation for the origins of the macchia type vegetation and has adapted to anthropogenic impact. This is an area that requires further investigation from the palaeoenvironmental to the contemporary record, using both records to improve understanding of this specific type of vegetation.

Chapter 7

This chapter was divided into three sections: the first compared the results with the archaeological excavation, with the differences examined and explained; second, the sensitivity of the studied environmental system processes to climate and human drivers of change were examined; and finally the implications for modern system functioning and future sustainability are discussed.

The pre-Roman environment shows a fire-disturbed landscape, with both D6 and Pozzo Napoliello cores showing the presence of disturbance in the pre-Roman period, which may have been natural and/or anthropogenic. The pollen record from D6 shows a low AP:NAP (18:82), but this low ratio may represent an area not as heavily forested as the contemporary site. Furthermore, Pozzo Napoliello showed a dominance of *Poaceae* in the plant macrofossils. No molluscs were found at either D6 or Pozzo Napoliello for the pre-Roman period, and therefore no tertiary proxy was available for the local vegetation in addition to the plant macrofossils and pollen, to show how open or closed the local environment was. The record for the Roman period environment continues to show the presence of local fires, with the presence of eutrophic indicators in at D6 from Core 3 with absence of ostracods, bryozoan statoblasts, chara oospores, and macrophytes. The presence of fires along with grazing of animals may explain the absence of *Betula*. A major fire that was noted in the archaeological record at the Vicus Augustanus coinciding with an absence of nearly all proxies at D6, but they returned shortly after including the presence of *Arbutus unedo* wood, which is known to grow a few weeks after a fire.

The post-Roman Period shows the return of *Betula*, *Alnus* and *Salix* within the plant macrofossil and pollen records at D6. This sequence also shows the presence of molluscs, which indicates the local environment, was wet woodland. However, the extent of anthropogenic impact is not known as archaeological excavation has generally focused on the Roman remains.

The next section examined the sensitivity of the local environment to change from fire and eutrophication during the Roman period, however due to ecological resilience within Mediterranean environments, these changes were soon reversed. With the regard to the future sustainability of the local environment, overgrazing, particularly by deer, is notable in the current environment, particularly in areas where trees have been coppiced and without sufficient time periods to allow the environment to recover.

Final thoughts

By examining the environmental changes in association with the archaeological evidence for anthropogenic action, human-environmental interactions can be examined in relation to changes through time, evidence of specific activities or events, and interaction with the contemporary landscape. It encompasses the reciprocal influences on human behaviour of stability or change in the ecosystems of which they are part, particularly in the Mediterranean with its long history of human-environment interactions, thus enabling better understanding of local processes. By understanding these processes, theories such as the “ruined landscape” can be examined in more detail. The Mediterranean does have resilience to change but it is the comparative absence of anthropogenically-driven change that has enabled the Castelporziano Estate to retain much of its “character” for so long.

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Appendix 1: References to Figure: Location of late Pleistocene and Holocene Pollen records in Italy

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3 – Palughetto di Cansiglio

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5 – Fiorentina

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6 – Palazzetto

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7 – Ca' Tron

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9 – Lago della Costa

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10 – Lago di Fimon

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11 – Forcellona

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12 – Pian Venezia

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13 – Passo del Tonale

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14 – Col di Val Bighera

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15 – Pian di Gembro

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16 – Palù bei Edolo

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17 – Laghetti del Crestoso

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Appendix 2: Methodologies

Loss on Ignition (Based on University College London methodology)

1. Weigh an empty crucible to 3 decimal places.
2. Add between 1 and 2 grams of wet sediment being careful to keep sediment away from the rim of the crucible where it may become dislodged and fall out during handling.
3. Re-weigh crucible and place in the oven for at least 12 hours or overnight. Using tongs remove the crucibles from the oven and allow to cool in a desiccator (to prevent re-absorption of moisture) before re-weighing.
4. The dried (overnight at 105°C) sediment samples in crucibles are placed in the furnace and kept at 550°C for 2 hours.
5. It is easier to pack the furnace (it will take up to 80 samples) when it is cold in which case a further $\frac{3}{4}$ hour should be allowed for heating up.
6. After 2 hours the furnace door should be opened to allow some of the heat to disperse before removing the crucibles with long-handled tongs and placing them on an asbestos mat.
7. When they have cooled slightly they should be placed in a desiccator and allowed to cool fully before re-weighing. The percentage of the dry weight lost on ignition can then be calculated.
8. This was adapted to by changing the length of time in the furnace to four hours for the minerogenic component.

Charcoal

Pollen slides

This used the methodology set out for Durham University's pollen

Macroscoping sieving

This used the same methodology set out for plant macrofossils

Rhodes Method

1. Place 0.2 g of air dry sediment in a 250 ml conical flask. Add 20 ml of distilled water cover and leave for 24 hours to allow the sediment to rehydrate.
2. Add 20 ml of 6% hydrogen peroxide, cover and leave in an oven at 50°C for 48 hours.
3. Filter through a Whatman Number 1 filter paper (pore size approximately 11 μm). Retain the contents of the filter paper.
4. Wash the filtrate into a 9-cm diameter plastic petri dish using distilled water. In an oven at 50°C evaporate away.
5. Add 20 ml of 6% hydrogen peroxide, cover and leave in an oven at 50°C for 48 hours.
6. In an oven at 50°C, evaporate off the excess liquid until the samples are dry. The samples are now ready to count.

Palaeoworks

Laboratory outline

1. Measure out about 1-2 cc wet sediment into a test tube or sample vial.
2. Disperse in 5-10ml KOH or Sodium Pyrophosphate solution. Heat sample if rapid dispersal required or leave overnight.
3. Pour off and discard supernatant after sediment settles.
4. Re-suspend in very dilute Hydrogen Peroxide (4-6% only), or alternatively Sodium Hypochlorite (4-6%), leaving it overnight. This is enough to bleach the organics excluding the charcoal.
5. Mix well and wet sieve this through a 125 μm sieve and then put the coarse fractions back into a test tube in water. This can be stored until counting is done.
6. Pour the solution into a petri dish with graph paper underneath and place under a binocular microscope (approx. x10-15 magnification). Count the angular black (opaque) particles. If there are few, count all of them. If there are many, then count a proportion of randomly selected squares on the graph paper and calculate the total charcoal fragments from this. The final result can be expressed as particles/unit volume.

Digital Imaging

An alternative to hand counting is to photograph the charcoal with a digital camera. The image can then be analysed with free image analysis software available on the internet, such as image-J. Images need to be converted to grey scale to do this.

Pollen

Durham Methodology

Pollen Preparation for organic and minerogenic samples

WEAR LAB COAT AND GLOVES THROUGHOUT AND WORK IN FUME CUPBOARD WHENEVER USING ANY OF THE CHEMICALS

1. Turn on hot water bath to maximum heat (approx 1 hour to warm up).
2. Label two sets of conical bottom test-tubes.
3. Write down depths in pollen prep book.
4. *Put 1ml of sediment in each test tube using a syringe (Wash between each sample with distilled water)
5. Add Lycopodium tablet to each sample. Record the batch number in the book.
6. Put approx. 1ml of distilled water in each tube + 1ml of 10% HCl to dissolve tablet. Wait for effervescence to stop.
7. Put about 6ml of NaOH 10% in each tube. Put a glass rod in each tube.
8. Put test tubes in bath for 15 minutes.
9. Stir with glass rods occasionally.
10. Sieve samples (using a 10 μ m mesh below and 125 μ m sieve on top, tripod, funnels and distilled water).
11. Transfer pollen from mesh back to the test tubes using distilled water. Make sure the levels are even.
12. Put on the test tube lids and mix on the vortex mixer. Centrifuge tubes for 4 minutes at 3000rpm, then decant.
13. Add 10ml of distilled water, mix on vortex, then centrifuge for 4 minutes and decant.

GLACIAL ACETIC ACID IS HARMFUL AND CORROSIVE ON CONTACT WITH SKIN. WEAR PROTECTIVE GLASSES FOR STAGES 14-24 AND DO NOT REMOVE TUBES FROM FUME CUPBOARD.

14. Add 10ml glacial acetic acid, mix on vortex.
15. Centrifuge for 4 minutes and decant into large (1000ml) beaker of water in fume cupboard. Decant contents of beaker down fume cupboard sink.

ACETIC ANHYDRIDE IS ANHYDROUS. AVOID CONTACT WITH WATER. THE ACETYLATION MIXTURE CAN CAUSE SEVERE BURNS IF SPILT ON SKIN. WASH WITH WATER.

16. Make up acetylation mixture just before it is required. Using a measuring cylinder, mix acetic anhydride and concentrated sulphuric acid in proportions 9:1 by volume. Measure out 45ml acetic anhydride first, and then add (dropwise) 6ml concentrated sulphuric acid carefully, stirring to prevent heat build-up. Stir again just before adding mixture to each tube.
17. Add 8ml of mixture to each sample **. Stir with clean, dry glass rods.
18. Remove the glass rod. Put in boiling water bath for 1 minute. (Never leave glass rods in tubes as steam condenses on the rods and runs down into the mixture reacting violently). One minute is usually adequate as longer acetylation makes the pollen grains opaque.
19. Switch off the water bath.
20. Centrifuge for 4 minutes and decant the tubes into a large (1000ml) beaker of water in fume cupboard.
21. Decant contents of beaker down fume cupboard sink.
22. Add 10ml of glacial acetic acid, mix on vortex, centrifuge and decant.
23. Add 10ml of distilled water, mix on vortex, centrifuge and decant.
24. Repeat stage 23.

25. Add 3ml of Sodium Polytungstate (SPT) to each tube.
26. Use vortex for 1 minute on each tube to suspend sediment. (Loosen with rods if necessary).
27. Centrifuge tubes for 20 minutes.
28. While waiting. Fill new labelled tubes with 10ml of distilled water. Prepare vials with labels.
29. Pipette of floating pollen and transfer to new tubes (N. B. Using a different pipette for each sample). Dispose of pipettes in glass waste box.
30. Use vortex for 1 minute on each tube to suspend sediment.
31. Centrifuge tubes for 10 minutes then decant.
32. Add 10ml of distilled water. Use vortex.
33. Centrifuge tubes for 4 minutes then decant.
34. Add 4 drops of aqueous safranin stain to a large (e.g. 600ml) beaker of distilled water.
35. Add 10 ml of diluted stain to each of these tubes. Use vortex.
36. Centrifuge for 4 minutes and then decant.
37. Add 10ml of distilled water to each tube. Use vortex.
38. Centrifuge for 4 minutes and then decant.
39. Add 5ml of Industrial methylated spirits (IMS) to each tube. Use vortex.
40. Centrifuge for 4 minutes and then decant.
41. Add 2ml of Tetra-butyl alcohol (TBA) to each tube. Use vortex.
42. Centrifuge for 4 minutes and then decant.
43. Transfer remaining pollen to labelled vials with little (TBA) using new pipettes for each.
44. Add small amount of Silicone fluid to vials using a glass rod.
45. Leave to evaporate in fume cupboard.

Notes

*It is best to put the 1ml of distilled water in tube first, followed by sediment, followed by the Lycopodium tablet.

**It does not matter if you end up with slightly uneven levels in each tube at this stage, as you can top the tubes with Glacial Acetic Acid when you remove it from the water bath.

Spillage absorption granules should be used if there are acid spills.

Hull University (Wetland Unit)

- Samples should be stored wet at $<4^{\circ}\text{C}$.
- If sampling from an unsliced core, all the samples should be taken at one time to prevent having to re-open the bags and drying out the core material.
- Beware of contamination - clean all spatulas etc. thoroughly between samples.
- If the core is long but covers a short time period, a large sample volume (1cm^3) may be necessary. However if the core is short, covering a long time period use 0.5cm^3 .
- If using absolute pollen techniques (quantitative), add weighed tablets of exotic taxon to a known volume of sediment in a labelled 50 ml boiling tube.

Removal of Calcium

1. Slowly add about 10ml of 10% HCl to the sample. When effervescence stops, place the tube in a boiling water bath and stir well until effervescence again stops. If the tube threatens to froth over, reduce the foam with a squirt of acetone. Centrifuge and decant.
2. All centrifugation should be at 3000 rpm. for 4 minutes and about 2ml of methanol should be added to reduce the specific gravity and reduce the losses in decanting.
3. If sediment is highly calcareous, it will be necessary to centrifuge, decant and add a further 10ml of HCl. It is essential to remove all calcium carbonate at this stage, as the later addition of HF will result in the formation of insoluble calcium fluoride.
4. After supernatant has been decanted, thoroughly mix sediment at each stage.
5. Wash with distilled water, centrifuge and decant.
6. If the samples are extremely calcareous, this process should be repeated 2 or 3 times.

Removal of Humic Acid

7. Add 10ml of 10% KOH. Place in a boiling water bath for no longer than 5 minutes. Stir occasionally.
8. Record the darkness of the supernatant as a measure of the degree of humification of the sample.

Removal of organics

9. Strain and wash the sample through a fine mesh screen (170-180 μm) into a 50ml polypropylene tube. Wash the residue on the screen thoroughly with a jet of distilled water
10. Centrifuge and decant.
11. Place the coarse residue trapped on the screen into a labelled petri dish and examine under a low power microscope for seeds, fruits, moss remains, large pieces of charcoal, etc.
12. Wash and centrifuge at least 5 times with distilled water until no trace of brown colour remains in the supernatant, remembering to mix thoroughly each time after decanting. This removes many small organic and inorganic particles.

Removal of silicates

13. Add 10% HCl, stir, centrifuge and decant.
14. If sediment contains mineral matter, treat with 40% HF. In a suitable fume cupboard add about 10ml HF and place tube in a boiling water bath for 20 minutes.
15. Stir occasionally with a polythene rod.
16. Remove tube from the water bath, add methanol to reduce the specific gravity and centrifuge.
17. Decant carefully into a sodium carbonate neutralising solution.
18. Half fill tube with 10% HCl and place in water bath for 20 mins. Stirring occasionally, centrifuge and decant.

19. If supernatant is yellow (or green) repeat this procedure - it is better to add fresh HF rather than leaving the tubes in the water bath for longer!
20. Add about 10ml water, stir, centrifuge, and decant.
21. Removal of water
22. It is essential to remove all water before the acetolysis step as the acetolysis mixture reacts very violently with water.
23. Add 10ml Glacial Acetic Acid, stir, centrifuge and decant.
24. Repeat this step to ensure all water is gone.
25. Removal of cellulose (acetolysis)
26. Add 9ml acetic anhydride and 1ml concentrated sulphuric acid (Erdtman's acetolysis solution) and place in water bath for a maximum of 3 minutes, stirring after 1.5 min.
27. Remove tube from bath and fill with Acetic acid, stir, centrifuge, and decant.
28. Wash with a further 10ml Acetic Acid. (Stir, Centrifuge, Decant)
29. This removes the soluble cellulose products of the acetolysis.

Staining and mounting

30. Wash the sample into 15ml glass centrifuge tubes using water.
31. Centrifuge and decant.
32. Add 9ml water and 1ml KOH to obtain correct pH for staining (about pH7). Stir, centrifuge and decant.
33. Add 1 or 2 drops of 1% aqueous safranin and 10 ml water. Stir, centrifuge and decant. Do Not Overstain
34. Add about 10ml Tertiary butyl alcohol. Stir, centrifuge and decant Stir, centrifuge and decant
35. Wash sediment into a labelled vial with the minimum amount of TBA, centrifuge and decant
36. Add silicon oil (200cs viscosity equal in amount to the remaining residue, stir well and leave unstoppered in a fume cupboard (lightly covered) to allow residual TBA to evaporate.
37. Slides are prepared by pipetting a drop of the suspension onto a slide and covering with a square coverslip. The coverslip is then held in place using clear nail polish.

Pollen Pollsters

1. Store samples until required in a refrigerator at 4°C.
2. Use standard pollen pre-treatment, using potassium hydroxide, sieving through 250 and 10mm polyester meshes, and acetolysis.
3. Wash twice with distilled water, and dehydrated in alcohol.
4. Stain with safranin and mount in silicone fluid.

Plant Macrofossils (Based on Birks (2007))

1. Take a sample of sediment 20 cm³, and measure by weight by volume in a 100 cm³ measuring cylinder with 50 cm³ of distilled water.
2. If the sediment is very aggregated, add a few drops of dilute NaOH to disaggregate the sediment and leave overnight.
3. Sieve the sample through a 125µm meshed sieve, and with a coarser sieve if necessary.
4. The residue is then transferred to a storage bottle and refrigerated.
5. When analysing - The residue is suspended in 2-3 mm of water, in a Petri dish, and examine systematically under 10-12 x magnification with a light microscope. Any remains of interest are placed in a second Petri dish to be identified.
6. The fossils in the second Petri dish are then identified, counted and recorded for each taxon.
7. The identified material can then stored in vials with glycerine + phenol, to prevent fungal growth, so they samples could be re-examined at any stage or used for radiocarbon dating.
8. Tabulate results in Excel and analyse with C2.

This methodology was also used for Bryozoan statoblasts, Stonewort oospores, Branchipod crustaceans, and Beetle elytra.

Molluscs (Based on Miller and Tevesz (2001))

1. Dry the sample to remove most of the interstitial water.
2. Immerse in a container of cold water for several hours or overnight to disaggregate the sediment.
3. Wash the sediment-water slurry through stacked sieves (2.00mm to 0.071mm) using a gentle spray of water.
4. Wash the contents from the sieve into container and store in fridge until examined under light microscope.
5. Use steps 5 and 6 from Plant macrofossil methodology
6. Tabulate results in Excel and analyse with C2.

Ostracods (Based on Holmes (2001))

1. Use steps 1-2 from molluscs methodology
2. Wash the sediment-water slurry through 250µm and >5mm sieves to leave the size fractions that contains most adult and juveniles.
3. Take the sieved fraction and dry in an oven at 105°C.
4. Store the sample until needed in the fridge.
5. Use steps 5-6 from molluscs methodology
6. N.B. Pick out all ostracods within the sample, and identify on based on size, shape, ornamentation, and muscle-scale pattern.

Testate Amoebae (Based on Charman et al. (2000))

1. Peat sub-samples of 1cm (depth) x 2 x 1 cm cut from core.
2. Place a subsample of 2cc in a 250ml beaker and leave to soak in distilled water for 3-4 hours or overnight. Boil samples (10 minutes) if necessary to aid disaggregation. This step is merely to ensure disaggregation of the sample without the need for chemical agents.
3. Add two tablets of the innoculum *Lycopodium clavatum* L. as an exotic marker to give quantitative concentration data. These should be dissolved in dilute HCl then diluted with distilled water before adding to the sample.
4. Wash each sample through a coarse sieve (300mm mesh) to remove the coarse detritus, and back-sieve through 15mm mesh to remove the fine fraction detritus with distilled water. Retain material between 15mm and 300mm.
5. Wash the remains of each sample into centrifuge tubes and centrifuge at 3000 rpm for five minutes.
6. Samples can be stored with a small amount of distilled water in stoppered vials..
7. For mounting, samples can be counted in water only, or an aqueous mountant such as glycerol or Canada balsam can be used.

Diatoms (Based on UCL's protocol (adapted by Dave Ryves))

Digestion procedure

1. Place about 0.1g (dry weight, 1 g wet weight) sediment into a beaker. If diatom concentration is to be assessed, the sediment should be weighed to three decimal places.
2. Add about 20 mls H₂O₂.
3. Heat on a hotplate set at 90°C in a fume cupboard until all organic material has been oxidised (1-3 hours). Coarse plant material in macrophyte samples may be removed after half an hour.
4. Remove the beakers from the heat. Add a few drops of HCl (50%) to remove remaining H₂O₂. plus any carbonates and wash down sides of beaker with distilled water.
5. Allow to cool in the fume cupboard (chlorine is generated from the HCl) and pour into centrifuge tubes, leaving any coarse sand in the beaker. Top up with distilled water.
6. Centrifuge at 1200 rpm for 4 minutes.
7. Decant off supernatant and resuspend pellet by tapping the base of the tube. Top up with distilled water and centrifuge as before.
8. Repeat washing process at least three times. Clay may be removed during the last wash by adding a few drops of very weak ammonia solution (1%) to the sample. The clay is then decanted off with the supernatant. The sample is now ready to make into slides.

Slide making procedure

1. Dilute the cleaned diatom suspension to a suitable concentration. It takes practice to get the concentration right. The suspension should look neither totally clear nor milky. Fine particles in suspension should be just visible when the suspension is held up to the light.
2. Place metal settling out trays with cover slips in a position where they will not be disturbed, away from dust sources and air currents.
3. Using the 1 ml pipette, place up to 0.5ml of well mixed diatom suspension on each cover slip; cover the tray to keep off dust and leave to dry. This may take up to two days.
4. Heat a hotplate in a fume cupboard to 130oC.
5. Place 1 drop of Naphrax on a glass slide and invert the cover slip with the dried diatoms over the drop.
6. Heat the slide on the hotplate for 15 minutes to drive off the toluene in the Naphrax.
7. Allow the slide to cool and then check that the cover slip does not move when pushed with a fingernail. If it does move then the slide will need to be heated a little longer.

This methodology was used for evaluation of diatoms, testate amoebae, grass cuticles and phytoliths.





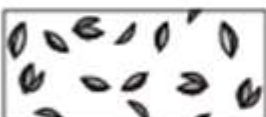
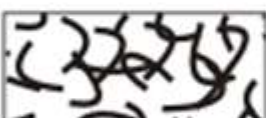
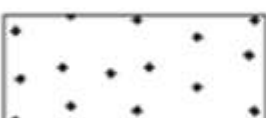



Geochemistry

This was carried out with the help of Wolverhampton University's School of Applied Science. Below is the protocol for sample preparation, as the actual analysis was carried out by David Thompsett at the university.

Preparation of samples for XRF

1. Samples must be completely dry prior to XRF analysis, if they are not place in an oven for 24 hours and dry.
2. Weigh-out 8.5 ± 0.5 g of dried sample to a XRF sample cup.
3. The sample with XRF sample beads is then shaken on an auto shaker for 10 minutes. As the sample is shaking, the next sample can be weighed, if there are enough cups.
4. The first sample is transferred to a clear tube, and add 1.5g of Hoechstwax to give a total weight of 10g, if less than 8.5g of sample are available, half this ratio.
5. Shake this tube for one to two minutes.
6. Empty the tube into a die with an aluminium cup at the bottom.
7. The loaded sample die is placed in a hydraulic press, and the pressure raised to a level that will cause the sample or sample/binder mixture to cohere into a stable sample disc.
8. The sample is released from its casing, and is now in the form of a disc. This disc is now ready for XRF analysis, so label and place in a small bag for analysis.
9. Clean all the equipment used with ethanol, and repeat for all samples.

Appendix 3: Key for Core Stratigraphy and descriptions

	Charcoal
	Laminations
	Molluscs
	Peat
	Plant Remains
	Roots
	Sand
	Wood
	Graduational Contact
	Sharp Contact