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Holocene environmental instability in the wetland north of the Tiber delta (Rome, Italy): sea-lake-man interactions

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Abstract Combined analyses of pollen, seeds, woods, micro-charcoal and non-pollen palynomorphs from Stagno di Maccarese, an artificially dried out coastal basin north of the Tiber delta now occupied by the Fiumicino Airport (Rome, Italy), document marked vegetation and environmental changes during the last 8300 years. Between 8300 and 5400 cal. a BP dense mixed deciduous and evergreen forests surrounded a eutrophic freshwater basin. An abrupt change around 5400 cal. a BP marks the transition to a marshy environment, due to a lowering of the water table. An increase of cereals and micro-charcoals matches the presence of a nearby Eneolithic settlement. Between 5100 and 2900 cal. a BP there is a remarkable expansion of riparian trees, indicating an increase of the water level. Between 2900 and 2000 cal. a BP, a new development of marshlands points to a progressive lowering of the lake. After 2000 cal. a BP, during the Roman exploitation of the area, an expansion of arboreal vegetation is recorded, characterized by evergreen and deciduous oak-dominated forests, while an extensive chenopods marshland matches the presence of saltworks. On the whole, the Stagno di Maccarese area appears very unstable, due to changes in lake level, introgression of marine water, eutrophic phases, flood events, desiccations and openings of the forest vegetation.

Keywords Pollen analysis · Plant macrofossils · Tiber delta · Hydrological changes · Saltworks

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Introduction

Estuarine areas are characterized by marked environmental instability related to both intense depositional actions of rivers and reworking of sediments by the sea. These factors determine strong environmental changes and in turn vegetational modifications. In addition, the effects of geomorphic agents on the landscape may be exacerbated by climate processes and human impact.

Pollen analyses from estuarine sites (Biserni and van Geel 2005; Naughton et al. 2007; Reille 1992; Sánchez Goñi 1996) generally feature a vegetation history characterized by rapid environmental changes, often marked by radical modifications of the local vegetation structure and floristic composition in relation to physiographic changes. However, the relationships between coastal environmental processes reconstructed from palaeobotanical data and the local human occupations documented by archaeological evidence have been seldom explored.

In this paper we present the results of pollen and plant macrofossil analyses from Stagno di Maccarese, a large coastal basin located 20 km south-west of the centre of Rome, formed by the combined action of

the River Tiber and the Tyrrhenian Sea. The area has been intensively studied from both the archaeological (Manfredini 2002; Morelli et al. 2004 and references therein) and geological points of view (Amorosi and Milli 2001; Bellotti et al. 2007; Giraudi 2004).

A large part of the coastal plain adjacent Stagno di Maccarese is presently occupied by Fiumicino Airport, inaugurated in 1956 and repeatedly enlarged. In particular, in the last 10 years systematic works have been carried out to increase the international cargo activities, favoured by the strategic location of the Airport. These works have allowed the discovery of extensive anthropic layers of Middle-Late Bronze age, and structures and reclamation works of Roman and Medieval age, documenting a continuous and massive impact of human activities in the region since antiquity. At present, the natural landscape of the area is completely lost.

The palaeobotanical data allow a recovery of environmental information that cannot be gained starting from the modern landscape, through reconstruction of timing, modes and rates of past ecological dynamics, involving both terrestrial and aquatic domains, in relation to natural and human-induced landscape transformations. In particular we address two specific questions: (1) the importance of local geomorphic factors versus regional climate changes in determining the vegetational fluctuations of the Stagno di Maccarese area; (2) the relationships between the local human populations and the coastal development. Generally, these questions may help reconstruct the environmental variability of Mediterranean coastal environments, which deserve special attention, being particularly endangered (Nicholls et al. 1999), and requiring conservation actions based on long-term environmental monitoring.

Study area

The Tiber delta is located 25 km SW of the centre of Rome along the mid-Tyrrhenian coast of the Italian peninsula (Fig. 1a). The area has been subject to a complex and long-lasting interaction of geomorphic factors: (1) post-orogenic extensional tectonics in the Tuscan-Latium margin since the late Miocene; (2) magmatic activity, reaching a maximum during the Middle-Late Pleistocene with the development of the Roman Magmatic Province; (3) combined actions of solid load by the Tiber and reworking processes carried out by glacio-eustatic sea-level changes during the Quaternary (Amorosi and Milli 2001; Bellotti et al. 2007). The shelf, coastal and fluvial depositional sequences characterizing the hills surrounding the Tiber delta plain are assumed to have formed in

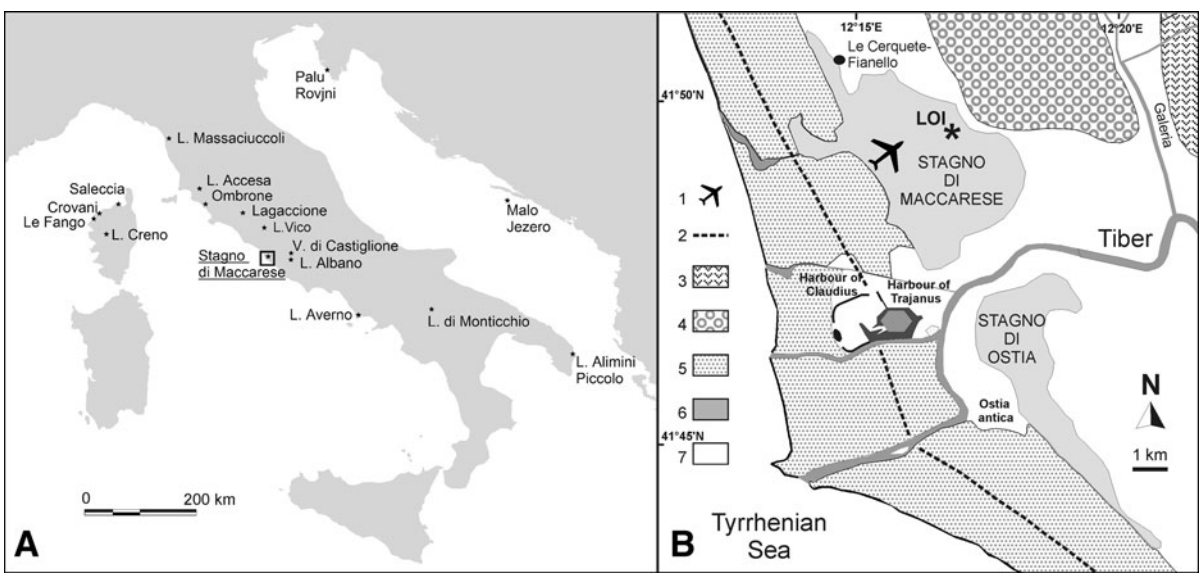

Fig. 1 **a** Location of the sites mentioned in the text. **b** Location of the Lingua d'Oca (LOI) site; *1* Fiumicino airport, *2* coast line of the first century AD (from Tuccimei et al. 2007), *3* Plio-Pleistocene sands, *4* middle and upper Pleistocene sands and gravels, *5* holocene beach ridges, *6* ancient ponds near the Tiber delta, *7* holocene alluvial deposits (modified from Giraudi 2004; Tuccimei et al. 2007)

response to sea-level variation cycles of approx. 100 ka (Amorosi and Milli 2001). The Late Pleistocene/Holocene Tiber delta sedimentary succession represents the last of these depositional sequences (Amorosi and Milli 2001; Bellotti et al. 2007).

The Tiber delta topography is split into an outer deltaic plain along the coast, mostly formed by several beach ridges of different depositional phases, and a very flat inner plain characterized by wide depressions that were occupied by two ponds, reclaimed in the nineteenth century: Stagno di Ostia, located at the southern side of the Tiber mouth, and Stagno di Maccarese at the northern side (Bellotti et al. 2007; Fig. 1b). Geomorphological investigations carried out in the northern sector revealed that beach ridges were broken up a number of times during the last thousands of years, determining connections between the sea and the Maccarese pond (Giraudi 2004). These processes probably determined major changes in the Stagno di Maccarese groundwater, influencing both salinity and sedimentation, as recorded in various stratigraphic sequences (Bellotti et al. 2007; Giraudi 2004).

In the wetland corresponding to Stagno di Maccarese, several archaeological sites have been discovered, dating from the Paleolithic to the Middle-Late Bronze Age (Manfredini 2002). Systematic surveys and extensive excavations have been carried out to find and investigate Eneolithic settlements. In particular, the lake-dwelling of Le Cerquete-Fianello, located at the margin of the ancient lake, has been the subject of multidisciplinary investigations because of the excellent preservation state of the anthropic layers (Manfredini 2002; Fig. 1b). This 1 ha-wide settlement, with several huts and different functional areas, testifies intensive pastoral and agricultural activities between approx. 5370–4920 cal. a BP. At Le Cerquete Fianello, an evaporitic calcareous layer, whose base is radiocarbon dated 3660 $\pm$ 40 ^{14}C a BP (3870–4140 cal. a BP, 2σ), indicates a dramatic lowering of the water table during the Middle Bronze Age (Giraudi 2002). Close to Le Cerquete-Fianello, Middle-Late Bronze Age settlements have been discovered (Arnoldus-Huyzendveld et al. 1998; Carboni 2002).

The Etruscans set up a large artificial saltwork in the Maccarese area (sixth century BC) that became an important economic resource and caused several fights between Rome and the Etruscan city of Veius, until the final Roman occupation of the area (Morelli et al. 2004). In Republican and Imperial times the Romans developed the so-called *Campus Salinarum Romanarum* saltworks, which were active until the end of the fifteenth century as reported by numerous documentary sources (Lanciani 1888). The saltwork area was connected to the city of Rome by the ancient *Via Campana*, active from the fourth century BC to the sixteenth century AD (Tuccimei et al. 2007).

The Emperor Claudius built up the main harbour of the city of Rome (*Portus*) between the Tiber delta and the wet area of Stagno di Maccarese in 54–60 AD, in an area that is currently located in the hinterland (Fig. 1b). The harbour was inaugurated in 64 AD by the Emperor Nero. Under the Emperor Trajanus (98–117 AD) another harbour farther inland was built (Fig. 1b). It was a hexagonal basin communicating by canals with the harbour of Claudius, and surrounded by a complex system of annex storage buildings and infrastructures, partly added by Marcus Aurelius (end second century; Keay et al. 2006).

In the second to third century AD the commercial activities of the harbour of Ostia and *Portus* were balanced, but starting in the fourth century Ostia declined and *Portus* gained an administrative and commercial autonomy, as demonstrated by the walls of the fifth century built as a protection against the barbarian invasions. The presence of a number of churches testifies that *Portus* was functional until at least the twelfth century (Verduchi 2004).

Starting in the thirteenth century, a rapid progression of the coastline, due also to a number of important floods (e.g. 1557 AD), is indicated by the successive construction of sighting towers, which are located at different distances from the modern coast line.

A rich cartography is available since the sixteenth century, highlighting a considerable variability of the dimensions of the lacustrine formations (Manfredini 2002). The area of Stagno di Maccarese was reclaimed and traversed by drainage canals only in the nineteenth century (Amenduni 1884).

Residual isolated stands of the coastal vegetation belt north and south of the Tiber delta testify the original natural vegetation, which is completely lost at present. They are characterized by sclerophyllous elements on the coastal dunes, riparian and aquatic vegetation in the retrodunal wetlands, and planitial forest with patchy stands formed by mixed deciduous and evergreen taxa more inland (Lucchese 1996; Manes et al. 1997). Mobile dunes are characterized by psammophilous communities with *Cakile maritima*

Scop., *Ammophila littoralis* (Beauv.) Rothm., *Agropyron junceus* (L.) Beauv. Stable dunes are covered by Mediterranean scrubland vegetation or *maquis*, passing from low seaward maquis to high landward maquis. The most important species are: *Quercus ilex* L., *Asparagus acutifolius* L., *Arbutus unedo* L., *Smilax aspera* L., *Rhamnus alaternus* L., *Phillyrea angustifolia* L. and *Erica arborea* L. In the most arid zones, the maquis contains *Myrtus communis* L., *Olea europea* L. var. *sylvestris* Brot., *Rosmarinus officinalis* L., *Pistacia lentiscus* L. and *Juniperus phoenicea* L. At the margin of the maquis vegetation, wood develops with *Quercus ilex* L., often replaced by *Quercus suber* L. Around the pools, meso-hygrophilous riparian woods are found with *Populus* and *Salix* spp., *Ulmus minor* Miller, *Alnus glutinosa* (L.) Gaertner, *Fraxinus oxycarpa* Bieb. and *Quercus robur* L. Deciduous forests are dominated by *Quercus frainetto* Ten. and *Quercus cerris* L. with many other deciduous taxa, especially *Carpinus orientalis* Miller. The shrub stratum of the planitial wood contains patches of *Erica arborea* L.

Materials and methods

Palynological and plant macrofossil analyses were carried out on lacustrine sediments dug in 2001 near the Lingua d'Oca canal (lat. 41°49′50″N, long. 12°16′30″E, 2 m a.s.l.), during an archaeological survey in the area of the Fiumicino International Airport, formerly occupied by the Stagno di Maccarese.

The uppermost 170 cm of the Lingua d'Oca-Interporto sedimentary sequence (LOI), consisting of reclaimed sediments and agricultural soil, were not sampled for palaeobotanical analyses. On the whole, 64 samples were taken at 5-cm intervals along a 320 cm thick sedimentary sequence.

Pollen extraction from the sediments followed the following procedure: each sample ($\sim$1 g) was chemically treated with HCl (37%), HF (40%) and NaOH (10%). A known amount of exotic *Lycopodium* spores was added to estimate pollen concentrations.

An average of 440 terrestrial pollen grains per sample was counted. The total sum includes all terrestrial pollen types, excluding aquatics, fern spores and other non-pollen palynomorphs (algal and fungal remains). Three pollen types of *Quercus* have been distinguished: *Quercus* evergreen type, *Quercus* deciduous type, and *Quercus suber* type, including both *Q. suber* and *Q. cerris*. The pollen type *Ostrya/Carpinus orientalis* represents the pollen sum of the two species *Ostrya carpinifolia* and *Carpinus orientalis*. Pollen of *Typha latifolia* has been distinguished from other Typhaceae, which have been included in the *Sparganium/Typha* group.

Micro-charcoal analysis was carried out in order to reconstruct the fire history of the area and the vegetation responses to fires. The methodological approach followed the procedures described by Clark (1982). Micro-charcoals were counted in 150 microscope fields per sample, excluding the fragments <5 μm. *Lycopodium* spores were used to estimate micro-charcoal concentrations.

Plants macroremains analysis (fruits, seeds and wood fragments) was carried out on 23 samples taken along the whole sedimentary sequence. They were water-separated and analyzed by means of a stereomicroscope and a metallurgical microscope.

The computer program Psimpoll 4.25 (Bennett 2005) was used to plot the pollen and macrofossil diagrams and subdivide them into local assemblage zones.

Seven AMS radiocarbon datings (Table 1) were carried out on the organic content of sediment samples at the CEDAD Laboratory, University of Lecce. The radiocarbon dates were calibrated using the program Bcal (http://bcal.sheffield.ac.uk; Buck et al. 1999), available on line at http://bcal.sheffield.ac.uk, with IntCal04 calibration datasets (Reimer et al. 2004). The age-depth model was calculated by the computer program Psimpoll (Bennett 2005).

Results

Sediment lithology and chronology

The studied sedimentary sequence (LOI), underneath 170 cm of reworked sediments, shows the following stratigraphy:

0–80 cm	Greyish silt, rich in *Cerastoderma* sp. and other brackish molluscs
80–134 cm	Grey silt with dark levels of organic mud
134–185 cm	Black organic silt
185–275 cm	Peat with abundant wood remains
275–292 cm	Black organic silt
292–320 cm	Grey silt with molluscs remains

Table 1 AMS dates from the Lingua d'Oca sediments

Lab. code	Depth (cm)	^{14}C a BP	Calendric age (cal. a BP)	Material	Rejected
LTL2073A	30–32	2318 ± 45	2311 ± 153	Molluscs/sediment	x
LTL1494A	70–72	1955 ± 50	1898 ± 144	Bulk sediment	
LTL1495A	138–140	2967 ± 60	3118 ± 165	Bulk sediment	
LTL2074A	198–200	706 ± 65	643 ± 97	Wood/sediment	x
LTL1496A	256–260	4529 ± 55	5089 ± 174	Bulk sediment	
LTL2075A	278–280	4618 ± 60	5427 ± 189	Bulk sediment	
LTL2076A	313–315	7191 ± 60	7984 ± 139	Bulk sediment	

The age-depth model is based on five internally consistent dates (Fig. 2). The date at 200–198 cm, erroneously performed on a root, is very recent and was therefore excluded from the age-depth model. The date at 32–30 cm (2311 ± 153 cal. a BP) has been rejected because it is not consistent with the other dates, possibly because of the presence of marine molluscs. Besides, the vegetation characters of this level point to an age younger than the Roman times. On the whole, the calculated timescale indicates that the sedimentary sequence spans approximately the last 8300 years (Fig. 2).

Pollen data

The pollen sequence from Stagno di Maccarese (LOI) reveals a high floristic richness. On the whole, 129 taxa have been identified, including pollen, spores and other palynomorphs. The highest number of terrestrial pollen taxa per sample was 47 and the lowest 18. Pollen preservation was generally good and the abundance of indeterminable grains never exceeded 5%. The total pollen concentration is very heterogeneous along the sequence, varying between 6,000 and 1,800,000 grains g^{-1} sediment.

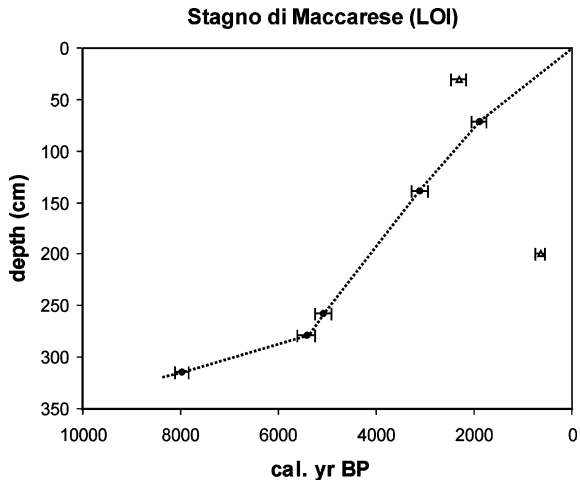

Fig. 2 Age-depth model for the Lingua d'Oca sediments. *White triangles* indicate the rejected dates. *Black dots* represent the dates used for the linear interpolation age-depth model

The results of pollen analysis are presented as a percentage diagram (Fig. 3) and a summary diagram (Fig. 4), including the most important ecological groups, the micro-charcoal record and the pollen concentration. The ecological groups are composed as follows: riparian trees include *Alnus*, *Salix*, *Populus* and *Tamarix*; evergreen trees and shrubs include all the evergreen broadleaved taxa excluding *Olea*, which is represented separately because it may also be an indicator of cultivation; freshwater aquatics include Typhaceae, Nymphaeaceae, *Myriophyllum* and *Alisma*; anthropogenic markers include taxa probably related to cultivation (cereals, *Juglans* and Cannabaceae).

Five zones, numbered from the base upwards and prefixed by the site abbreviation LOI (Lingua d'Oca-Interporto), have been identified using the binary splitting by sums-of-squares method.

Zone LOI-1 (320–277 cm; 8300–5400 cal. a BP)

This zone is characterized by arboreal pollen (AP) values always exceeding 70%. The most important arboreal component is represented by evergreen taxa (up to 45%), in particular *Quercus* evergreen type (36%) and *Erica* (9%). The deciduous vegetation is mostly represented by pollen of *Quercus* deciduous type (16%), *Corylus* (9%), *Ostrya/Carpinus orientalis* (6%) and appreciable values of *Fagus* (4%). *Myriophyllum*, *Sparganium/Typha* and Cyperaceae/Juncaceae show relatively high abundances. Total pollen concentrations vary between 10,000 and 100,000

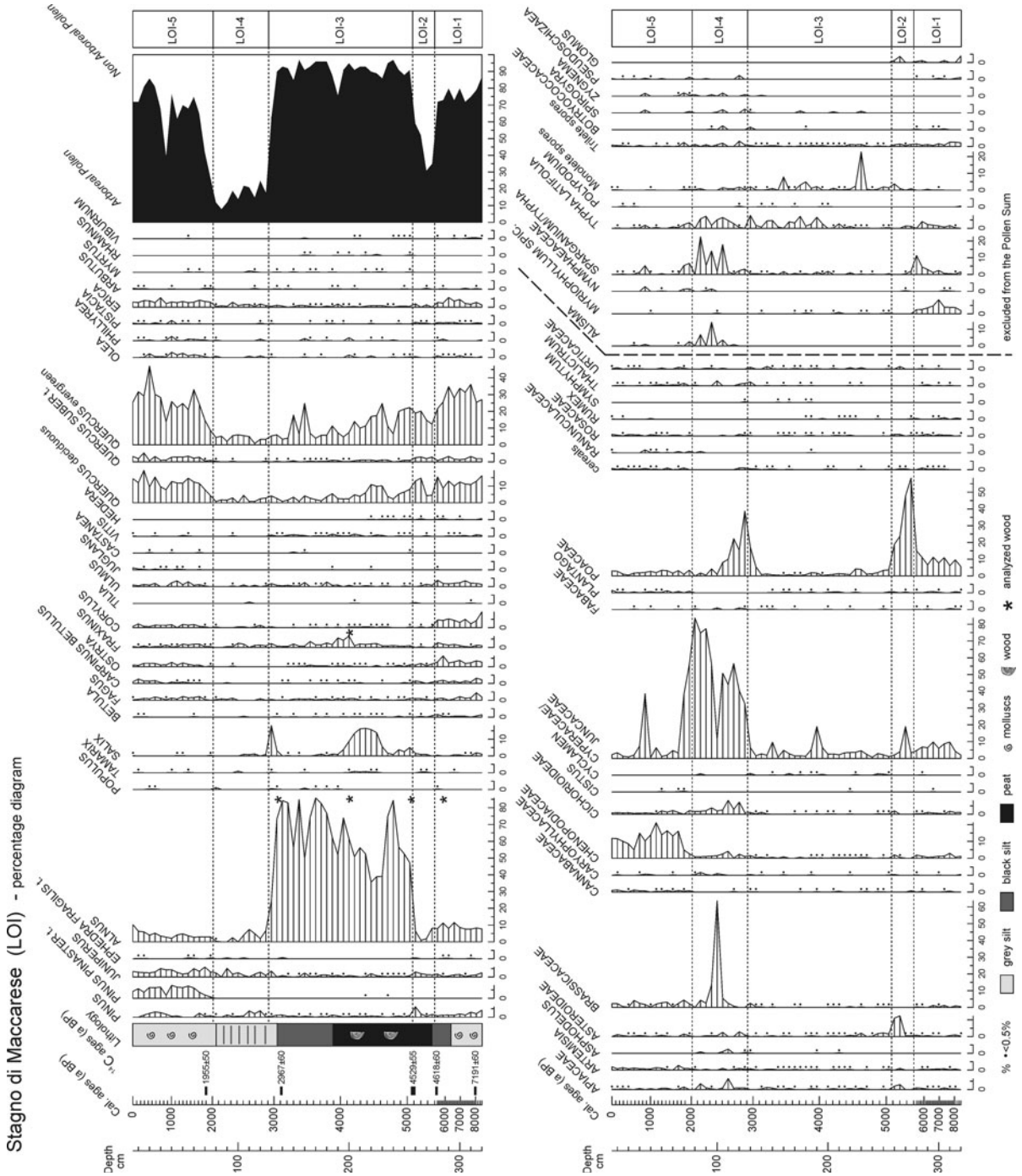

Fig. 3 Pollen percentage diagram of selected taxa from Stagno di Maccarese (LOI). Main lithology, zonation, ^{14}C dates, and relative abundances of arboreal pollen (AP) and non arboreal pollen (NAP) are also presented

grains g^{-1} sediment. Besides, this interval records very high percentages of cyanobacteria structures belonging to the family Rivulariaceae (Fig. 4). The presence of *Glomus* type spores and *Pseudoschizaea* is noteworthy. Micro-charcoal concentrations never exceed 1 cm^2 g^{-1} sediment.

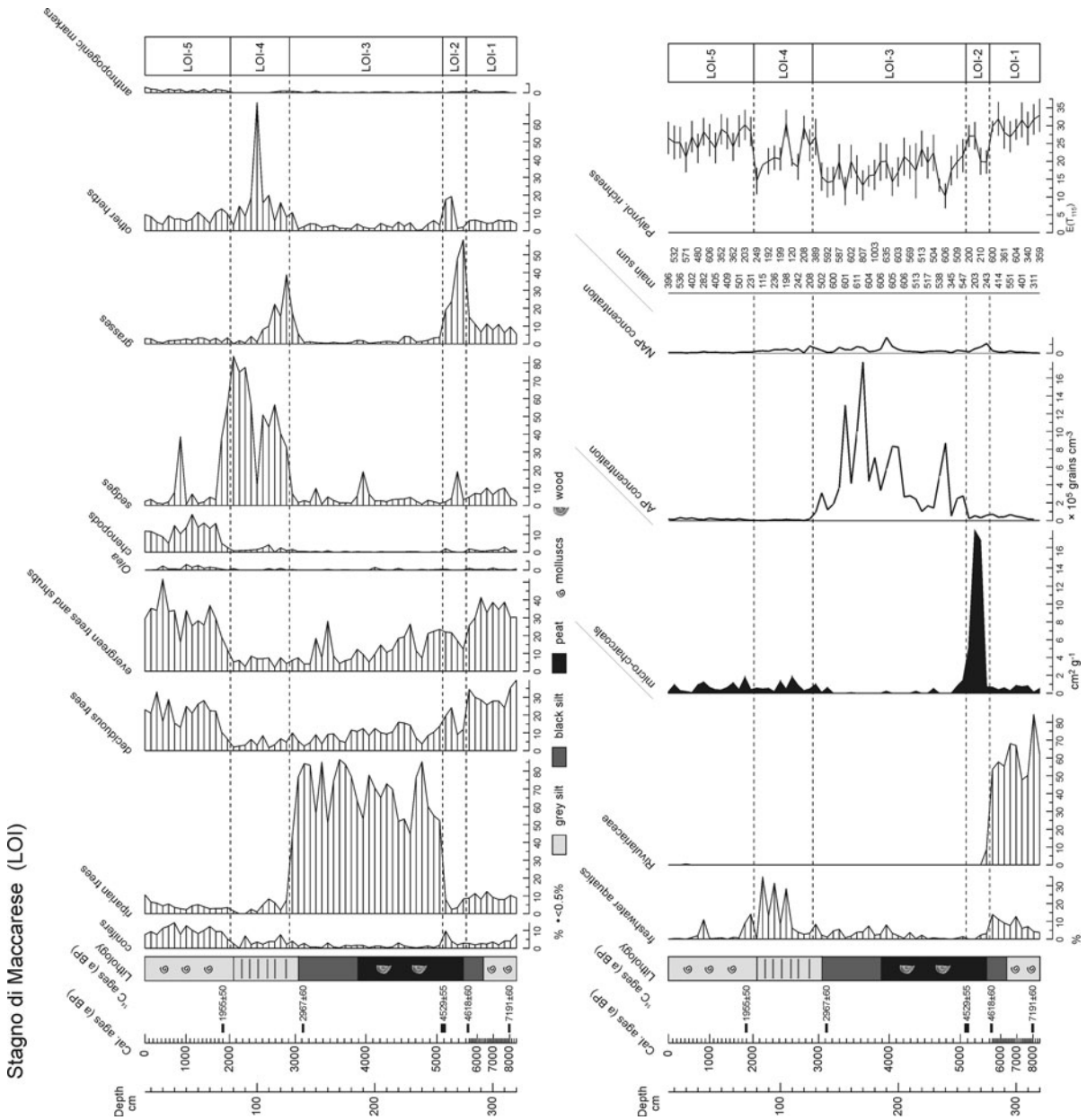

Fig. 4 Summary pollen diagram from Stagno di Maccarese (LOI)

Zone LOI-2 (277–257 cm; 5400–5100 cal. a BP)

AP percentages drop abruptly from 73 to 30%. This process parallels a temporary expansion of herbs, characterized by a succession of peaks of different herbaceous taxa, namely Poaceae (up to 60%) in the lower part of the zone, Cyperaceae (20%) in the middle part, and other herbs (18%), mostly represented by Asteroideae (8%) and Chenopodiaceae (3%), in the upper part (Fig. 4). Total pollen concentrations range from 25,000 to 165,000 grains g^{-1}. Cereal pollen is recorded together with a notable micro-charcoal peak (16 cm^2 g^{-1}).

Zone LOI-3 (257–128 cm; 5100–2900 cal. a BP)

Total pollen concentrations show very heterogeneous values ranging from 50,000 to 1,800,000 grains g^{-1}.

AP percentages show a rapid and considerable increase, mainly related to an expansion of riparian trees, mostly represented by *Alnus* (85%) and *Salix* (18%). Among other trees, *Quercus* evergreen type (25%) and *Quercus* deciduous type (10%) are important elements of the vegetation together with *Fraxinus* (7%), reaching its highest values in the sequence. Only few herbaceous taxa reach the 1% value. One single peak of Cyperaceae reaches 20%. Zone LOI-3 is characterized by scarcity of micro-charcoals.

Zone LOI-4 (128–78 cm; 2900–2000 cal. a BP)

A very important drop of AP percentage values characterizes this interval. Arboreal pollen reaches the lowest values in the sequence (8%). In the lower part of the zone, herbaceous taxa show a pattern similar to zone LOI-2, with a succession of peaks of different taxa: Poaceae (48%), Cyperaceae (55%), and other herbs mostly represented by very high percentages of Brassicaceae (70%). This pattern ends with a new expansion of Cyperaceae (84%). Total pollen concentrations never exceed 100,000 grains g^{-1}. An increase in aquatics is recorded, in particular *Sparganium/Typha*, *Typha latifolia*, *Alisma* and Nymphaeaceae. Among non-pollen palynomorphs there are algal spores of *Spirogyra*, *Zygnema* and Botryococcaceae. Micro-charcoal concentrations are rather heterogeneous and never exceed 2 cm^2 g^{-1}.

Zone LOI-5 (78–0 cm; ca. 2000–0 cal. a BP)

A new rapid increase in AP percentages is recorded (40–86%), mostly represented by evergreen taxa, in particular *Quercus* evergreen type (47%), *Erica* (6%) and *Olea* (3%). These are accompanied by high percentages of deciduous taxa, mainly deciduous *Quercus*, *Ostrya/Carpinus* and *Fagus*, and conifers, mostly represented by *Pinus* and *Juniperus*. Among the herbs, Chenopodiaceae increase to 21%. The anthropogenic markers (cereals, *Juglans* and Cannabaceae) show a continuous record. Total pollen concentrations never exceed 40,000 grains g^{-1}. The micro-charcoal record is similar to the preceding zone.

Macrofossil data

Waterlogged carpological remains, consisting of 16 taxa, were present only in 12 out of the 23 analysed samples (Fig. 5). Wood fragments were recovered from four samples (130–125 cm: *Alnus* sp.; 205–200 cm: *Alnus* sp. and *Fraxinus* sp.; 255–250 cm: *Alnus* sp.; 270–265 cm: *Alnus* sp.). They are marked on the pollen diagram (Fig. 3).

The results of carpological remains are presented as a concentration diagram (number of seeds per 50 g; Fig. 5). Two zones, labelled from the base upwards and prefixed by the site abbreviation LOI, were identified.

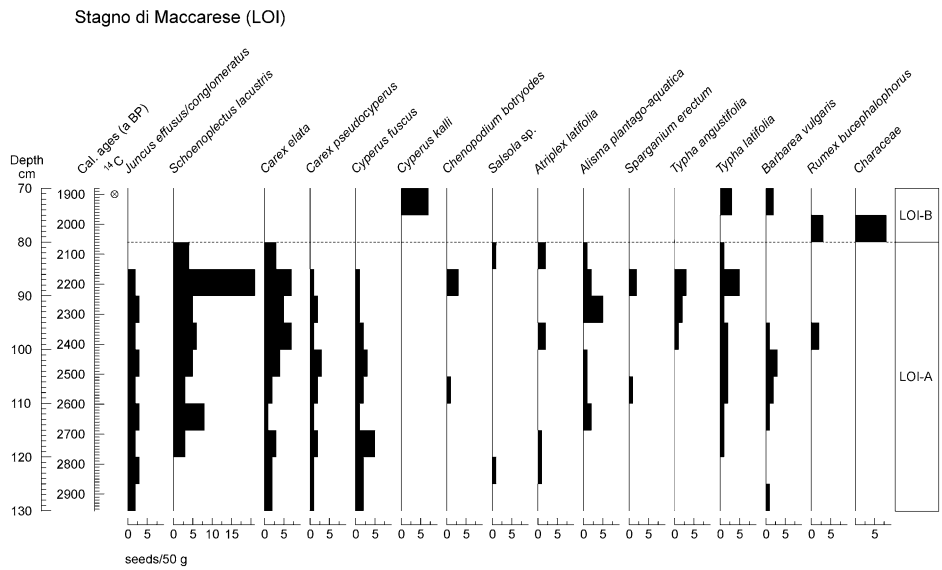

Fig. 5 Carpological diagram from Stagno di Maccarese (LOI)

Zone LOI-A (130–80 cm; 2950–2060 cal. a BP)

Various species of Cyperaceae are abundant in this zone, with *Schoenoplectus lacustris* dominant, accompanied by *Carex elata*, *Carex pseudocyperus* and *Cyperus fuscus.* In addition, Juncaceae, *Alisma* and *Typha* are frequently represented. On the whole, they outline a marshy landscape, including ponds and wet sandy areas. Halophilous taxa are also present, including *Chenopodium botryodes*, *Atriplex latifolia* and *Salsola* sp. In the interval 115–95 cm there is a significant presence of *Barbarea vulgaris*, generally living on wet soils.

Zone LOI-B (80–70 cm; 2060–1880 cal. a BP)

Only five taxa are found in this zone, including both taxa related to wetlands (*Typha latifolia*, *Barbarea vulgaris* and Characeae) and taxa living on sandy soils and maritime dunes (*Cyperus kalli* and *Rumex bucephalophorus*).

Discussion

The pollen diagram from Stagno di Maccarese provides an outstanding example of marked environmental variability during the last 8000 years, causing major vegetational changes. Water salinity changes and water level fluctuations are also recorded, favouring a better definition of the environmental evolution, also in relation to local human occupations.

Early-middle Holocene forests:
8300–5400 cal. a BP

Between approximately 8300 and 5400 cal. a BP the Maccarese area was covered by dense oak-dominated forests, probably with a patchy distribution of evergreen and deciduous communities. The evergreen oak forest was presumably more abundant along the coastal belt. At the margins and in the glades of the evergreen oak woods, *Erica* scrublands could develop, as they do at present. The scarcity of important evergreen elements, such as *Olea*, *Phillyrea, Pistacia*, *Pinus* and *Juniperus*, suggests that the dunal vegetation was not particularly developed. However, it cannot be excluded that the scarcity of evergreen shrubby taxa was related to climatic conditions not especially favourable for the development of thermophilous evergreen Mediterranean taxa. Dense deciduous oaks-dominated forests with a number of different trees (e.g. *Corylus*, *Ulmus*, *Ostrya/Carpinus orientalis*, *Carpinus betulus*) extended from the retro-dunal wetland up to the first hills inland. In the surroundings of Stagno di Maccarese this vegetation probably formed widespread woods.

The herbaceous vegetation of Stagno di Maccarese between 8300 and 5400 cal. a BP was mostly composed by sedges and grasses, probably representing local elements of marshy environments. A remarkable amount of fragments of cyanobacteria (family Rivulariaceae, *Gloeotrichia* type, N. Abdel-ahad, personal communication) matches high amounts of aquatics, in particular *Myriophyllum spicatum*, a typical freshwater species not tolerant of rising salinity (van Wijck et al. 1994). The presence of *Myriophyllum* strongly suggests that a freshwater coastal lake was already in existence. The freshwater genus *Gloeotrichia* is particularly active in nitrogen and phosphorus fixations (Fay 1992; Pettersson et al. 1993) and is often involved in eutrophication processes related to nutrients loading (Aavad 1994). Therefore it represents a valuable palaeoecological indicator of eutrophication (Carrión and Navarro 2002). The abundance of Rivulariaceae in the freshwater Stagno di Maccarese may be assumed as a phase of nutrients enrichment.

A significant frequency of fungal spores of *Glomus*, a good marker of sediment erosion (van Geel 1986), may be indicative of unstable sandy bars affected by intense erosional processes. The presence of *Pseudoschizaea* supports this hypothesis, suggesting seasonal desiccations (Scott 1992) and freshwater flows with erosional processes in the basin (Pantaleón-Cano et al. 2003).

Although it was not possible to date the most ancient sandy bars, sediments with freshwater molluscs dated at around 7300 cal. a BP confirm the existence of a freshwater basin (Giraudi 2004). This evidence testifies that the Stagno di Maccarese marshland was isolated from the sea during this phase.

A vegetation composition very similar to Stagno di Maccarese is found at Lago di Massaciuccoli (Colombaroli et al. 2007; Mariotti Lippi et al. 2007), the only coastal site in the Italian side of the Tyrrhenian Sea recording with accuracy the period between 8000 and 5000 cal. a BP, located about 270 km northwest

of Maccarese (Fig. 1a). Two pollen sequences at Lago di Massaciuccoli show a landscape dominated by mixed evergreen and deciduous oak vegetation. The deciduous vegetation is especially characterized by *Corylus*, while the evergreen vegetation is mainly composed of oaks and *Erica*, accompanied by very sparse occurrences of other mediterranean shrubs. The main difference with Maccarese is the presence of *Abies*, which could extend in the nearby hills, while in the region of Rome *Abies* is missing during the Holocene (Follieri et al. 1988). The main inland sites in the Latium region (Lagaccione: Magri 1999; Lago di Vico: Magri and Sadori 1999; Valle di Castiglione: Follieri et al. 1988; Lago Albano: Lowe et al. 1996; Mercuri et al. 2002) highlight widespread deciduous oaks-dominated forests, rich in *Fagus*, *Corylus* and many other deciduous taxa, with local floristic differences. The evergreen vegetation was mostly represented by appreciable amounts of oaks and *Erica*.

Mid-Holocene opening of the landscape: 5400–5100 cal. a BP

An abrupt change around 5400 cal. a BP marks the transition to the next vegetational phase. This is documented by both major changes in the vegetation structure, floristic composition and aquatic proxies, and a clear variation of sedimentation rate (Fig. 2). The age-depth model clearly indicates a change from 0.13 mm a^{-1} for the interval 8000–5400 cal. a BP, to 0.64 mm a^{-1} for the interval 5400–3100 cal. a BP, corresponding to a lithological change from a grey silt with molluscs remains to a peat with abundant wood remains and microcharcoal fragments. A sedimentation hiatus at this level is possible, as geological investigations report many discontinuity surfaces in the sedimentary sequences of the Tiber delta area (Bellotti et al. 2007; Giraudi 2004).

Between ca. 5400 and 5100 cal. a BP, the vegetation history of Stagno di Maccarese records an open landscape, related to the development of a marshy environment, as indicated by the successive dominance of Poaceae, followed by Cyperaceae and then other herbaceous taxa. These dynamics represent a lowering of the water table, which in coastal lakes is generally connected to variations of the sea level (Ataie-Ashtiani et al. 1999; Turner et al. 1996).

A coeval opening of the landscape is recorded also in other coastal sites of the central Mediterranean region. At Lago Alimini Piccolo, a tectonic lake close to the Apulian coast (Fig. 1a), an episode of open vegetation between 5500 and 5100 cal. a BP was interpreted as the possible result of over-representation of local taxa producing pollen resistant to oxidative stress, such as Cichorioideae and Chenopodiaceae, due to erosional processes in the sediments (Di Rita and Magri 2009).

Other coastal Mediterranean sites are not dated well enough to detect this short event, except Lago di Massaciuccoli (Colombaroli et al. 2007), Le Fango (Reille 1992), and Crovani (Reille 1992), where a development of marshy environment is clearly visible at 5400–5100 cal. a BP (Fig. 1a). These basins were formed by sandy bars and kept a more or less close connection with the sea. At Massaciuccoli, Marchetto et al. (2008) interpreted the opening of the vegetation as the result of a pervasive change towards a drier climate, on the basis of different proxies. However, the inland pollen sites of peninsular Italy (Lago dell'Accesa: Drescher-Schneider et al. 2007; Lagaccione: Magri 1999; Lago di Vico: Magri and Sadori 1999; Lago Grande di Monticchio: Allen et al. 2002) do not show a clear opening of the forest that may be related to an aridification process. For this reason, we suggest a different interpretation, relating the expansion of marshlands to variations in the level of coastal aquifers, possibly influenced by sea level rise and geomorphological changes in the sedimentation dynamics of coastal areas. Before 6000 cal. a BP the eustatic sea level rise, reflected also by many central Mediterranean sites (Lambeck et al. 2004), caused changes in the depositional setting around the Tiber delta, following a backstepping of lagoonal deltas (Bellotti et al. 1994, 2007). The eustatic deceleration of the sea level rise triggered major hydrological changes in the coastal lakes near the Tiber delta, in turn inducing the development of local reed fens and marshlands, indicating a lowering of the water level. It is also possible that the dominance of herbaceous vegetation may have been favoured by a rapid progradation of the delta, following the change from a river-dominated delta to a wave-dominated delta, and the formation of new coastal ridges.

The pollen record from Stagno di Maccarese provides clear evidence of human impact on the landscape, documented by a peak of micro-charcoal concentrations indicating local fires, matching the

presence of cereal-type pollen. The sudden increase in grasses, representing fuel availability, might have provided ideal conditions for humans to use fire. This time interval is consistent with the age of the archaeological surfaces of the nearby middle Eneolithic settlement of Le Cerquete-Fianello, dated between 5370 and 4920 cal. a BP. The presence of a millstone and a lithic reaping hook in the archaeological site confirms grain farming activity (Manfredini 2002). Lithic industry and animal bones (*Ovis* vel *Capra*, *Bos taurus*, *Sus scrofa*, *Equus caballus*, *Canis familiaris*, *Felis sylvestris*, *Capreolus capreolus*, *Testudo* sp.) indicate breeding and hunting (Tagliacozzo et al. 2002). Archaeobotanical investigations detected abundant charcoal remains of both deciduous and evergreen vegetation, indicating that there was a planitial forest with a mosaic of deciduous and riparian woods (deciduous *Quercus*, *Alnus*, *Fraxinus*, *Ulmus*, *Cornus*, *Populus*, *Acer*, and *Vitis*) and Mediterranean maquis (evergreen *Quercus*, *Phillyrea*, *Rhamnus*, and *Juniperus*) (Celant 2002).

In spite of this clear human presence, low values of tree pollen percentages were probably not due to forest clearance. In fact, pollen concentrations highlight a strong increase of grasses coupled with stable values of forest vegetation (Fig. 4). This stability of the forest cover does not support the hypothesis of a climate change towards aridification (Marchetto et al. 2008). Most likely, the development of the marshy environment, related to a low water table, induced favourable conditions for the human settlement at the margin of the Stagno di Maccarese.

Mid-Holocene alder carr: 5100–2900 cal. a BP

Between 5100 and 2900 cal. a BP there is a remarkable expansion of riparian trees, mostly represented by *Alnus*, with temporary spreads of *Salix*. Several factors may have contributed to this change: (1) over-representation of local pollen of riparian vegetation, especially *Alnus* that is a strong pollen producer; (2) increased fluvial inflow in the basin, transporting pollen from inland areas and favouring the representation of riparian vegetation around inland lakes (Naughton et al. 2007; Sánchez Goñi 1996); (3) formation of a broad alder carr bordering the coastal lake coinciding with the sea-level stillstand interval, similarly to modern estuarine areas of Northern Europe (Prager et al. 2006; Tapper 1996). A synergy of these factors is very likely.

A comparison with other central Mediterranean coastal records reveals that a conspicuous spread of riparian trees started at many sites around 5200–5000 cal. a BP. At Massaciuccoli, soon after the event of vegetation opening, an important expansion of *Alnus* is recorded, with a maximum around 5100 cal. a BP (Colombaroli et al. 2007). In the Corsican sites, similar dynamics are recorded: in the estuarine area of Le Fango the spread of *Alnus* occurs around the ^{14}C date 4450 ± 140 (5100 ± 450 cal. a BP), soon after an opening of the vegetation (Reille 1992). At Crovani, from the base of the diagram (ca. 5100 cal. a BP) until 3800 cal. a BP very high percentages of *Alnus* are found (Reille 1992). At Saleccia a spread of *Alnus* with a peak at around 5200 cal. a BP is recorded (Reille 1992). Along the Adriatic Sea, the sequence of Palu Rovjni (Beug 1977), although distant from important rivers, shows a spread of *Alnus* and *Salix* after the ^{14}C date 4490 ± 125 (5150 ± 300 cal. a BP).

Similar dynamics are recorded also in Atlantic coastal sites (Sánchez Goñi 1996; Santos et al. 1993). Santos and Sánchez Goñi (2003) interpreted the spread of *Alnus*, often accompanied by *Salix*, as a consequence of the expansion of freshwater habitats coeval with a period of deceleration of the sea level rise after 6000 cal. a BP. In the Santo André Lagoon, SW Portugal, (Santos and Sánchez Goñi 2003), the expansion of freshwater habitats was triggered by the formation of coastal barriers, preventing the evacuation of freshwater to the sea and leading to the formation of freshwater ponds with development of riparian trees. Our data outline a similar scenario, also considering an increase of *Juniperus* and *Pinus* which are typically involved in the stabilization of coastal dunes, just before the spread of *Alnus*.

This increase of riparian vegetation is also found in inland sites in the Latium region, indicating either a regional increase of *Alnus* or pollen transportation by wind from coastal areas. At Lagaccione (355 m a.s.l.) a clear and sudden increase in *Alnus* is recorded around 5000 cal. a BP (Magri 1999). At Lago di Vico (510 m a.s.l.) *Alnus* shows an increase around 5200 cal. a BP (Magri and Sadori 1999).

Between 5100 and 2900 cal. a BP, also *Fraxinus* and *Vitis* develop at Stagno di Maccarese. Macrofossil remains document a significant presence of *Fraxinus*,

which often represents an important accompanying taxon in alder carrs (Tapper 1996). The continuous presence of *Vitis* seems related to the development of riparian vegetation rather than to human activity. In fact, *Vitis* is also a natural partner of the alder-dominated riparian vegetation, where it is often recorded in pollen diagrams without evidence of human impact (Mariotti Lippi et al. 2007; Reille 1992).

The occurrences of taxa typical of underwood environment, such as *Hedera*, *Cyclamen*, *Symphytum*, and *Polypodium*, suggest that the riparian community did not form a restricted belt surrounding the Stagno di Maccarese, but formed dense and extensive forests.

A considerable single peak of sedges, indicating the development of a marshland around 4000 cal. a BP, matches the geological evidence of a temporary lowering of the water level documented by an evaporitic level dated around 4000 cal. a BP at Le Cerquete-Fianello (Giraudi 2004). At approximately the same time, in many sites of the central Mediterranean region, a temporary deforestation is recorded, interpreted as a drought event (Di Rita and Magri 2009). It is possible that this arid event did not determine a significant decrease of the forest cover in such a wet site like Stagno di Maccarese, where only a temporary lowering of the water level occurred.

Late Holocene marshlands: 2900–2000 cal. a BP

Between 2900 and 2000 cal. a BP there is a new development of marshlands. As already discussed for the interval 5400–5100 cal. a BP, a succession of different herbaceous taxa (Poaceae, Cyperaceae/Juncaceae, and other herbs) is recorded. The carpological remains indicate that several species of Cyperaceae are represented, together with Juncaceae (Fig. 5). A slight increase of Chenopodiaceae pollen around 2600 cal. a BP, evidenced also by carpological analyses (*Chenopodium botryodes*), indicates increased salinity. This is contemporary to the usage of the basin as saltworks by the local Etruscan populations in the sixth century BC (Giraudi 2004; Morelli et al. 2004). A temporary development of pioneer terrestrial plant communities, as suggested by a pollen peak of Brassicaceae, indicates a possible decrease of the water level around 2450 cal. a BP. The fossil seeds of *Barbarea vulgaris*, an herbaceous taxon living in moist, disturbed fields, peaking at 2500–2400 cal a BP, confirm this hypothesis (Fig. 5).

A spread of Cyperaceae and freshwater aquatic taxa around 2300 cal. a BP, documented by both pollen and carpological remains, corresponds to a new expansion of the sedges fen (Figs. 4, 5). In particular, the presence of high values of *Alisma* pollen, documented also by macrofossils, together with *Spirogyra* and *Zygnema*, indicate that freshwater swamps with stagnant water were interspersed within the sedges marshland.

The usage of the area as saltworks since the first century BC is documented by a slight increase of chenopods pollen and by the presence of macrofossils of halophytes (*Atriplex* and *Salsola)* around 2200 cal. a BP.

On the whole this extensive and unstable marshy environment, continuously fluctuating from ponds, to brackish wetlands, to sedges fens and wastelands, was not suitable for stable human settlements. This is confirmed by the absence of important archaeological sites and by the scarcity of anthropogenic markers indicating cultivation (e.g. cereals, *Olea*, *Juglans*) or pastures (e.g. *Rumex* and *Plantago*). A considerable amount of *Asphodelus* (up to >2%) suggests a widespread wasteland.

Late Holocene saltmarsh: after 2000 cal. a BP

After 2000 cal. a BP the Romans intensively exploited the area, as evidenced by the construction of Portus Claudius (64 AD), Portus Trajanus (113 AD), the annex storage buildings by Marcus Aurelius (end second century AD) and the progressive enlargement of the city of Ostia. Besides, the Romans took control of the ancient Etruscan saltworks located in the southern margin of the Stagno di Maccarese and traced a road for the transportation of the salt to the city of Rome.

In the pollen diagram from Stagno di Maccarese, anthropogenic markers are continuously found since the Roman exploitation of the area. They include cereals, Cannabaceae and *Juglans*. The cultivation of Cannabaceae for plant textiles is well documented at Lago Albano and Lago di Nemi approx. 30 km SE of Stagno di Maccarese, where great amounts of *Cannabis* effectively prove intense cultivation of hemp by the Romans in the region since in the first century AD (Mercuri et al. 2002). An increase of *Olea* is probably to be referred to cultivation.

An important spread of Chenopodiaceae, starting already 2200 cal. a BP suggests the development of a

local saltmash, documented also by brackish molluscan faunas (Giraudi 2004). This environmental change represents the development of the Roman saltworks since the Republican times, and especially in Imperial times. It is interesting to notice that a similar increase of chenopods is recorded in the coastal alluvial plain of the Ombrone river (south Tuscany), where it was interpreted as a response to cooler, wetter climatic conditions and a decline of solar activity (Biserni and van Geel 2005). However, landscape archaeological investigations have shown that the coastal area north of the Ombrone area, close to the Etruscan harbour of Roselle, well known for salt trade, was occupied by saltworks in Roman times and early Middle Ages (Arnoldus-Huyzendveld and Citter 2008). In the fourteenth century, extensive saltworks were located at Squartapaglia, very close to the Ombrone drilling, whose pollen record shows a contemporary increase of chenopods up to 80%. The relationship Chenopodiaceae-saltwork activity in these coastal areas is counterdemonstrated by low values of chenopods in the pollen record from Lago di Massaciuccoli (Colombaroli et al. 2007), a coastal area where saltworks are not archaeologically documented. This indicates that the increase of chenopods in the last 2000 years in the Latium and south Tuscany coastal areas is not related to natural sea water intrusion but to human activity.

In spite of the presence of an extensive saltwork area and a conspicuous human occupation, a significant increase of arboreal vegetation is recorded both in percentage and in concentration after 2000 cal. a BP, possibly because, following a vary rapid coastal aggradation (Rendell et al. 2007), the area available for forests also increased (Fig. 4). The landscape was characterized by evergreen and deciduous oak-dominated forests, with the evergreen component probably mostly located seawards. The deciduous woodland, representing the main regional vegetation component, formed mixed stands also along the coastal plain surrounding Stagno di Maccarese, as suggested by macrofossil finds of Roman Age (*Fraxinus*, *Alnus*, evergreen and deciduous *Quercus*) in the Lingua d'Oca site, and by the modern diffusion of planitial forests in the protected areas of Macchiagrande north of the River Tiber (Lucchese 1996), and Castelporziano, south of Ostia (Manes et al. 1997). A deciduous oak of Roman Imperial Age (1690 ± 50 ^{14}C a BP) from the Lingua d'Oca site has been the subject of genetic analyses (chloroplast DNA), which demonstrated the local provenance of the wooden posts used by the Romans, as the fossil haplotype matches exactly the modern oak haplotype in the area (Deguilloux et al. 2006).

The formation of extensive dunes around 2000 cal. a BP is testified by macrofossils of *Cyperus kalli* and *Rumex bucephalophorus* and by an increase in *Juniperus* and *Pinus* pollen. They are coupled with evergreen maquis shrubs (*Erica*, *Pistacia* and *Phillyrea*), forming a vegetation type still well preserved locally in the coastal environments north and south of Stagno di Maccarese (Macchiagrande: Lucchese 1996; Castel Porziano: Manes et al. 1997).

A morphological analysis of *Pinus* pollen indicates that in the last 2000 years two distinct *Pinus* types are recorded. In particular, a clear increase of *P. pinaster/pinea* took place. A similar pattern has been recognized in Corsica at various sites (Lac de Creno, Saleccia, Le Fango: Reille 1992; Reille et al. 1999) and interpreted as the result of high fire frequency (Carcaillet et al. 1997). This interpretation would not explain the Stagno di Maccarese record, where there are no significant increases of microcharcoal concentrations. In other central Mediterranean coastal sites, undifferentiated *Pinus* pollen shows clear increases in the last 2000 years, including Lago di Massaciuccoli (Colombaroli et al. 2007), Lago Alimini Piccolo (Di Rita and Magri 2009) and Malo Jezero (Jahns and van den Bogaard 1998). At Lago d'Averno an abrupt rise of *Pinus* is found in relation to the building of *Portus Julius* in 37 BC, pointing to a human-induced introduction of pine (*Pinus pinea*?) in the area, together with many cultivated trees (e.g. *Platanus* and *Castanea*; Grüger and Thulin 1998). In conclusion, due to the difficulty of distinguishing different pine species on the basis of their pollen morphology, it is not possible to argue whether the generalized increase of pine in many central Mediterranean coastal sites during the last 2000 years was related to human influence or to a natural spread.

At Stagno di Maccarese, a rapid change of the local environmental conditions towards an ephemeral freshwater marshland is indicated by a peak of sedges and freshwater aquatics around 1100 AD. This episode matches an increase of water level, dated 620 ± 100 ^{14}C a BP, recognized on a sedimentological

basis (Giraudi 2004) and might indicate a major flood event.

Conclusions

The combined analyses of pollen, seeds, woods, micro-charcoal and non-pollen palynomorphs from Stagno di Maccarese indicate that in the marshy area north of the Tiber delta very diversified ecological situations have followed each other, with abrupt transitions and deep renewals of vegetation structure and floristic composition during the last 8300 years:

- 8300–5400 cal. a BP: Stagno di Maccarese was a eutrophic freshwater basin, surrounded by a fairly forested landscape characterized by both evergreen and deciduous trees.
- 5400–5100 cal. a BP: extensive marshlands developed, pointing to a remarkable decrease of the water level, found also in other coastal sites of the Tyrrhenian Sea and Corsica.
- 5100–2900 cal. a BP: an extensive alder carr characterized the coastal landscape, possibly triggered by increased water influx. Other central Mediterranean coastal sites record this event.
- 2900–2000 cal. a BP: an unstable marshy environment, formed by ponds, wetlands, sedges fens and salted soils, was induced by a lowering of the water level. It was an unfavourable environment for stable human settlements.
- 2000–0 cal. a BP: the Stagno di Maccarese area was transformed by the Romans in a wide saltwork. In spite of intensive human exploitation, there was an increase of forest cover, represented by a complex mosaic of thermophilous and mesophilous woods.

Aquatics and hygrophytes pollen and macroremains, as well as non-pollen palynomorphs, have been especially helpful in reconstructing the history of the water body, providing information on the instability of the basin, the introgression of marine water, possible flood events and eutrophic phases. Local geomorphic coastal processes have certainly been a main driver for these abrupt changes of the landscape, although a number of environmental situations appear to be related to variations of the sea-level, being recorded in other sites of central Italy and Corsica. They include a low lake level at 5400–5100 cal. a BP and an increase of water influx around 5100 cal. a BP. A widespread aridification event, affecting the central Mediterranean evergreen vegetation around 4000 cal. a BP (Di Rita and Magri 2009) can be recognized at Stagno di Maccarese only as a temporary lowering of the water table, coeval with the formation of an evaporitic layer at the lake margin.

Human activity appears to have had only a marginal role in the landscape evolution of the area, in spite of the vicinity of prehistorical and protohistorical settlements, Etruscan saltworks and Roman reclamation works, documented by extensive and detailed archaeological excavations. The Eneolithic settlement of Le Cerquete-Fianello, at the northern lake margin, took advantage of a low-stand phase of the lake and disappeared when the water level arose. Very weak evidence of human activity is found between the Eneolithic and Etruscan settlements in the pollen diagram, when the area was occupied by an extensive alder carr followed by a marshland, most likely unhealthy for human populations. The Romans exploited the area in Republican and Imperial times, building an important harbour between the Tiber and the Stagno di Maccarese wetland, which was partly transformed in saltworks, very well represented in the pollen record by the development of a saltmarsh. Cultivated plants are present, although not very abundant. Between the thirteenth to eighteenth centuries AD the area, surrounded by mixed evergreen and deciduous forests, subject to floods and affected by malaria, was largely abandoned, until the reclamation works of the nineteenth to twentieth century.

The palaeovegetational record from Stagno di Maccarese clearly documents that even in relatively recent times major recurrent and ineluctable events, including eustatic sea-level variations, geomorphological changes related to the sedimentation dynamics of the river delta, groundwater fluctuations, desiccation events and micro-climatic processes, have produced dramatic and repeated landscape transformations, with inevitable repercussions on the local biodiversity of the Tiber delta area. When considered within the last thousands of years, the modern vegetational situation appears a snap-shot, destined to new, abrupt and dramatic future changes. In a long time perspective, the conservation and management of this area does not appear an easy task, if the main goal is to maintain stable ecological conditions.

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