Quaternary International

Holocene palaeoenvironmental evolution of the southern margin of the Salpi lagoon (Apulia, Southern Italy)

--Manuscript Draft--

Manuscript Number:	QUATINT-D-22-00245
Article Type:	Regular Article
Keywords:	Holocene; Tavoliere coastal plain; Palaeoenvironmental reconstruction; Pollen; Ostracoda; Human impact
Abstract:	A total of ten cores were drilled to understand the relationship between the palaeoenvironmental evolution of the southern margin of the Salpi lagoon (Tavoliere coastal plain, Apulia, Italy) and the development of settlements on its shores during the last part of the Holocene (Late Northgrippian to Late Meghalayan). Micropalaeontological, palynological, and sedimentological analyses revealed local and regional events, some of which have already been recognised in the northern part of the coastal plain, close to the archaeological site of Coppa Nevigata. Facies and micropalaeontological analyses show that the lagoon was partially connected to the sea between 6.2 ka BP and 4.2 ka BP. Between 4.2 ka BP and 2.4 ka BP, the area was characterised by marshes and swamps with restricted brackish lagoon conditions and permanent freshwater input. After 2.4 ka BP, the continuous freshwater influx from the Carapelle River determined the progradation of the floodplain and the closure of the lagoon, with the formation of the two coastal lakes of Lago Salso (north) and Lago Salpi (south). Pollen data show the expansion of halophytic herbs under local brackish conditions during the Early Meghalayan and the exponential spread of dryland herbs consistent with the closure of the basin. The emersion of the land during the Late Meghalayan allowed the intensive exploitation of the area and the development of a highly anthropogenic landscape. The development of the settlements of pre-Roman Salpia Vetus , Roman Salapia , and Medieval Salpi was mainly determined by the insalubrious condition of the surrounding marshes, due to the reduction in water depth and oscillations in salinity.

Holocene palaeoenvironmental evolution of the southern margin of the Salpi lagoon (Apulia, Southern Italy)

Davide Susini[a,*], Cristiano Vignola[b, c], Roberto Goffredo[d], Darian Marie Totten[e], Alessia Masi[b, c], Alessandra Smedile[f], Paolo Marco De Martini[f], Francesca Romana Cinti[f], Laura Sadori[b], Luca Forti[g], Girolamo Fiorentino[h], Andrea Sposato[a], Ilaria Mazzini[a]

[a] Institute of Environmental Geology and Geoengineering, IGAG-CNR, Area della Ricerca di Roma 1, Strada Provinciale 35d, 9 – 00100, Montelibretti, Rome, Italy

[b] Department of Environmental Biology, Sapienza University of Rome, Piazzale A. Moro 5, 00185, Rome, Italy

[c] Palaeo-Science and History (PS&H) Independent Research Group, Max Planck Institute for the Science of Human History, Kahlaische Strasse 10, 07745, Jena, Germany

[d] Dipartimento di Studi Umanistici, Lettere, Beni Culturali, Scienze della Formazione, Università di Foggia, Via Arpi 176, 71121, Foggia, Italy

[e] Department of History and Classical Studies, McGill University, 855 Sherbrooke Street West, H3A 2T7, Montreal, Quebec, Canada

[f] Istituto Nazionale di Geofisica e Vulcanologia, Via di Vigna Murata 605, 00143, Rome, Italy

[g] Department of Earth Sciences 'Ardito Desio', University of Milano, via Mangiagalli 34, 20133, Milan, Italy

[h] Dipartimento di Beni Culturali, Università del Salento, Via Dalmazio Birago 64, Lecce, Italy

[*] Corresponding author.
E-mail address: davide.susini@igag.cnr.it (D. Susini).

Abstract

A total of ten cores were drilled to understand the relationship between the palaeoenvironmental evolution of the southern margin of the Salpi lagoon (Tavoliere coastal plain, Apulia, Italy) and the development of settlements on its shores during the last part of the Holocene (Late Northgrippian to Late Meghalayan). Micropalaeontological, palynological, and sedimentological analyses revealed local and regional events, some of which have already been recognised in the northern part of the coastal plain, close to the archaeological site of Coppa Nevigata. Facies and micropalaeontological analyses show that the lagoon was partially connected to the sea between 6.2 ka BP and 4.2 ka BP. Between 4.2 ka BP and 2.4 ka BP, the area was characterised by marshes and swamps with restricted brackish lagoon conditions and permanent freshwater input. After 2.4 ka BP, the continuous

freshwater influx from the Carapelle River determined the progradation of the floodplain and the closure of the lagoon, with the formation of the two coastal lakes of Lago Salso (north) and Lago Salpi (south). Pollen data show the expansion of halophytic herbs under local brackish conditions during the Early Meghalayan and the exponential spread of dryland herbs consistent with the closure of the basin. The emersion of the land during the Late Meghalayan allowed the intensive exploitation of the area and the development of a highly anthropogenic landscape. The development of the settlements of pre-Roman *Salpia Vetus*, Roman *Salapia*, and Medieval *Salpi* was mainly determined by the insalubrious condition of the surrounding marshes, due to the reduction in water depth and oscillations in salinity.

Keywords

Holocene; Tavoliere coastal plain; Palaeoenvironmental reconstruction; Pollen; Ostracoda; Human impact

1. Introduction

Coastal areas are well-studied, unique, and dynamic systems located between marine and continental environments, and highly dependent on sedimentary and erosive processes, glacio-eustatic oscillations, and tectonic regimes (Lambeck et al., 2011; Ruello et al., 2017; Corrado et al., 2020; Buffardi et al., 2021). The sedimentary sequences preserved ~~within~~ these environments represent high-resolution physical archives and are ~~considered contexts~~ of primary interest in the Mediterranean region for the palaeoecological evolution of the Late Quaternary ~~and~~ the complex interaction between anthropic and natural forcing mechanisms (Sabatier et al., 2010; Ghilardi et al., 2013; Carmona et al., 2016; Cosentino et al., 2017; Natali and Bianchini, 2018; Emmanouilidis et al., 2020; López-Belzunce et al., 2020; Di Lorenzo et al., 2021). With so many examples ~~of natural contexts~~, as well as human strategies and motives for inhabiting these coastal zones, their long-term evolution is neither obvious nor assured. Therefore, reconstructing the palaeoenvironmental picture is crucial for ~~writing~~ the history of these areas from prehistoric times to the present-day.

Indeed, the coastal wetlands of the Italian peninsula have been thoroughly studied through multiproxy analyses (Mazzini et al., 1999; Amorosi et al., 2013; Sacchi et al., 2014; D'Orefice et al., 2020; Pieruccini and Susini, 2020). In the Apulian region (Southern Italy), the most

important is the wetland of the Tavoliere Plain, also known as the Salpi lagoon, an area densely settled and exploited since the Early Neolithic (Whitehouse, 2014, and references therein). Earlier studies by Delano Smith and Morrison (1974) and Delano Smith (1976) at Palude Frattarolo and Lago Salso (Fig. 1), on the north-eastern edge of the coastal plain, revealed the presence of wetlands during the 1st cent. CE, south of the ancient port of *Sipontum* and separated from the open sea by a sandy barrier. Investigations continued mainly in the northern part of the coastal plain, focusing on the area surrounding the archaeological site of Coppa Nevigata, a settlement inhabited from the Early Neolithic to the Iron Age (Caldara et al., 2003; 2004). Here, palaeoenvironmental analyses showed that the wetlands at the periphery of the settlement underwent several rapid changes during the Bronze and Iron Ages due to anthropogenic activities (Caldara and Simone, 2005; 2012). In contrast, analyses within the lagoon basin showed a natural regressive trend of the wet environment, gradually becoming dryland (Caldara and Simone, 2005; Di Rita et al., 2011).

However, there is little data available from the southern part of the coastal plain (Battista et al., 1994; Caldara et al., 2002). Archaeological fieldwork has been focused on the remains of the superimposed Roman town of *Salapia* and the Medieval city of *Salpi* (Marin, 1973; De Venuto et al., 2022). According to historical records, this sector of the coastal plain has been inextricably linked to the Salpi lagoon. For instance, the historian Vitruvius writes about the foundation of the Roman town of *Salapia* that the lagoon was transformed into a natural harbour (*de Arch.* I.4.12). From its inception, this body of water was considered crucial for the economic development, connections, and coastal character. Later historical sources, such as the Peutinger Table (Marin, 2018; Totten, 2022), have gestured towards the close links between settlement on the lagoon and salt production.

In order to fill this gap, this paper presents for the first time the sedimentological, palynological and micropalaeontological results of continuously drilled boreholes collected within the area of the "Capitanata" at the southern margin of the coastal plain. This study aims to shed light on the processes that have shaped the coastal dynamics and the relative influence of the natural and anthropic forcing factors that have driven the evolution of the coastal plain during the Holocene, so that future studies could begin to link the palaeoenvironmental results to the archaeological data.

2. Study area

The so-called "Capitanata" (Fig. 1) covers an area of 440.459 hectares. It lies within the southern margin of the Tavoliere coastal plain, bordered on the north by the Gargano Promontory (northern part of the Apulian foreland), on the west by the southern Apennines chain (known as *Subappennino Dauno*), on the east by the Gulf of Manfredonia (Adriatic Sea), and on the south by the Ofanto River watershed. Four major rivers flow into the Gulf of Manfredonia, from north to south: the Candelaro River, the Cervaro River, the Carapelle River, and the Ofanto River. The latter is the main watercourse of the area and the main geomorphological control feature of the coastline dynamics (Simeoni, 1992; Caldara, 1996; Spagnoli et al., 2008; De Santis et al., 2018).

Due to the abundance of water, the flat morphology, and the altitude, often below sea-level, the area was routinely affected by seasonal flooding, resulting in ~~unhealthy~~ conditions for the population. For these reasons, the area was the subject of an extensive infrastructural land reclamation project which began in the 1920s and drained the wetlands through embankments and direct channelling (e.g. Marana Castello, C.le Carapellotto, C.le Regina and F.so della Pila, Fig. 1). Moreover, the Tavoliere coastal plain underwent various land-tenure, agronomic, and hydraulic re-organisation phases, leading up to the agrarian reform of 1951 and the consequent completion of a large-scale irrigation infrastructure, which is still the main feature of the area (Ciccone, 1984; Russo, 1985).

The climate of the study area is semi-arid, with mean annual precipitation below 500 mm/year (Battista et al., 1993). The scarcity of humid air masses coming from the surrounding mountains reduces seasonal variability and results in dry conditions in summer. The natural vegetation of the coastal plain and the southern slopes of the Gargano Promontory consists of steppic plants with patches of Mediterranean elements (Biscotti, 2001). Nonetheless, agricultural activities have shaped the landscape since prehistoric times (Barker et al., 1987). In contrast, dense mixed forests of oak, beech, and conifer woods are widespread on the headland (Biscotti, 2001).

2.1. Geological background

Structurally, the area belongs to the Bradanic foredeep, which opened at the beginning of the Lower Pliocene and gradually filled throughout the Late Quaternary (Tropeano et al.,

2002). At the same time, the area underwent phases of subsidence and discontinuous tectonic uplift (Doglioni et al., 1994; 1996), with the onset at the end of the Early Pleistocene. Thus, the vertical sedimentary succession shows a general polycycle transgressive-regressive trend from marine to continental depositional environments.

The first sedimentary cycle occurred between the Middle Pliocene and the Early Pleistocene, overlaying the Mesozoic limestones basement of the Apulian foreland, which forms a system from west to east in the Gargano headland (Pieri et al., 1996; 1997). The transgressive units belong to the "Bradanic cycle" (De Santis et al., 2010 and reference therein) and consist of shallow-marine carbonate deposits passing conformably upward to silty-clayey hemipelagic deposits (Fig. 1).

The second sedimentary cycle, unconformably overlaying the Plio-Pleistocene carbonate deposits, occurred during the Middle Pleistocene and continued throughout the Holocene due to the uplift of the Apulian foreland (Pieri et al., 1996; 1997; Patacca and Scandone, 2001; Mastronuzzi and Sansò, 2002b) and the glacio-eustatic sea-level changes (Mastronuzzi et al., 2011; Maselli and Trincardi, 2013; Maselli et al., 2014). These processes resulted in several marine and continental terraces (De Santis et al., 2010), which are also recognised in many areas of the Bradanic foredeep (Boenzi et al., 1991; Gallicchio et al., 2014; De Santis et al., 2021). Thus, the sedimentary sequence, going unconformably from the oldest to the youngest deposits according to their progressive elevation from sea-level, consists of shallow marine and infralittoral sandy deposits, continental conglomerates deposits, alluvial sandy-gravelly deposits, and recent and present-day alluvial plain deposits (De Santis et al., 2010, Fig. 1).

During the Holocene, climate amelioration and sea-level rise (Dini et al., 2000; Primavera et al., 2011; De Santis and Caldara, 2015; Vacchi et al., 2016; De Santis et al., 2020) resulted in the formation of a lagoon within the coastal plain, dammed seaward by a system of coastal dune belts (Caldara and Pennetta, 1993b; Mastronuzzi and Sansò, 2002a), which stretched ca. 40 km at its maximum extension, from the foothill of the Gargano Promontory to the delta of the Ofanto River (Caldara and Pennetta, 1990; 1992; Caldara et al., 2002). Whilst the chronology for assessing the palaeo-lagoon is still uncertain, archaeological data suggest that wetlands were most likely already present during the Early Neolithic (Di Rita et al., 2011 and references therein). Since the Northgrippian (Walker et al., 2018), the coastal

lagoon has undergone several changes, both in terms of dimension and environment (Caldara and Pennetta, 1993a; Boenzi et al., 2001; 2006; Caldara et al., 2002; Di Rita, 2013), up to the recent definitive land reclamation (Ciccone, 1984; Russo, 1985).

2.2. Archaeological background

The Tavoliere coastal plain, like many other areas of the northern coast of Apulia, has been densely populated since the Neolithic period (6.5 ka-3.7 ka BCE, Hamilton and Whitehouse, 2021). The inhabitants practised agriculture and livestock breeding, and exploited the locally available natural resources (Tafuri et al., 2014; Muntoni et al., 2022). Between the Late and Final Neolithic (5th and early 4th millennium BCE), drier climatic conditions (Caldara and Pennetta, 1993b; Boenzi et al., 2001; Fiorentino et al., 2013) are considered the main reason for the sudden abandonment and massive depopulation of the coastal plain (Whitehouse, 2014). In addition, this drought induced people living in the Tavoliere to adopt a more pastoral type of farming (Whitehouse, 2014).

Re-colonisation of the coastal area most likely began during the Copper Age (4th-3rd millennium BCE) and intensified during the Bronze Age (early 2nd millennium BCE - 12th cent. BCE), when numerous sites ~~have been documented~~, along the northern Adriatic coast and at key inland locations (Cazzella et al., 2017). However, most of these settlements were short-term small villages devoted to agro-pastoral activities or salt exploitation. In the Tavoliere coastal plain, however, the most important archaeological evidence is the fortified settlement of Coppa Nevigata, located south of the Gargano Promontory (Fig. 1). This settlement was continuously inhabited until the Early Iron Age (18th–8th cent. BCE) and practised craft and exchange activities (Cazzella et al., 2012), eventually shifting towards agricultural production and subsistence strategies (Primavera et al., 2017).

During the Iron Age, archaeological and historical data (Goffredo, 2014 and references therein) indicate that the Tavoliere coastal plain was intensively colonised by Daunian settlements. These settlements developed over time into new central places, the most important of those being *Arpi* (off-map), *Cupola-Beccarini* (*Daunian Sipontum* in the figures) and *Salpia Vetus* (Fig. 1, Marin, 1973). During the 5th–4th cent. BCE, these indigenous settlements developed into proto-urban centres with strong, local, Hellenised aristocracies,

whose wealth was based on land-tenure, breeding, production and trade of cereals (Buglione et al., 2016).

According to the chronicles of Vitruvius, between the 3rd and 1st cent. BCE, the marshland conditions surrounding the city of *Salpia Vetus* became insalubrious. As a result, the population was forced to move away from the lagoon and founded a new urban centre called *Salapia*, about 6 km from the abandoned *Salpia Vetus* and closer to the coastline (De Venuto et al., 2022). Archaeological excavations carried out in different parts of the settlement have highlighted the main frequentation sequences from the 1st cent. CE to the 8th cent. CE (De Venuto et al., 2022). Moreover, archaeological findings of pier-like structures on the coast of Torre Pietra suggest that the settlement of *Salapia* was connected to the sea (Volpe, 1990; Cocchi et al., 2012).

Over the 9th cent. CE (Early Middle Ages), the settlement of *Salapia* was largely abandoned, although human occupation probably continued within the ruins of some sectors of the city. The re-foundation of the settlement and its community was not completed until the 11th cent. CE (Late Middle Ages), when *Salpi* (no longer *Salapia*) regained its status as a city (Goffredo, 2021). The new medieval settlement was reorganised at a significantly higher elevation than the surrounding countryside, and enclosed by a deep moat, probably served for defensive and drainage purposes (Goffredo, 2021).

2.3. Palaeoenvironmental background

The diachronic palaeoenvironmental reconstruction of the wetlands in the Tavoliere coastal was initially based on the study of some agricultural trenches and cores drilled in the northern area for water research (Boenzi et al., 2001). During the Early Neolithic, the lagoon was characterised by euryhaline and eurythermal molluscs living in brackish water or muddy sands of sheltered zones. After 6.3 ka BP, the lagoon evolved into a *sabkha* (Caldara and Pennetta, 1993b; Boenzi et al., 2001), a saline sand/mud flat area where evaporite minerals (gypsum) accumulated under arid conditions are associated with desertification processes. According to Caldara et al. (2004), this event led to the abandonment of coastal settlements of the Tavoliere at the end of the Neolithic.

New systematic coring activities near the archaeological site of Coppa Nevigata (Caldara and Simone, 2005; 2012; Caldara et al., 2004; Di Rita et al., 2011) provided detailed

information on the evolution of wetlands and the surrounding vegetation in relation to the human occupation of this portion of the coastal plain. A brackish lagoon with *Hydrobiidae* spp. and *Cerastoderma glaucum* was identified between 3600 and 3090 BP, followed by alternating terrestrial, wetland and salt marsh phases up to 370 ±50 BP (Caldara et al., 2004). As no evidence of sea-level fluctuations was found towards the middle of the basin, such deposition of terrestrial/marshy sediments was interpreted as aggradation of the coastline due to human colonisation of the lagoon shore between the Neolithic and the Iron Age (Caldara and Simone, 2005). Away from the settlement, a brackish wet environment was established before 6340 BP with local changes caused by salinity fluctuations leading to a progressive transformation of the semi-closed lagoon into a coastal lake until 3230 BP (Di Rita et al., 2011).

After an erosive episode around 370 ±50 BP, a seasonal freshwater marsh formed around the end of the Middle Ages, which evolved into a terrestrial environment until the historical reclamation. Locally, saltmarsh vegetation still existed towards the sea, whereas inland, a deforested landscape consisting mainly of pastures and cultivated fields was widespread (Caldara et al., 2004; Caroli and Caldara, 2007; Di Rita et al., 2011).

3. Materials and methods

Analyses were carried out on a total of 10 drilled boreholes (Fig. 2) obtained during two coring campaigns in 2017 (cores labelled SAL, Tab. 1) and 2019 (cores labelled SAM, Tab. 1). The location of the cores followed a geomorphological survey and mapping of the area, also taking into account the two archaeological sites of *Salpia Vetus* and *Salapia-Salpi*. The first two coring campaigns were performed using a drilling machine equipped with a hydraulic piston, a 1 m-long cylindrical corer, and a 101 mm-diameter cutting shoe (max. depth of 16 m). For the 2019 coring campaign, a gasoline-powered percussion hammer was used (max. depth of 9 m). Both drilling systems and sedimentological characteristics allowed for ca. 90% recovery of the whole sedimentary sequence. The cores were studied and sampled in the laboratories of IGAG-CNR and INGV (Rome, Italy).

Calibrated AMS 14C ages were obtained from 21 selected charcoal, ostracod shells, and organic sediments. Samples were processed by Beta Analytic Radiocarbon Dating (Miami, USA), using pre-treatment of acid washes and acid-alkali-acid protocols for organic

sediments and sonication in de-ionised water for shells. Calibrated dates were calculated using the BetaCal4.20 protocol, based on the IntCal20 calibration curve database (Reimer et al., 2020) and the high probability density range (Bronk Ramsey, 2009). Dating performed on ostracod shells used Siani et al. (2000) as reference for the MARINE20 curve selection.

The sedimentary sequence was described following the facies analysis method (Miall, 1985; 2010), taking into account texture, colour, fabric and sedimentary structures, biological remains and pedological features. Sediment colour has been determined with the Munsell Soil Colour Charts under moist conditions.

SAM and SAL cores were sampled for a ~~total of 200 micropaleontological samples.~~ All samples were processed following the standard procedure of drying, disaggregation in ~~diluted hydrogen~~ peroxide solution (20%), washing in 1.25 mm and 0.63 mm mesh sieves and drying in an oven at 50°C. Each dried and sieved sample was observed using a stereomicroscope (X14-150) to identify ostracoda, charophytes, foraminifera (planktic and benthic) and other biogenic remains. For the ostracod analysis, Ostracods Ecological Groups (OEG) were used, following Mazzini et al. (2017). The OEG enables standardising species by their ecological tolerance (SM: Shallow Marine, BM: Brackish to lagoonal Marine, EU: Euryhaline and FLB: Freshwater to Low Brackish) and reduces to 4 quantitative variables (% of each OEG) the biological information brought by the fossil assemblages of ostracods.

The grain size analysis has been performed in SAM9, on 15 samples, using a fraction of 30 g of dry sediment. Coarse fraction (>2 mm), sand (2 mm), silt (63 mm) and clays fraction (<63 mm) were differentiated through weighing sieve residue.

Palynological analysis was conducted on 58 sediment samples collected from SAL2, SAL3, and SAM9 cores. For each sample, 1.70 to 2.70 g of dry sediment was chemically processed for removal of detrital matter, following Fægri and Iversen (1989) method, with the alternating treatment of HCl (37%), HF (40%) and hot NaOH (10%). Following Stockmarr (1971), tablets containing a known amount of *Lycopodium* spores were added to estimate concentrations of pollen, spores, NPPs (Non-Pollen Palynomorphs) and microcharcoals. The identification of pollen morphology is based on pollen atlases and taxonomic keys (Fægri and Iversen, 1989; Moore et al., 1991; Reille, 1992; 1995; 1998; Beug, 2004) and reference pollen collections. *Quercus* species are grouped as described by Smit (1973),

whereas pollen grains of cereals have been distinguished within the Poaceae family following Andersen (1979). Cichorieae corresponds to the only European tribe of Asteraceae with fenestrate pollen grains belonging to the subfamily Cichorioideae (Florenzano et al., 2015). The pollen percentages have been calculated on the basic pollen sum, which includes all the terrestrial spermatophytes; percentages of macrophytes, ferns, green algae, cyanobacteria, fungi, and *Pseudoschizaea* have been calculated as the sums of terrestrial spermatophytes plus, in turn, each group of considered palynomorphs (Berglund and Ralska-Jasiewiczowa, 1986). The concentration values have been calculated per weight unit of dried sediment (pollen grains and NPP remains / g). The influx values have been obtained from the concentration values based on the sedimentation rates inferred from the age-depth model (grains/cm2 year; Berglund and Ralska-Jasiewiczowa, 1986). Pollen influx (i.e., the amount of pollen grains incorporated annually per unit of sediment) is an estimation of the plant biomass. The pollen diagrams have been plotted against depths using the TILIA program (Grimm, 1992). All Arboreal Pollen (AP) and Non-Arboreal Pollen (NAP) taxa with values of the basic pollen sum higher than 2 % have been considered in the CONISS cluster analysis, which supported the pollen zonation (Grimm, 1992). Charcoal particles have been identified and counted from pollen slides in order to evaluate the fire impact on past landscape. Following Sadori and Giardini (2007) and Whitlock (2010) the fragments have been sorted in three dimensional classes, which represent regional fire (10-50 µm), fire occurred at landscape/regional scale (50-125 µm), and local fire (>125 µm). Data are presented as concentration values (charcoals/g).

4. Results

4.1. Chronology

The relative scarcity of datable material did not allow for obtaining a very consistent chronological sequence for all available cores, except for the SAM9 core (Tab. 2). In addition, 5 dates have been rejected due to chronological inversion or exceptionally ancient age, most likely due to surface runoff processes. Available dates show a good chronological coherence, with an interval spanning from the Late Northgrippian (6210-6001 cal BP, SAM9-724b, Tab. 2) to the Late Meghalayan (231-124 cal BP, SAL3_260, Tab. 2). It is worth noting that dates obtained at the base of SAM9 (from SAM9_724a to SAM9_730b) also display a chronological inversion. However, the short distance that elapses from one dating to another (approx. 6

cm) and the smallness of the chronological gap make it possible to consider them all valid. Moreover, the age-depth model is based on 3 AMS 14C ages as reported in Tab. 2. It is used for all data from the SAM9 core presented in this study

4.2. Facies Analysis

The description of the sedimentary facies observed in all cores allowed the identification of 5 main sedimentary facies associations grouped into Alluvial facies (AF), Swamp-Marshy facies (SMF), and Lagoon-Brackish facies (LBF). Additionally, a series of cm-thick tephra layers have been recognised in SAL1 and SAL3 cores. They consist mainly of grey (7.5YR 6/1) fine- and medium-grained ash with common pyroclastic material made of irregular pumice fragments. However, the tephra layers resulted in being altered and weathered to varying degrees, making them unsuitable for chemical and microprobe analysis (Giaccio, B. personal comment).

4.2.1. Alluvial facies (AF)

AF1 – this facies consists of greyish brown (10YR 5/2) to brown (10YR 4/3) silts with fine-grained sands (Fig. 3abc). Locally, scarce fine gravels and occasional subangular cm-sized pebbles are present. The facies is massive and occasionally interbedded with few cm-thick (3-5 cm on average) fine-grained sand layers. The colour variation is due to the varying proportion of sands and silts. Fine rootlets are occasionally present, although neither organic matter nor charred material have been observed. Common redox Fe-Mn mm-sized nodules (0.2 mm on average), rare mottles, and abundant secondary carbonate precipitation in mm- to cm-sized (0.3 mm to 1.5 cm on average) nodules are present. Stratigraphy boundaries are mainly sharp and clear. The sedimentary features and architectural elements are consistent with distal partially- to well-drained or partially flooded floodplains under low-energy conditions, although the presence of gravel and pebbles indicates short-term high-energy events. The interbedded thin sandy layers suggest the occurrence of sand sheets or sand splays due to the nearby presence of channels. The presence of rootlets and the development of secondary carbonate and redox features point to weakly pedogenetic post-depositional modification, thus indicating rapid episodes of sub-aerial exposure under well-drained conditions.

AF2 – this facies consists of alternating cm-thick brown-greyish brown (7.5YR 4/3 to 10YR 5/2) to dark yellowish-brown (10YR 4/4) massive silty-sand facies with fine gravel and rare pebbles and dark brown (10YR 3/3) moderately laminated silty-clayey facies (Fig. 3b). Locally, the sandy to silty facies show fining- upward trend with sharp lower boundaries, locally erosive where the pebbles and gravels are present. Scarce redox Fe-Mn mm-sized nodules (0.2 mm on average) and common secondary carbonate precipitation in mm-sized (0.5 mm on average) nodules are also present. Locally, the sand bodies are red-coloured (2.5YR 7/3 to 2.5YR 5/6). Although no organic matter has been observed, scattered mm-sized (0.1 mm on average) charcoal fragments are present. The overall facies association reflects a channel-related deposit. The alternation between silty-sands and silty-clays facies is consistent with rhythmical depositional sub-environments related to natural levees. The gradual channel filling, with decreasing bedload energy, is attested by the fining-upward trends from gravel to sandy-silt to silty-clayey, whilst bodies with erosive lower boundaries are most probably related to channel migrations or crevasse channels within which the bedload was conveyed. Pedogenic features testify to a short-term subaerial exposure determined by the topographically elevated areas formed by the natural levees and crevasse splays.

AF3 – this facies is made of brown (7.5YR 4/3) coarse-grained sand with common fine- to coarse gravel and pebbles (Fig. 3c), the latter with smooth surfaces. The facies shows a local fining-upward trend, where pebbles are found above erosive lower boundaries. Locally, the succession is capped by 1 cm- thick dark brown (7.5YR 3/3) clayey-silt layers, with sharp or transitional boundaries when located at the top of the succession. The overall sedimentary features are typical features of fluvial-channel deposits. The sharp boundaries between sands and silty layers likely indicate an abrupt abandonment of the channel, whereas the gradual transitions may reflect a gradual filling of the channel.

4.2.2. Swamp – Marshy facies (SMF)

SMF1 – this facies consists of dark greenish-grey (5GY 4/1) to dark grey (7.5YR 4/1) massive clay and silty-clay, with local occurrence of cm-thick greyish brown (10YR 5/2) massive fine sand beds with abundant unidentifiable fine shell fragments at the base (Fig. 3d). Occasional mm-sized charcoal or charred fragments are also found. Concentrations of organic matter with very fine rootlets infrequently occur in a few cm-thick peaty layers with gradual lower

boundaries and clear upper boundaries, along with local reddish-yellow (7.5YR 6/8) mottles of Fe-Mn oxides. The overall facies indicates a very low-energy depositional environment consistent with swampy-marshy areas such as ponds or coastal lakes that were occasionally subjected to rapid sub-aerial processes, as indicated by Fe-Mn oxides mottles. The sporadic presence of organic matter and thin peaty layers suggests these as mostly non-vegetated or occasionally weakly vegetated environments, whilst sandy layers reflect occasional short high-energy ingression of river floods from adjacent fluvial channels.

4.2.3. Lagoon – Brackish facies (LBF)

LBF1 – this facies consists of monotonous greenish-grey (5GY 6/1) massive clay (Fig. 3e) with scattered rare marine shell fragments of *Cerastoderma*. Lower and upper boundaries are mostly gradual. The homogeneous sedimentary features and the overall absence of architectural elements suggest deposition from suspension under low-energy conditions. The light grey colour is possibly related to the almost absence of organic matter, whilst the presence of marine shell fragments is indicative of reworking by storms within shallow to deep lagoon or brackish environments partially connected to the open sea.

LBF2 – this facies consists of very dark grey (10YR 3/1) to very dark brown (10YR 2/2) massive silts with clay and very scarce sand, with abundant enrichment of fibrous organic matter, charred or poorly decomposed plant fragments (Fig. 3e). The distinctive sedimentological features indicate for this facies association a low-energy depositional setting, rich in wood vegetation, in which organic material was able to accumulate due to the decreasing energy. The overall facies is consistent with a marginal-shallow and well-vegetated lagoonal environment.

4.3. Micropalaeontological analyses

~~Micropalaeontological analyses were carried out on the cores and the most suitable sediments (clays to fine-grained sands).~~ Although ostracods were the most abundant group, dominating the total microfauna, their occurrence is scattered in SAL1 and SAL2 cores and in the SAM cores. SAL3 was totally barren. In general, all ~~the~~ ostracod species observed in the cores are referable to the OEGs euryhaline and freshwater to low brackish, whereas the marine component lacks completely. In SAL1 and SAL2, in the AF1, AF2 and AF3 facies, only the OEG freshwater occurs, with species typical of springs or waters connected to

springs (*Cypria ophtalmica*, *Ilyocypris bradyi*, *Herpetocypris brevicaudata*, *Prionocypris zenkeri*). In SAM1, SAM5, SAM6, SAM7 and SAM8, in the SMF1 facies, *Candona* gr. *neglecta*, *Pseudocandona* gr. *marchica* and *Limnocythere inopinata* occur, all species tolerating a wide range of environmental conditions. *Characeae* gyrogonites are also present in some samples, indicating relatively shallow depths and clear waters. The foraminifera observed were mostly displaced or reworked from older sediments.

In SAM9, ostracods are abundant and occur within the whole cored sedimentary sequence. A total of ~~7~~ ostracod species were identified: *Cyprideis torosa*, *Candona* gr. *neglecta*, *Heterocypris salina*, *Ilyocypris bradyi*, *Eucypris virens*, *Limnocythere inopinata*, *Cypridopsis vidua*. *C. torosa* only occurs with smooth shells. The ~~densities~~ of the identified ostracod species for each sample are shown in Fig. 4, together with the occurrence of the two foraminifera species *Ammonia tepida* and *Haynesina germanica*, diatoms, *Characeae*, fish remains and ephippia *Daphnia*-type. Through the correlation of all these proxies, four different zones were identified:

MZ1 (730-613cm; 5348-4198 BP) – the lowermost part of the core is characterised by the occurrence of *Cerastoderma* cockles, abundant *Cyprideis torosa*, and scattered occurrence of *Cypridopsis vidua* and charophyte gyrogonites. *Ammonia tepida* and *Haynesina germanica* are alternately represented.

MZ2 (590 -480cm; 3970-3115 BP) – *I. bradyi* and *E. virens* become the dominant species, followed by *C. torosa* and *C. vidua*. *A. tepida* and *H. germanica* are poorly represented except in the uppermost samples.

MZ3 (465-259 cm; 3075-2489 BP) – this is the most diversified interval, where all ostracod species are represented with ~~frequencies lowering~~ towards the top. Charophyte gyrogonites are abundant, and diatoms also occur. Ephippia *Daphnia*-type is observed only in the uppermost samples. At around 350 cm, *A. tepida* and *H. germanica* disappear.

MZ4 (239-52 cm; 2286-446 BP) – the uppermost zone is characterised by low ostracod ~~frequencies~~ (*L. inopinata*, *E. virens* and scarce *C. torosa*) and few reworked and displaced foraminifera. Fish remains (pharyngeal teeth of Cyprinids) are abundant.

421 4.4. Pollen analysis

422 Due to the scarcity and bad preservation of pollen grains in SAL2 and SAL3 cores, only
423 results from the 26 samples of SAM9 core are described. The mean pollen count per sample
424 is 253. A total of 76 terrestrial pollen taxa have been identified, including 33 arboreal, 43
425 herbaceous plants plus 13 taxa of water plants and NPPs. AP prevails only in the lowermost
426 two levels, up to 58 % of the total pollen sum. Pollen concentrations range from 1232 (at 196
427 cm – 1870 BP) to 59,193 (at 700 cm – 5050 BP) pollen grains/g. The percentage and
428 concentration values of selected taxa are shown in Fig. 5 and Fig. 6.

429 Four pollen assemblage zones (PAZ) are described from bottom to top. Pollen zonation is
430 based on CONISS cluster analysis and visual inspection.

431 4.4.1. PAZ 1 (720-619 cm; 5250-4260 BP)

432 At the bottom of the sequence AP values decrease from 58% to 26%. The total pollen
433 concentration reduces from 59,193 to 10,995 pollen grains/g. *Quercus robur* type (max. 20%)
434 and *Quercus cerris* type (max. 6 %) in association with *Ostrya/Carpinus orientalis* (max. 7%)
435 prevail between mesophilous taxa. ~~Mediterranean~~ vegetation is mainly dominated
436 by *Juniperus* (max. 12%) and *Quercus ilex* type (max. 8%). *Alnus* (max. 8%) ~~well~~ represents
437 riverine trees. Among herbs, Poaceae (max. 23%) and Amaranthaceae (max. 35%) prevail
438 with an opposite trend of decrease (former) and increase (latter). Cereals pollen is poorly
439 but significantly present (max. 2%) and is accompanied by pollen of *Plantago* undiff. (max.
440 4%), *P. lanceolata* type (max. 3%), *Urtica* (max. 5%). Charcoal concentrations of the 10-50 μm
441 dimensional class vary from 10,321 to 202 charcoals/g.

442 4.4.2. PAZ 2 (602-452 cm; 4090-3040 BP)

443 AP (max. 22%) progressively decreases, with a minimum of 2 % at 452 cm. All the arboreal
444 taxa, apart from *Abies* (max. 1 %) strongly reduce. *Olea* is absent, whereas *Juglans* (max. 1%)
445 appears in this zone at ca. 3210 years BP. Herbs are predominant and almost exclusively
446 dominated by Amaranthaceae (max. 90%), as also evidenced by concentration values where
447 the peak of Amaranthaceae (40,425 charcoals/g) correspond to the increase of total pollen
448 concentration at ca. 3040 BP. A special mention is due to *Urtica* (max. 8%), increasing
449 through the zone. The highest peak of charcoal concentration (19,815 charcoals/g) is
450 recorded at ca. 3210 BP when the >125 μm dimensional class is attested. The

overrepresentation of local halophilous non arboreal vegetation probably emphasizes the forest opening.

4.4.3. PAZ 3 (400-269 cm; 2900-2550 BP)

~~The~~ pollen zone shows important differences and is characterised by a low amount of AP (max. 30%). The total pollen concentration is still dominated by herbs (Amaranthaceae: 19,090 pollen grains/g at ca. 2740 BP). First a mesophilous vegetation, with *Quercus robur* type (max. 8%), *Quercus cerris* type (max. 4%), *Ostrya/Carpinus orientalis* (max. 3%), *Carpinus betulus* and *Fraxinus excelsior* type (max. 1% and 3%, respectively) is present and accompanied by ferns; then, freshwater riverine vegetation expands, first with a peak of *Typha angustifolia* type (max. 22%) and *Potamogeton* (max. 3%), then with riparian trees such as *Alnus* (max. 11%) and *Populus* (max. 1%). Worthy of mention is the presence of green algae (i.e. Zygnemataceae, max. 4% and *Botryococcus*, max. 3%) in the uppermost part of the zone. ~~The Mediterranean shrubland increases at the end of the zone~~ when the record shows a significant peak of *Juniperus* (max. 19%). Apart from Amaranthaceae (max. 74%), which continue to dominate all over this zone, Cyperaceae (max. 15%) and Liliaceae (max. 4%) are the main NAP taxa. At the same time, herbs from dry environments, such as Asteroideae (max. 10%), start to expand. Moreover, a two-folded expansion of *Gloeotrichia*, a Cyanobacteria genus, is recorded at ca. 2740 BP both in percentage (max 30 %) and concentration (12,666 NPP remains/g) values. Concentration values of charcoals are low (max. 1369 charcoals/g).

4.4.4. PAZ 4 (250-54 cm; 2400-470 BP)

AP oscillates from 0% to 23% in this uppermost pollen zone. Mediterranean taxa from shrublands increase (i.e. *Ephedra*, max. 6%; *Pistacia*, max. 5%; Ericaceae, max. 1%). *Olea* (max. 4%) also expands in this zone, seeming to correlate with the increase of *Juglans* (max. 2%). Cichorieae (max. 72%) from dry and pastured environments suddenly substitute Amaranthaceae (max. 14%) as predominant herbs and increase exponentially in this zone as clearly attested by concentration values (12,237 pollen grains/g in the uppermost level). The *Hordeum* group (max. 8%) increases among cereals, *Avena/Triticum* (max. 1%) and *Secale* (max. 1%) show their first appearance in the record. Weedy herbs are represented by *Centaurea* (max. 2%) whilst Apiaceae (max. 5%) and

Brassicaceae (max. 13%) also increase. The highest values of ferns (i.e. monolete spores, max. 14% and trilete spores, max. 6%), green algae (i.e. Zygnemataceae, max. 11% and *Botryococcus*, max. 7%), fungi (i.e. *Glomus*, max. 7%), and *Pseudoschizaea* (max. 8%) of the record are found. A significant peak of charcoal concentration (8369 charcoals/g) is attested at ca. 1460 BP when all the dimensional classes are represented.

5. Palaeoenvironmental reconstruction

The stratigraphic data from the new drilled cores of the "Capitanata" show the interplay between coarse-grained alluvial facies and silty-sandy swamp/marshy facies in controlling the evolution of the southern margin of the Salpi lagoon (Fig. 7), whilst lagoonal facies are only observed at the bottom of the sedimentary sequence of the SAM9 core (Fig. 7). On the one hand, one of the most striking features of the sedimentary sequence of the cores is the poor chronological resolution due to the average coarse grain size (silty sands to coarse sands), the general lack of organic matter, and the poor preservation of pollen grains. On the other hand, the sedimentary sequence of the SAM9 core has resulted in a reliable age-depth model, based on a set of consistent 14C dates. Thus, facies analysis, coupled with micropalaeontological and pollen data, indicates that the coastal lagoon in the area of the "Capitanata" gradually shifted from a transitional marine-brackish environment into a more sheltered environment, influenced by freshwater inputs, leading to the complete emersion due to the alluvial plain progradation. This regressive sequence is commonly recorded in many Mediterranean coastal plains (Lakhdar et al., 2004; Sacchi et al., 2014; Carmona et al., 2016; López-Belzunce et al., 2020).

5.1. Late Northgrippian (5.2 ka–4.2 ka BP)

Between ca. 6.2 ka and 3.1 ka cal BP, sedimentary facies from the SAM9 core indicate that the southern portion of coastal plain was occupied by a semi-open coastal lagoon that was partially connected to the sea. The dominance of the euryhaline species *C. torosa,* which has a wide tolerance to hydrological changes such as temperature and salinity, confirms the occurrence of a lagoonal environment, whilst the occurrence of the foraminifera *A. tepida* and *H. germanica* points to an aquatic environment characterised by fluctuating temperatures and food sources (Fig. 8, Lintner et al., 2020). The lack of chronology for the inner areas of the coastal plain (cores SAL1, SAL2 and SAM1) prevents further hypotheses.

511 However, the presence of four tephra layers within the floodplain environments in the SAL1
512 core (Fig. 7), although too altered to be identified, could be ascribed between the fallout
513 phase of the Plinian 3.7 ka BP Avellino eruption of Vesuvius and the AP3 phreato-Plinian
514 2.8 ka BP Somma-Vesuvius eruption (Andronico and Cioni, 2002; Calanchi and Dinelli,
515 2008; Santacroce et al., 2008), as also demonstrated by Caldara and Simone (2005) in the
516 Tavoliere coastal plain. If such is the case, these tephra layers could be considered as
517 a *terminus ante-quem* for the progradation of floodplain environments in the innermost area
518 of the coastal plain. In fact, considering the stratigraphic depth at which the lagoonal
519 environments are observed, Fig. 7 clearly shows that the innermost part of the coastal area
520 was already deactivated and characterised by floodplain environments (SAL1 core) and
521 marshlands (cores SAL2 and SAM1). The emergence of these environments was likely the
522 result of the distribution of the sedimentary load from the former palaeodrainage of the
523 Carapelle River prior to the anthropic drainage regulation, which bypassed the threshold of
524 the Upper Pleistocene alluvial deposit (Fig. 9a).

525 The dominance of alluvial environments is also observed in cores SAM4 and SAL3 (Fig. 7),
526 collected close to the archaeological site of *Salapia–Salpi* and at the top of the Upper
527 Pleistocene alluvial deposits. Thus, these cores confirm that this part of the coastal plain was
528 already stable and not affected by lagoonal or marshland environments during the
529 Holocene.

530 The vegetation of the lagoon also testifies to the widespread presence of freshwater
531 elements. In fact, among the riparian trees, *Alnus* (alder) shows high values from the
532 sequence bottom to ca. 4200 cal BP. Poaceae pollen could refer to *Phragmites* (reeds),
533 although this family also includes grasses of dry meadows, whose distribution in the
534 surrounding drylands is evidenced by pollen of *Plantago lanceolata* type (ribwort plantain,
535 Fig. 6). Other species of *Plantago* are halophytes, associated with brackish environments, as
536 attested today in the Apulian region (Marchiori et al., 1998). However, from 4.8 ka BP the
537 pollen concentrations drop, whilst halophytic herbs (Amaranthaceae) exponentially
538 expanded (Fig. 8). The growth of saltmarsh vegetation indicates an increase in salinity,
539 possibly related to the progressive shallowing of waters and closure of the lagoon.

540 At around 5 ka cal BP and 4.1 ka cal BP (Fig. 5), the palynological record shows two peaks
541 of pollen of the pioneer shrubs *Juniperus* (juniper), indicating the formation of sand barriers

seaward. This differs from the circumstances in the Lago Salso, in which an increase of *Juniperus* is only evident at ~4 ka BP (Di Rita et al., 2011). Thus, this evidence confirms the northward progradation of the dune coastal barriers and the progressive closure of the southern portion of the lagoon, in contrast to the picture painted by Caldara and Simone (2005) and Di Rita et al. (2011) in the northern sector, who report that the lagoon was open to the sea (Hydrobiidae spp. and *Cerastoderma* lagoon) between 6.3 ka and 3.2 ka cal BP. The overall evidence is consistent with the marine direction of sediment transport reconstructed by De Santis and Caldara (2015) and De Santis et al. (2020) before the Holocene climatic transition (5.5 ka–4.5 ka cal BP). The anticyclonic gyre is also responsible for the distribution of Ofanto River sediments toward north and northwest and into the central area of the Gulf of Manfredonia (Spagnoli et al., 2008). The gradual development of sand barriers favoured the progressive isolation of the brackish water body with consequent silting and evaporation if freshwater inputs do not overprint the RSL signal. This led to considerable shallowing and silting of the semi-enclosed lagoons compared to the open lagoons. The depth of these lagoons seldom exceeds a few decimetres (Ruiz et al., 2006). In the micropalaeontological assemblage of the SAM9 core, this corresponds to the first clear inputs of freshwater fauna (*I. bradyi* and *E. virens*) and the first disappearance of foraminifera (Figs. 4, 8).

Arboreal pollen of mesophilous taxa possibly refers to a relict plain forest, growing in the coastal humid area and dominated by oaks tolerant of wet soils (*Quercus robur* L.). A deciduous oak forest associated with thermophilous elements, such as *Quercus ilex* (evergreen oak), *Ostrya carpinifolia* and/or *Carpinus orientalis* (hornbeams), and *Fraxinus ornus* (manna ash), also covered the study area up to the slopes of the southern Apennines, bordering the "Capitanata" to the west. The co-occurrence of deciduous trees with thermo-xerophilous species from different bioclimatic zones is typical of the Apulian woodlands (Russo and Strizzi, 2013). Moreover, evergreen oaks could have been part of the xerophilous vegetation, such as the Mediterranean *maquis* formations of *Quercus*, *Olea* (olive), *Pistacia* (pistachio), and Ericaceae (heather). These vegetation types characterised the Apulia region (Lago Battaglia - Caroli and Caldara, 2007; Lago Salso - Di Rita et al., 2011; Lago Alimini Piccolo - Di Rita and Magri, 2009), as well as other contemporary coastal areas in Sicily (Noti et al., 2009; Tinner et al., 2009) and along the Tyrrhenian coast (Di Donato et

al., 2008; Sadori et al., 2010; Bellotti et al., 2016; Russo Ermolli et al., 2018; Sadori et al., 2016; Di Rita et al., 2018a; 2018b; Vignola et al., 2022). Among mountain taxa recognised in the SAM9 core (Fig. 5), *Fagus* (beech) sparse pollen grains are likely from the Gargano Promontory, where this broadleaved tree forms a dense forest below its common altitudinal belt (Hoffmann, 1961).

Of note is also the sparse presence of *Abies* (fir) pollen from ca. 5 ka cal BP to 3.1 ka cal BP. The silver fir (*A. alba* Mill.) is tolerant to dry conditions and is still recorded in the mountains of the Calabria region (South Italy) and even along the Tyrrhenian coasts of Northern and Central Italy during the early-mid Holocene (Colombaroli et al., 2007, 2008; Bellini et al., 2009). As the potential spatial range of *A. alba* also include the northern part of Apulia (Tinner et al., 2013), the occurrence of this conifer in the Salpi lagoon cannot be excluded. In this context, the role of the Gargano Promontory as a post-glacial refugium for altitudinal trees (beech and fir) can be hypothesised. Another possibility is the transport of *Abies* pollen from the southern Apennines, where it was abundant until ca. 3 ka BP (Allen et al., 2002; Joannin et al., 2012). The other mountain trees occur only sporadically and probably originated from a greater distance, both from the Italian Apennines (e.g. *Betula*; see the pollen record of Lago Grande di Monticchio, Allen et al., 2002) and exceptionally from the Balkans (e.g. *Picea* which is not present in Southern Italy; see the pollen record of Lake Shkodra, Albania, Sadori et al., 2015). This evidence and interpretation is confirmed by their occurrence even in the palynological sequence of Lago Alimini Piccolo (Di Rita and Magri, 2009).

Pinus pollen is not abundant in the SAM9 core record, suggesting that pinewoods were not widespread in the Tavoliere plain, but were restricted to the northern side of the Gargano Promontory (Lago Battaglia - Caroli and Caldara, 2007).

Towards the end of the Northgrippian (4.2 ka BP), AP percentage and concentration values abruptly decrease, whilst NAP percentage increases (Figs. 5, 6). This indicates a decline in forest cover. As anthropogenic pollen indicators are scant (Fig. 5), such deforestation is interpreted as a regional event, most probably caused by the arid conditions that the Mediterranean basin experienced at around 4.2 ka BP (Bini et al., 2019; Di Rita and Magri, 2019; Di Rita et al., 2022). A similar decline in broadleaved vegetation, accompanied by an opening of the landscape, is attested throughout Apulia before 4 ka BP (Caroli and Caldara,

2007; Di Rita and Magri, 2009). It is possible that this climatic episode contributed to the further lowering of the water table in the southern sector of the Salpi lagoon, paving the way to the colonisation of halophytic herbs during the Early Meghalayan.

5.2. Early Meghalayan (4.2 ka–2.4 ka BP)

During the early phases of the Meghalayan (Fig. 9b), facies analysis in the SAM9 core shows the closure of the lagoon and the formation of a marsh environment (Fig. 7), indicating a reduction in the water table, the steady-progressive retreat of the lagoon, as well as a decrease in salinity. These conditions reflect the aforementioned continuous development of the beach barrier, prograding up to the northern sector of the Salpi lagoon during the 4.2 ka BP dry climatic event (Di Rita et al., 2011). The dunes most likely isolated the back-coastal areas and promoted the formation of marshy wetlands, especially in the inner sector of the coastal plain. Conversely, floodplain progradation can be observed in the innermost part of the coastal plain, as shown by cores SAL2 and SAM1 (Fig. 7). Conversely, the fauna of the cores from Coppa Nevigata (Caldara et al. 2003, Caldara and Simone, 2005) display a strong marine influence, both in the foraminifera (*A. beccari*, *H. germanica*, *Porosonion granosum*, *Elphidium oceanensis*, *Rosalina bradyi* and *R. floridensis*), as well as among the ostracoda (*C. torosa*, *Loxoconcha elliptica*, *Leptocythere* spp., *Propontocypris pirifera*) and the molluscs (*Cerastoderma glaucum*, *Abra segmentum*, *Ciclope nerite*, *Loripes lacteus*). Caldara and Simone (2005) identified a lagoonal environment (Hydrobiidae spp. and *Cerastoderma* lagoon) that spans from 3.6 ka BP to 2.8 ka BP, thus indicating open marine lagoon conditions in the northern area of the coastal plain.

The freshwater input is clearly recorded by the ostracod assemblage of SAM9 core (Fig. 8). Indeed, the relevant OEG is freshwater. ~~The dominant species, *I. bradyi* and *H. salina*, indicate low-energy waters and a maximum salinity of 4-5‰.~~ The periodic increase in ostracod freshwater species during this time span is alternated with peaks of Amaranthaceae (in both pollen percentage and pollen concentration; Figs. 5, 6), indicating that halophytic vegetation continued to dominate such patchy shallow-water environments (Fig. 8). As at the same time the AP concentration values tend to be nought (Fig. 6), it can be argued that the SAM9 core records indicate an open landscape with an over-representation of local halophytes, probably due to increasing aridity and the definitive replacement of the former plain forest with a saltmarsh.

635 The rapid expansion of saltmarsh herbs, combined with water level changes and fostered
636 by the climatic exacerbation at the early stages of the Meghalayan, is a regional event
637 recorded in the Salpi lagoon and surrounding areas (Caroli and Caldara, 2007; Di Rita et al.,
638 2011; Di Rita, 2013). These data confirm the onset of drier climatic conditions along the
639 Apulian coast during the 4th millennium BP, although palaeoclimatic records from the
640 Adriatic Sea points out rapid fluctuations (Piva et al., 2008; Siani et al., 2013).

641 Arboreal pollen from the SAM9 core reveals that the woodland in the study area did not
642 recover after the opening at 4.2 ka BP, unlike at Coppa Nevigata (Caldara et al., 2003) and
643 in other part of Southern Italy (Noti et al., 2009; Tinner et al., 2009; Calò et al., 2012; Di Rita
644 et al., 2018b), where an increase of evergreen taxa is recorded. In the southern part of the
645 Salpi lagoon, the mixed deciduous and evergreen oak forest was replaced by an almost
646 treeless open landscape with scattered Mediterranean shrubs and trees (*Pistacia*, *Quercus ilex*
647 type; Fig. 5), which persisted up to the present (see also concentration values in Fig. 6). This
648 was most probably due to continuous human activities from the Bronze Age onwards,
649 affecting a transitional environment under semi-arid conditions. Indeed, during this period,
650 archaeological records show a strong intensification of settling, when many sites are
651 documented along the Northern Adriatic coast and at key inland locations (Cazzella et al.,
652 2017). The high frequency of fires, evidenced by the peaks of charcoal concentration (Fig. 6),
653 could have been favoured by the climatic change, although an anthropogenic source cannot
654 be ruled out. In fact, concomitantly to the largest class of charcoal fragments, the presence
655 of pollen of ruderal plants (nitrophilous *Urtica*, up to 8%; Fig. 5) testifies to an anthropogenic
656 environment, thus confirming the human frequentation of the lagoon during the Bronze
657 Age. However, in the absence of the primary anthropogenic pollen indicators (i.e. cereals,
658 *Olea*), it is possible that the marshland was not cultivated. An exception is the pollen of
659 *Juglans* (walnut), whose occurrence in pollen sequences of Southern Italy starting around
660 2.7 ka BP has been interpreted as an indication of the widespread use of walnut in Greek
661 and Roman times (Sadori, 2013). The earlier attestation in the SAM9 core (ca. 3 ka BP, Fig.
662 5) is noteworthy, although the presence of walnut in pollen samples from other Apulian
663 areas dated to 6 ka BP onwards (Di Rita and Magri, 2009; Di Rita et al., 2011) argue for
664 Mediterranean populations growing in glacial refugia (Pollegioni et al., 2017).

Between 3.2 ka and 2.4 ka BP, the age-depth model of the SAM9 core testifies to a higher sedimentation rate (Fig. 8). This increase could be attributed to a) cold climate phases occurring at 3.5 ka–3.2 ka BP and 2.6 ka–2.3 ka BP (Orombelli and Pelfini, 1985; Haas et al., 1998), also recognised in the Adriatic Sea and the Aegean Sea as the most recent Adriatic cooling event (Sangiorgi et al., 2003) or b) anthropic deforestation and short-term hydrological changes due to enhanced runoff processes. Regardless of the natural- or human-induced cause, the sedimentary accretion in alluvial plains appears to overwhelm the rate of relative sea-level rise, forcing lagoonal and brackish environments to a freshening of water due to a surplus of sediment supply (Nichols, 1989).

Caldara and Simone (2005) found many preserved organic materials in the sediment core closest to the archaeological site of Coppa Nevigata, dated to before 3 ka BP and interpreted as product of a rapid sediment accumulation caused by wash over. On the other hand, Caldara et al (2003) identified a sedimentation gap between 3.110±50 and 370±50 BP, related to arid phases and aquifer depletion. Pollen data of Lago Battaglia also testifies to the increased sediment deposition and the spread of Cyperaceae at the expense of halophytic vegetation during this period (Caroli and Caldara, 2007).

At around 2.8 ka BP, a spike of *C. torosa* marks a clear increase in salinity, which is confirmed by the occurrence of *A. tepida* and *H. germanica* (Fig. 8). Conversely, grain size analysis highlights a stable silty/clay ratio, pointing to overbank deposits possibly remobilised in the lagoonal environment due increased sediment inflow from the Carapelle River (Fig. 4). At the same time, pollen grains from hygrophilous herbs and riparian-emergent macrophytes (i.e. Cyperaceae and *Typha angustifolia* type) periodically increase. In addition, the cyanobacterium *Gloeotrichia* colonised the marsh environments to a fluctuating extent, as clearly indicated by the concentration peak at ca. 2.7 ka BP (Fig. 8). This filamentous cyanobacterium contributes to nutrient-poor eutrophication of lakes by transferring phosphates into the water (Stevenson, 1996; Kornijów et al., 2016). Thus, the increase in salinity is linked to evaporation processes and water shallowing under dry climate conditions, which have also contributed to the waves of expansion of Amaranthaceae.

The virtual disappearance of *Fagus* from the record after ca. 2.8 ka BP (only one pollen grain came from the sample dated to ca. 2190 BP) indicate the reduction of the Gargano beech forest due to the onset of drier conditions through the Meghalayan. This evidence is

confirmed by pollen data from the northern side of the Gargano Promontory (Caroli and Caldara, 2007). The same trend is seen in the *Abies* curve, whose last attestation is dated to ca. 3090 BP (Fig. 5). Since the decline of *Abies* in Lago Grande di Monticchio occurs simultaneously (Allen et al., 2002), it is probably a combination of climate change and human exploitation.

Archaeologically, during the Iron Age, the Tavoliere coastal plain experienced the emergence of new centres (Figg. 8, 9b). The settlement of *Cupola-Beccarini* (*Daunian Sipontum*) is attested from the 7th cent. BCE, whilst *Salpia Vetus* developed in the 10th cent. BCE. The latter was hypothesised to be surrounded by brackish waters (Lippolis and Giammatteo, 2008) and benefited from a favourable position, surrounded and protected by water to the north, whilst defended to the south by a bank with a ditch, built between the 7th and the 6th cent. BCE. Moreover, in his description of coastal Daunia (Northern Apulia), the Greek geographer Strabo pointed out that *Salpia* was located near a navigable river, most probably the Carapelle River, and a "*stomalimne megale*" (roughly translated as "big estuary") through which the grain was traded seaward from other areas of the coastal plain. Thus, this description may be a reference to a connection between the Carapelle River and the coastal lagoon.

5.3. Late Meghalayan (2.4 ka–0.2 ka BP)

During the last part of the Holocene, facies analysis of the SAM9 core shows that wetlands had already developed into floodplain environments (Fig. 7). However, in the SAM8 core, drilled a few metres away from the SAM9 core, the persistence of marshlands indicate that the area continued to be affected by seasonal flooding. The latter were most probably influenced by the migration of the Carapelle River within the coastal plain. In fact, Caldara et al. (2002) reported that the lagoon experienced a sudden increase in turbidity of the main inflowing rivers, particularly from the Carapelle River, which resulted in the separation of the Salpi lagoon into two minor basins (Fig. 9c), lately named Lago Salso (north) and Lago Salpi (south). The development of a floodplain is well recorded by the ostracod assemblage, where the euryhaline taxa disappear, and *L. inopinata* and *E. virens* occur (Fig. 8). These species are common in shallow waters, including temporary ponds, swamps, lakes, and rivers, with a salinity tolerance of 9‰ and 5‰ respectively (Meisch, 2000). The occurrence of ephippia *Daphnia*-type and abundant pharyngeal teeth of Cyprinids are recorded in the

SAM9 core as well as in the upper part of the SAL2 core, where *C. ophtalmica*, *I. bradyi*, *H. brevicaudata* and *P. zenkeri* also occur. This assemblage describes shallow, low-energy waters rich in aquatic vegetation, as attested also in the pollen data by the increase of *Typha angustifolia* type, *Typha latifolia* type and ferns (Fig. 5).

Pollen data from SAM9 core confirms a patchy scenario (Fig. 8). Amaranthaceae declined abruptly as riverine inputs and shallower waters were accompanied by a decrease in salinity, fostering the growth of macrophytes, ferns, and green algae living in shallow waters (Fig. 8). At the same time, new areas were colonised by herbs from the open landscape tolerant to xeric conditions. In addition, NPPs such as *Glomus*, a mycorrhizal fungus, and *Pseudoschizaea* testify to the increase in erosional processes on the drylands due to the combination of semi-arid climate conditions, deforestation, and human pressure already postulated since the beginning of the Meghalayan (Fig. 8). These factors acted on a regional scale, as a similar change in the palaeoenvironment (i.e. the expansion of aquatic and dryland taxa) can also be traced in the record of Lago Battaglia during the same period (Caroli and Caldara, 2007). In this regard, anthropogenic pollen indicators in the SAM9 core show that local communities benefited from this landscape change. Since ca. 2350 BP (4th cent. BCE), the inland was exploited for pastoral activities, as indicated mainly by pollen of Cichorieae (the chicory family) among xeric vegetation, which includes nitrophilous herbs resistant to animal trampling (Florenzano, 2019). Asteroideae, Poaceae, and *Plantago*, whose pollen grains are strongly present in the upper part of the core, are also indicators of pasturelands (Behre, 1981), bolstering support for 5th-4th cent. BCE (2450-2350 BP) breeding in Daunia revealed by the archaeological record (Buglione et al. 2016).

The slight increase in *Olea* pollen at ca. 2.4 ka BP (4th cent. BCE) could be linked to the expansion of olive groves inland. Although olive is a natural component of the Mediterranean *maquis*, the overall scarcity of this taxon in the previous levels suggests that its occurrence coincides with human exploitation of the area. The only occurrence of *Castanea* (chestnut) pollen (1%) at ca. 2190 BP (half 3rd cent. BCE) is noteworthy, since this plant, together with walnut, was frequently spread by humans across the Italian peninsula since ca. 2700 BP (Mercuri et al., 2013). Apiaceae (the carrot family) and Brassicaceae (the cabbage family), whose pollen reaches significant values during this period, could also represent cultivated herbs. In fact, they include plants poorly represented in natural pollen

deposits due to their entomophilous pollination, but have a crucial economic value as vegetable-garden and aromatic species. In particular, cabbages have been known as one of the most common vegetables in Southern Italy since pre-Roman times (Russo Ermolli et al., 2014; Vignola et al., 2022). Cereal pollen is absent during this period, although pollen grains of weedy plants such as *Centaurea* are attested since ca. 2900 BP (half 10th cent. BCE, Fig. 5). The evidence of human exploitation as highlighted by SAM9 core pollen recorded before the Roman occupation is consistent with other palaeoenvironmental and historical data for the region.

Evidence of local cereal cultivation (e.g. *Hordeum* group: 8%; Fig. 5) in the SAM9 core starts around 1850 BP during the Roman period. Since cereals are very low-pollen producers, it is possible that fields reached the former wetland. *Olea* disappears, while Cichorieae and Brassicaceae increase strongly (Fig. 5). These data indicate a highly anthropogenic landscape of pastures, cultivated fields, and vegetable gardens, typical of Roman agriculture (Vignola et al., 2022). From ca. 1460 BP (end of 5th cent. CE, Late Antiquity), cereal pollen (*Avena*/*Triticum*, *Hordeum* group, *Secale*; Fig. 5) occurs along with walnut and olive, although the latter does not reach a significant amount (3%, Fig. 5). Because of a low percentage in the upper part of the SAM9 core, the presence of *Olea* and other natural components of Mediterranean *maquis* (i.e. *Pistacia*, *Ephedra*, Ericaceae, Fig. 5) could be related to the progressive expansion of shrublands due to continuous woodland clearance. The fact that such vegetation development could be both natural- and human-induced is confirmed by the exponential increase in percentage and concentration values of Cichorieae up to the Middle Ages (Figs. 5, 6). The peak of charcoal concentration at ca. 1460 BP seems to confirm the intensification of anthropic fires, as demonstrated in the southwestern portion of the Tavoliere Plain (Heim, 1995; Marchesini et al., 1995; Caracuta and Fiorentino, 2009). On the other hand, the area of Lago Alimini Piccolo experienced a more intensive exploitation of olive trees from the 6th century CE (1450-1350 BP) up to the present-day (Di Rita and Magri, 2009).

The conditions of the coastal plain appear to be stable throughout the Roman period onwards. Nevertheless, a deep transformation of the settlement strategies took place between the 1st and 2nd cent. CE (2050-2150 BP). Vitruvius reports that the area surrounding *Salpia Vetus* became insalubrious and unhealthy. For this reason, the

789 population selected a new location for this city -Roman *Salapia* -adjacent to the southern half
790 of the lagoon system, in a more elevated area, and thus potentially protected from malaria
791 breeding. Historical data, however, does not correspond with that of the pollen. Evidence
792 of cereal cultivation is attested in the SAM9 core proximate to the pre-Roman city until ca.
793 780 BP (1170 CE, Fig. 5) signalling continued agricultural exploitation in this zone rather
794 than a complete takeover by unhealthy, marsh-like conditions. The reconstruction is even
795 more complex when considering sedimentological data from the other drillings. In fact, the
796 SAM5 and SAM6 cores indicate that eastward of the re-founded city of Medieval *Salpi*, the
797 area was dominated by marshes from the 3rd cent. CE (1640-1539 cal BP) until the 16th cent.
798 CE (476-312 cal BP), a trend which perhaps can be traced back to the founding of the Roman
799 town in the 1st cent. BCE. These are hardly the "ideal" conditions expected for a new town
800 supposedly fleeing an unhealthy marsh, if the perspective on marshes is wholly negative.
801 Rather, a more nuanced understanding of the benefits of life adjacent to a marsh must be
802 considered for the inhabitants of Roman *Salapia*, as do the ways the settlements was
803 positioned in and negotiated with the surrounding environment. In fact, the western part
804 of the city was characterised by floodplains, as shown by SAL3 and SAM4 cores, a
805 distinction in elevation that would have produced the kind of drainage possibilities that
806 Vitruvius advocates for in marshy areas, perhaps indication of more healthful conditions
807 than those found contemporaneously at *Salpia Vetus*.

808 **6. Conclusions**

809 The ~~high-resolution~~ palaeoenvironmental analyses, coupled with archaeological and
810 historical data, provides for the first time new insights regarding the evolution of the
811 southern margin of the Salpi lagoon. In particular, it has enabled outlining and refining the
812 understanding of its evolution from the Late Northgrippian up to the last part of the
813 Meghalayan. Until now, the bulk of knowledge of the processes involved in the evolution
814 of the Tavoliere coastal plain was focused on the northern part of the coastal plain, whilst
815 the southern margin remained poorly investigated.

816 As a result of this research, several conclusions can be drawn, as follows:

817 – ~~Drilling~~ data from the southern margin of the Tavoliere coastal plain show a general
818 regressive trend of the Salpi lagoon, indicated by a vertical stacking of swamp and

alluvial deposits over lagoonal facies. This highlights the progressive reduction of the lagoon, and the seaward progradation of swampy and floodplain environments up to the definitive emersion of most of the landscape.

- Stratigraphic analysis of the cores, coupled with ostracod analyses and radiocarbon calibrated ages, allowed a detailed reconstruction of the facies association and the identification of the three main palaeoenvironmental changes from the onset of the regression of the lagoon to the last phase of the Meghalayan. The lagoon was partially connected to the sea between 5.5 ka and 4.2 ka BP (Late Northgrippian). Between 4.2 ka and 2.4 ka BP (Early Meghalayan), the development of marshes and swamps with restricted brackish lagoon conditions and permanent freshwater input is recorded, possibly a consequence of increased river influx and continuous development of the dune barrier. Between 2.4 ka BP to present, the continuous freshwater influx from the Carapelle River caused the rapid progradation of the floodplain into the coastal plain and the closure of the lagoon, with the formation of the two coastal lakes of Lago Salso (north) and Lago Salpi (south).

- Pollen data confirm the palaeoenvironmental evolution of the lagoon, with the expansion of halophytic herbs under local brackish conditions during the Early Meghalayan and the exponential spread of herbs from drylands in correspondence with the closure of the basin. The emersion of the land during the last phase enabled the intensive exploitation of the area and the establishment of a highly anthropogenic landscape, consisting mainly of pastures and cultivated fields from the Roman period onwards. At a regional scale, the forest cover gradually decreased due to an aridification trend, documented in Apulia since 4.2 ka BP, whilst the enhanced human activities contributed to a deforestation process from the Hellenistic period to the Middle Ages.

- The comparison between the cores on the southern margin of the Salpi lagoon and the archaeological areas of Coppa Nevigata indicates an asynchronous evolution of the lagoonal facies, linked to the different development of the sand barriers and the different inputs of the main rivers crossing the "Capitanata" plain, in particular the Carapelle River and Candelaro River.

- Although the sedimentological, chronological and micropalaeontological data do not

provide detailed reconstruction of the major phases of floodplain progradation or retreat that may have occurred from Roman to Medieval times, it is assumed that coastal lakes and marshlands have survived before the extensive land reclamation project that took place at the beginning of the 20th cent. CE. Such environmental conditions were the main cause which triggered the decision of the inhabitants of *Salpia Vetus* to establish the settlement of *Salapia*. This newly occupied sector of the coastal plain was far from the influence of the Carapelle River and closer to the sea, therefore potentially protected from malaria breeding.

Author contributions

Davide Susini: Facies analysis, Images, Tables, Writing-Original draft preparation; **Cristiano Vignola**: Pollen analysis, Images, Writing-Reviewing; **Roberto Goffredo**: Project co-director; Archaeological background, Writing-Reviewing; **Darian Marie Totten**: Project co-director, Archaeological background, Writing-Reviewing; **Alessia Masi**: Pollen analysis, Images, Writing-Reviewing; **Alessandra Smedile**: Foraminifera analysis, Images, Writing-Reviewing; **Paolo Marco De Martini**: Coring, Facies analysis; **Francesca Romana Cinti**: Facies analysis, Writing-Reviewing; **Laura Sadori**: Writing-Reviewing; **Luca Forti**: Coring, Grain size analysis; **Girolamo Fiorentino**: Archaeological background, Writing-Reviewing; **Andrea Sposato**: Coring, Grain size analysis, Facies analysis; **Ilaria Mazzini**: Ostracods analysis, Images, Writing-Reviewing.

All authors were involved in the discussion and approved the final version of the manuscript.

Data availability

Remote images, and digital models used for the basemaps in Figures 1, 2, and 9 are free-downloaded from the SIT portal of the Apulia region (http://www.sit.puglia.it/portal/sit_portal). The geomorphological features in Figures 1 and 9 were digitally mapped in ArcGIS© environment and modified from the Geological Survey of Italy for the Geological Map of Italy at the scale 1:50.000, CARG Project (https://www.isprambiente.gov.it/Media/carg/index.html), and the Geological map of Italy at the scale 1:100.000

878 (https://www.isprambiente.gov.it/en/services/cartography/geological-and-
879 geothematic-maps/geological-map-at-a-scale-1-to-100000).

880 **Declaration of competing interest**

881 The authors declare that they have no known competing financial interests or personal
882 relationships that could have appeared to influence the work reported in this paper.

883 **Acknowledgements**

884 This research has been funded by The National Endowment for the Humanities: Democracy
885 demands wisdom (USA), Collaborative Grant program (grant number RZ-249965-16),
886 awarded for the term 2017–2020, to the Life on the Lagoon: Reconstructing the Biography
887 of Human-Landscape Dynamics on the Salpi Lagoon, Italy project, co-directed by R.
888 Goffredo and D.M. Totten. Any views, findings, conclusions, or recommendations
889 expressed in this article do not necessarily represent those of the National Endowment for
890 the Humanities. The 2017 coring campaign has been performed by the SONDAG srl under
891 the supervision of dr. Giorgio de Giorgio. We thank Francesco Versino for his precious work
892 on processing the samples from the cores.

893 **References**

894 Allen, J.R.M, Watts, W.A, McGee, E, Huntley, B., 2002. Holocene environmental
895 variability—the record from Lago Grande di Monticchio, Italy. Quaternary
896 International 88, 69–80. https://doi.org/10.1016/S1040-6182(01)00074-X

897 Amorosi, A., Bini, M., Giacomelli, S., Pappalardo, M., Ribecai, C., Rossi, V., Sammartino, I.,
898 Sarti, G., 2013. Middle to late Holocene environmental evolution of the Pisa coastal
899 plain (Tuscany, Italy) and early human settlements. Quaternary International 303, 93–
900 106. https://doi.org/10.1016/j.quaint.2013.03.030

901 Andersen, S.T., 1979. Identification of wild grass and cereal pollen [fossil pollen, Annulus
902 diameter, surface sculpturing]. Danmarks Geologiske Undersoegelse (Denmark),
903 Aarbog.

904 Andronico, D., Cioni, R., 2002. Contrasting styles of Mount Visuvius activity in the period
905 between the Avellino and Pompeii Plinian eruptions, and some implications for

906 assessment of future hazards. Bulletin of Volcanology 64, 372–391.
907 https://doi.org/10.1007/s00445-002-0215-4

908 Barker, G., Biagi, P., Castelletti, L., Cremaschi, M., Nisbet, R., 1987. Sussistenza, economia
909 ed ambiente nel neolitico dell'Italia settentrionale. Atti della XXVI Riunione Scientifica
910 dell'IIPP, Firenze, pp. 103–118.

911 Battista, C., Caldara, M., Pennetta, L., Zito, G.M., 1993. Analisi dell'aridità del clima nel
912 Tavoliere di Puglia. Bonifica 8, 67–72.

913 Battista, C., Caldara, M., Pennetta, L., Zito, G.M., 1994. Evoluzione del lago di Salpi fra
914 clima e interventi antropici. In: Piccione, V., Antonelli, C., Guerrini, C. (eds.), Atti III
915 Workshop Del Progetto Strategico: Clima Ambiente e Territorio, Potenza, 1990, Vol.2.
916 Italian National Research Council, Rome, pp. 155–178.

917 Behre, K.E., 1981. The interpretation of anthropogenic indicators in pollen diagrams.
918 Pollen Spores 23, 225–245.

919 Bellini, C., Mariotti-Lippi, M., Montanari, C., 2009. The Holocene landscape history of the
920 NW Italian coasts. The Holocene 19, 11611172.
921 https://doi.org/10.1177/0959683609345077

922 Berglund, B.E., Ralska-Jasiewiczowa, M., 1986. Pollen analysis and pollen diagrams. In:
923 Berglund, B.E. (ed.), Handbook of Holocene Palaeoecology and Palaeohydrology. John
924 Wiley & Sons, Chichester, pp. 455–496.

925 Beug, H.-J., 2004. Leitfaden der Pollenbestimmung. Pfeil, München.

926 Bini, M., Zanchetta, G., Perşoiu, A., Cartier, R., Català, A., Cacho, I., et al., 2019. The
927 4.2 ka BP Event in the Mediterranean region: an overview. Climate of the Past 15, 555–
928 577. https://doi.org/10.5194/cp-15-555-2019

929 Biscotti, N., 2001. I valori botanici del Gargano. Informatore Botanico Italiano 33, 289–291.

930 Boenzi, F., Caldara, M., Moresi, M., Pennetta, L., 2001. History of the Salpi lagoon-sabhka
931 (Manfredonia Gulf, Italy). Il Quaternario 14, 93–104.

932 Boenzi, F., Caldara, M., Pennetta, L., 1991. Osservazioni stratigrafiche e geomorfologiche
933 nel tratto meridionale della piana costiera del Tavoliere di Puglia. Geografia Fisica e
934 Dinamica Quaternaria 14, 23–31.

935 Boenzi, F., Caldara, M., Pennetta, L., Simone, O., 2006. Environmental Aspects Related to
936 the Physical Evolution of Some Wetlands Along the Adriatic Coast of Apulia
937 (Southern Italy): a Review. Journal of Coastal Research 1, 170–175.

938 Bronk Ramsey, C., 2009. Bayesian Analysis of Radiocarbon Dates. Radiocarbon 51, 337–
939 360. https://doi.org/10.1017/S0033822200033865

940 Buffardi, C., Barbato, R., Vigliotti, M., Mandolini, A., Ruberti, D., 2021. The Holocene
941 Evolution of the Volturno Coastal Plain (Northern Campania, Southern Italy):
942 Implications for the Understanding of Subsidence Patterns. Water 13, 2692.
943 https://doi.org/10.3390/w13192692

944 Buglione, A., De Venuto, G., Volpe, G., 2016. Agricoltura e allevamento nella Puglia
945 settentrionale tra età romana e Medioevo: il contributo delle bioarcheologie. Mélanges
946 de l'École française de Rome - Antiquité 128. https://doi.org/10.4000/mefra.3475

947 Calanchi, N., Dinelli, E., 2008. Tephrostratigraphy of the last 170 ka in sedimentary
948 successions from the Adriatic Sea. Journal of Volcanology and Geothermal Research
949 177, 81–95. https://doi.org/10.1016/j.jvolgeores.2008.06.008

950 Caldara, M., 1996. Aspetti di geologia ambientale e di morfologia costiera in alcuni tratti
951 del litorale nord-barese. Geologi 96, 39–61.

952 Caldara, M., Caroli, I., Simone, O., 2004. Geomorphological changes due to human actions
953 at Coppa Nevigata (Tavoliere di Puglia, Southern Italy) reconstructed through core
954 analyses. Il Quaternario 17, 495–508.

955 Caldara, M., Cazzella, A., Fiorentino, G., Lopez, R., Magri, D., Moscoloni, M., Narcisi, B.,
956 Simone, O., 2003. The relationship between Coppa Nevigata settlement and the
957 wetland area during the Bronze Age (south-eastern Italy). In: Fuoache, E. (ed.), The
958 Mediterranean World Environment and History. Elsevier, Paris, pp. 429–438.

959 Caldara, M., Pennetta, L., 1990. Evoluzione dell'ambiente olocenico nel basso Tavoliere di
960 Puglia. Bonifica 6, 47–66.

961 Caldara, M., Pennetta, L., 1992. Interpretazione paleoclimatica di dati preistorici e storici
962 relativi all'entroterra del Golfo di Manfredonia. Memorie della Società Geologica
963 Italiana 42, 197–207.

964 Caldara, M., Pennetta, L., 1993a. Ambienti aridi del tipo 'Sabkha' nei sedimenti olocenici
965 della piana costiera fra Manfredonia e Zapponeta. Bonifica 8, 73–82.

966 Caldara, M., Pennetta, L., 1993b. Nuovi dati per la conoscenza geologica e morfologica del
967 Tavoliere di Puglia. Bonifica 8, 25–42.

968 Caldara, M., Pennetta, L., Simone, O., 2002. Holocene Evolution of the Salpi Lagoon
969 (Puglia, Italy). Journal of Coastal Research 36, 124–133. https://doi.org/10.2112/1551-
970 5036-36.sp1.124

971 Caldara, M., Simone, O., Porzia, S., 2003. L'aera umida di Coppa Nevigata tra Neolitico e
972 l'Età del Bronzo. Atti del 23° Convegno Nazionale sulla Preistoria, Protostoria e Storia
973 della Daunia, S. Severo 23–24 Novembre 2002. Stabilimento Litografico Centrografico
974 Francescano, Foggia, 203–230.

975 Caldara, M., Simone, O., 2005. Coastal changes in the eastern Tavoliere Plain (Apulia,
976 Italy) during the Late Holocene: Natural or anthropic? Quaternary Science Reviews 24,
977 2137–2145. https://doi.org/10.1016/j.quascirev.2004.08.024

978 Caldara, M., Simone, O., 2012. L'ambiente fisico nell'area dell'insediamento di Coppa
979 Nevigata. In: Cazzella, A., Moscoloni, M., Recchia, G. (eds.), Coppa Nevigata e l'area
980 umida alla foce del Candelaro durante l'età del Bronzo. Claudio Grenzi Editore, pp.
981 339–359.

982 Calò, C., Henne, P.D., Curry, B., Magny, M., Vescovi, E., La Mantia, T., Pasta, S., Vannière,
983 B., Tinner, W., 2012. Spatio-temporal patterns of Holocene environmental change in
984 southern Sicily. Palaeogeography, Palaeoclimatology, Palaeoecology 323–325, 110–122.
985 https://doi.org/10.1016/j.palaeo.2012.01.038

986 Caracuta, V., Fiorentino, G., 2009. L'analisi archeobotanica nell'insediamento di Faragola
987 (FG): il paesaggio vegetale tra spinte antropiche e caratteristiche ambientali, tra
988 tardoantico e altomedioevo. In: Volpe, G., Favia, P. (eds), V Congresso Nazionale di
989 Archeologia Medievale (Foggia-Manfredonia, 30 settembre-3 ottobre 2009). Firenze,
990 717–726.

991 Carmona, P., Ruiz-Pérez, J.-M., Blázquez Morilla, A.M., López-Belzunce, M., Riera, S.,
992 Orengo, H., 2016. Environmental evolution and mid–late Holocene climate events in

993 the Valencia lagoon (Mediterranean coast of Spain). The Holocene 26, 1750–1765.
994 https://doi.org/10.1177/0959683616645940

995 Caroli, I., Caldara, M., 2007. Vegetation history of Lago Battaglia (eastern Gargano coast,
996 Apulia, Italy) during the middle-late Holocene. Vegetation History and
997 Archaeobotany 16, 317–327. https://doi.org/10.1007/s00334-006-0045-y

998 Cazzella, A., Moscoloni, M., Recchia, G., 2012. Coppa Nevigata e l'area umida alla foce del
999 Candelaro durante l'Età del Bronzo. Grenzi Editore, Foggia.

1000 Cazzella, A., Recchia, G., Tunzi, A.M., 2017. La Puglia tra Bronzo Antico e Bronzo Recente.
1001 In: Radina, F. (ed.), Preistoria e Protostoria della Puglia, Studi di Preistoria e
1002 Protostoria – 4. Istituto italiano di preistoria e protostoria, Firenze, pp. 431–442.

1003 Ciccone, S., 1984. Cinquant'anni di bonifica nel Tavoliere. Bastogi, Foggia, Italy.

1004 Cocchi, L., Stefanelli, P., Carmisciano, C., Caratori Tontini, F., Taramaschi, L. and Cipriani,
1005 S., 2012). Marine Archaeogeophysical Prospection of Roman Salapia Settlement
1006 (Puglia, Italy): Detecting Ancient Harbour Remains. Archaeological Prospection 19,
1007 89–101. https://doi.org/10.1002/arp.1420

1008 Colombaroli, D., Marchetto, A., Tinner, W., 2007. Long term interactions between
1009 Mediterranean climate, vegetation and fire regime at Lago di Massaciuccoli (Tuscany,
1010 Italy). Journal of Ecology 95, 755–770. https://doi.org/10.1111/j.1365-
1011 2745.2007.01240.x

1012 Colombaroli, D., Vanniere, B., Emmanuel, C., Magny, M., Tinner, W., 2008. Fire-vegetation
1013 interactions during the Mesolithic-Neolithic transition at Lago dell'Accesa, Tuscany,
1014 Italy. Holocene 18, 679–692. https://doi.org/10.1177/0959683608091779

1015 Corrado, G., Amodio, S., Aucelli, P.P.C., Pappone, G., Schiattarella, M., 2020. The
1016 Subsurface Geology and Landscape Evolution of the Volturno Coastal Plain, Italy:
1017 Interplay between Tectonics and Sea-Level Changes during the Quaternary. Water 12,
1018 3386. https://doi.org/10.3390/w12123386

1019 Cosentino, C., Molisso, F., Scopelliti, G., Caruso, A., Insinga, D.D., Lubritto, C., Pepe, F.,
1020 Sacchi, M., 2017. Benthic foraminifera as indicators of relative sea-level fluctuations:
1021 Paleoenvironmental and paleoclimatic reconstruction of a Holocene marine succession

(Calabria, south-eastern Tyrrhenian Sea). Quaternary International 439, 79–101. https://doi.org/10.1016/j.quaint.2016.10.012

Delano Smith, C., 1976. The Tavoliere of Foggia (Italy): an aggradating coastland and its early settlement pattern. In: Davidson, D.A., Shackley, M.L. (eds.), Geoarchaeology: Earth Science and the Past. Duckworth, London, pp. 197–211.

Delano Smith, C., Morrison, I.A., 1974. The buried lagoon and lost port of Sipontum (Foggia, Italy). The International Journal of Nautical and Underwater Exploration 3, 275–281.

De Santis, V., Caldara, M., 2015. The 5.5–4.5 kyr climatic transition as recorded by the sedimentation pattern of coastal deposits of the Apulia region, southern Italy. The Holocene 25, 1313–1329. https://doi.org/10.1177/0959683615584207

De Santis, V., Caldara, M., Marsico, A., Capolongo, D., Pennetta, L., 2018. Evolution of the Ofanto River delta from the 'Little Ice Age' to modern times: Implications of large-scale synoptic patterns. The Holocene 28, 1948–1967. https://doi.org/10.1177/0959683618798109

De Santis, V., Caldara, M., Torres, T. de, Ortiz, J.E., 2010. Stratigraphic units of the Apulian Tavoliere plain (Southern Italy): Chronology, correlation with marine isotope stages and implications regarding vertical movements. Sedimentary Geology 228, 255–270. https://doi.org/10.1016/j.sedgeo.2010.05.001

De Santis, V., Scardino, G., Ortiz, J.E., Sánchez-Palencia, Y., Caldara, M., 2021. Pleistocene terracing phases in the metropolitan area of Bari - AAR dating and deduced uplift rates of the Apulian Foreland. Rendiconti Online della Società Geologica Italiana 54, 49–61. https://doi.org/10.3301/ROL.2021.03

De Santis, V., Caldara, M., Pennetta, L., 2020. "Continuous" Backstepping of Holocene Coastal Barrier Systems into Incised Valleys: Insights from the Ofanto and Carapelle-Cervaro Valleys. Water 12, 1799. https://doi.org/10.3390/w12061799

De Venuto, G., Goffredo, R., Totten, D.M., 2022. Salapia-Salpi 1. Scavi e ricerche 2013-2016. Edipuglia, Bari, Italy.

Di Donato, V., Esposito, P., Russo Ermolli, E., Scarano, A., Cheddadi, R., 2008. Coupled atmospheric and marine palaeoclimatic reconstruction for the last 35 ka in the Sele plain-gulf of Salerno area (southern Italy). Quaternary International 190, 146–157. https://doi.org/10.1016/j.quaint.2008.05.006

Di Lorenzo, H., Aucelli, P., Corrado, G., De Iorio, M., Schiattarella, M., Russo Ermolli, E., 2021. Environmental evolution and anthropogenic forcing in the Garigliano coastal plain (Italy) during the Holocene. The Holocene 31, 1089–1099. https://doi.org/10.1177/09596836211003242

Dini, M., Mastronuzzi, G., Sansò, P., 2000. The effects of relative sea level changes on the coastal morphology of Southern Apulia (Italy) during the Holocene. In: Slaymaker, O. (ed.), Geomorphology, Human Activity and Global Environmental Changes. Wiley, Chichester, UK, pp. 43–65.

Di Rita, F., 2013. A possible solar pacemaker for Holocene fluctuations of a salt-marsh in southern Italy. Quaternary International 288, 239–248. https://doi.org/10.1016/j.quaint.2011.11.030

Di Rita, F., Lirer, F., Bonomo, S., Cascella, A., Ferraro, L., Florindo, F., et al. 2018a. Late Holocene forest dynamics in the Gulf of Gaeta (central Mediterranean) in relation to NAO variability and human impact. Quaternary Science Reviews 179, 137–152. https://doi.org/10.1016/j.quascirev.2017.11.012

Di Rita, F., Magri, D., 2009. Holocene drought, deforestation and evergreen vegetation development in the central Mediterranean: a 5500 year record from Lago Alimini Piccolo, Apulia, southeast Italy. The Holocene 19, 295–306. https://doi.org/10.1177/0959683608100574

Di Rita, F., Magri, D., 2019. The 4.2 ka event in the vegetation record of the central Mediterranean. Climate of the Past 15, 237–251. https://doi.org/10.5194/cp-15-237-2019

Di Rita, F., Molisso, F., Sacchi, M., 2018b. Late Holocene environmental dynamics, vegetation history, human impact, and climate change in the ancient Literna Palus (Lago Patria; Campania, Italy). Review of Palaeobotany and Palynology 258, 48–61. https://doi.org/10.1016/j.revpalbo.2018.06.005

1080 Di Rita, F., Simone, O., Caldara, M., Gehrels, W.R., Magri, D., 2011. Holocene
1081 environmental changes in the coastal Tavoliere Plain (Apulia, southern Italy): A
1082 multiproxy approach. Palaeogeography, Palaeoclimatology, Palaeoecology 310, 139–
1083 151. https://doi.org/10.1016/j.palaeo.2011.06.012

1084 Di Rita, F., Michelangeli, F., Celant, A., Magri, D., 2022. Sign-switching ecological changes
1085 in the Mediterranean Basin at 4.2 ka BP. Global and Planetary Change 208, 103713.
1086 https://doi.org/10.1016/j.gloplacha.2021.103713

1087 Doglioni, C., Mongelli, F., Pieri, P., 1994. The Puglia uplift (SE Italy): An anomaly in the
1088 foreland of the Apenninic subduction due to buckling of a thick continental
1089 lithosphere. Tectonics 13, 1309–1321. https://doi.org/10.1029/94TC01501

1090 Doglioni, C., Tropeano, M., Mongelli, F., Pieri, P., 1996. Middle-late Pleistocene uplift of
1091 Puglia: an anomaly in the Apenninic foreland. Memorie della Società Geologica
1092 Italiana 51, 101–117.

1093 D'Orefice, M., Bellotti, P., Bertini, A., Calderoni, G., Censi Neri, P., Di Bella, L., Fiorenza,
1094 D., Foresi, L.M., Louvari, M.A., Rainone, L., Vittori, C., Goiran, J.-P., Schmitt, L.,
1095 Carbonel, P., Preusser, F., Oberlin, C., Sangiorgi, F., Davoli, L., 2020. Holocene
1096 Evolution of the Burano Paleo-Lagoon (Southern Tuscany, Italy). Water 12, 1007.
1097 https://doi.org/10.3390/w12041007

1098 Emmanouilidis, A., Unkel, I., Triantaphyllou, M., Avramidis, P., 2020. Late-Holocene
1099 coastal depositional environments and climate changes in the Gulf of Corinth, Greece.
1100 The Holocene 30, 77–89. https://doi.org/10.1177/0959683619875793

1101 Fægri, K., Iversen, J., 1989. Textbook of Pollen Analysis, 4th Edition. John Wiley & Sons.

1102 Fiorentino, G., Caldara, M., De Santis, V., D'Oronzo, C., Muntoni, I. M., Simone, O.,
1103 Primavera, M., Radina, F., 2013. Climate changes and human–environment
1104 interactions in the Apulia region of southeastern Italy during the Neolithic period. *The*
1105 *Holocene 23*, 1297–1316. https://doi.org/10.1177/0959683613486942

1106 Florenzano, A., 2019. The History of Pastoral Activities in S Italy Inferred from
1107 Palynology: A Long-Term Perspective to Support Biodiversity Awareness.
1108 Sustainability 11, 404. https://doi.org/10.3390/su11020404

1109 Florenzano, A., Marignani, M., Rosati, L., Fascetti, S., Mercuri, A. M., 2015. Are Cichorieae
1110 an indicator of open habitats and pastoralism in current and past vegetation
1111 studies?. Plant Biosystems – An International Journal Dealing with all Aspects of Plant
1112 Biology149, 154–165. https://doi.org/10.1080/11263504.2014.998311

1113 Gallicchio, S., Moretti, M., Spalluto, L., Angelini, S., 2014. Geology of the middle and
1114 upper Pleistocene marine and continental terraces of the northern Tavoliere di Puglia
1115 plain (Apulia, southern Italy). Journal of Maps 10, 569–575.
1116 https://doi.org/10.1080/17445647.2014.895436

1117 Ghilardi, M., Colleu, M., Pavlopoulos, K., Fachard, S., Psomiadis, D., Rochette, P., Demory,
1118 F., Knodell, A., Triantaphyllou, M., Delanghe-Sabatier, D., Bicket, A., Fleury, J., 2013.
1119 Geoarchaeology of Ancient Aulis (Boeotia, Central Greece): human occupation and
1120 Holocene landscape changes. Journal of Archaeological Science 40, 2071–2083.
1121 https://doi.org/10.1016/j.jas.2012.12.009

1122 Goffredo, R., 2014. Città, insediamenti rurali e paesaggi agrari della Daunia tra le guerre
1123 sannitiche e l'età post-annibalica. BABESCH 84, 47–73. doi:10.2143/BAB.89.0.3034669

1124 Goffredo, R., 2021. Salpi tra Medioevo ed Età Moderna: nascita, sviluppo e scomparsa di
1125 una città. MEFRM 133, 421–465. https://doi.org/10.4000/mefrm.10098

1126 Grimm, E.C., 1992. Tilia and Tilia-graph: pollen spreadsheet and graphics programs. In:
1127 8th International Palynological Congress, Aix-En- Provence, France, 6–12 September
1128 1992. p. 56.

1129 Haas, J.N., Richoz, I., Tinner, W., Wick., L., 1998. Synchronous Holocene climatic
1130 oscillations recorded on the Swiss Plateau and at timberline in the Alps. The Holocene
1131 8, 301–309. https://doi.org/10.1191/095968398675491173

1132 Hamilton, S., Whitehouse, R., 2021. Neolithic Spaces: Volume 1: Social and Sensory
1133 Landscapes of the First Farmers of Italy. Specialist Studies on Italy. Accordia Research
1134 Institute, University of London, London.

1135 Heim, J., 1995. Il paesaggio vegetativo. In: Mertens, J. (ed), Herdonia. Scoperta di una città.
1136 Bari, pp. 321–324.

1137 Hoffmann, J., 1961. Ergebnisse eines Anbauversuches mit Buchen verschiedener
1138 Herkünfte in Tharandter Wald. Forstwissenschaftliches Centralblatt 80, 240–252.
1139 https://doi.org/10.1007/BF01824386

1140 Kornijów, R., Kowalewski, G., Sugier, P., Kaczorowska, A., Gasiorowski, M., Woszczyk,
1141 M., 2016. Towards a more precisely defined macrophyte-dominated regime: the recent
1142 history of a shallow lake in Eastern Poland. Hydrobiologia 772, 45–62.
1143 https://doi.org/10.1007/s10750-015-2624-3

1144 Lakhdar, R., Soussi, M., Ben Ismail, M.H., M'Rabet, A., 2004. A Mediterranean Holocene
1145 restricted coastal lagoon under arid climate: Case of the sedimentary record of Sabkha
1146 Boujmel (SE Tunisia). Palaeogeography, Palaeoclimatology, Palaeoecology 241, 177–
1147 191. https://doi.org/10.1016/j.palaeo.2006.02.014

1148 Lambeck, K., Antonioli, F., Anzidei, M., Ferranti, L., Leoni, G., Scicchitano, G., Silenzi, S.,
1149 2011. Sea level change along the Italian coast during the Holocene and projections for
1150 the future. Quaternary International 232, 250–257.
1151 https://doi.org/10.1016/j.quaint.2010.04.026

1152 Lintner, M., Biedrawa, B., Wukovits, J., Wanek, W., and Heinz, P., 2020. Salinity-
1153 dependent algae uptake and subsequent carbon and nitrogen metabolisms of two
1154 intertidal foraminifera (*Ammonia tepida* and *Haynesina germanica*), Biogeosciences, 17,
1155 3723–3732. https://doi.org/10.5194/bg-17-3723-2020

1156 Lippolis, E., Giammatteo, T., 2008. Salpia vetus. Archeologia di una città lagunare. Osanna
1157 Edizioni, Matera.

1158 López-Belzunce, M., Blázquez, A.M., Carmona, P., Ruiz, J.M., 2020. Multi proxy analysis
1159 for reconstructing the late Holocene evolution of a Mediterranean Coastal Lagoon:
1160 Environmental variables within foraminiferal assemblages. CATENA 187, 104333.
1161 https://doi.org/10.1016/j.catena.2019.104333

1162 Marchesini, M., Marvelli, S., Bandini Mazzanti, M., Accorsi, C.A., 1995. Ricerche
1163 archeoambientali nella Daunia antica. In: Quilici, L., Quilici Gigli, S. (eds), Atlante
1164 tematico di topografia. Suppl. l, pp. 103–111.

1165 Marchiori, S., Medagli, P., Ruggiero, L., 1998. Guida botanica del Salento. Congedo
1166 Editore.

1167 Marin, M., 1973. Il problema delle tre "Salapia". Archivio Storico Pugliese 26, 365–388.

1168 Marin, M., 2018. Problemi riguardanti la stazione Salinis della Tabula Peutingeriana. In:
1169 Russo, S., Goffredo, R. (eds.), Saline e sale nell'antichità, Atti del convegno sul Basso
1170 Tavoliere (1989), Bari, pp. 81–90.

1171 Maselli, V., Trincardi, F., 2013. Large-scale single incised valley from a small catchment
1172 basin on the western Adriatic margin (central Mediterranean Sea). Global and
1173 Planetary Change 100, 245–262. https://doi.org/10.1016/j.gloplacha.2012.10.008

1174 Maselli, V., Trincardi, F., Asioli, A., Ceregato, A., Rizzetto, F., Taviani, M., 2014. Delta
1175 growth and river valleys: the influence of climate and sea level changes on the South
1176 Adriatic shelf (Mediterranean Sea). Quaternary Science Reviews 99, 146–163.
1177 https://doi.org/10.1016/j.quascirev.2014.06.014

1178 Mastronuzzi, G., Caputo, R., Di Bucci, D., Fracassi, U., Iurilli, V., Milella, M., Pignatelli, C.,
1179 Sansò, P., Selleri, G., 2011. Middle-Late Pleistocene evolution of the Adriatic coastline
1180 of the Southern Apulia (Italy) in response to relative sea-level changes. Geografia
1181 Fisica e Dinamica Quaternaria 34, 207–221.

1182 Mastronuzzi, G., Sansò, P., 2002a. Holocene coastal dune development and environmental
1183 changes in Apulia (southern Italy). Sedimentary Geology 150, 139–152.
1184 https://doi.org/10.1016/S0037-0738(01)00272-X

1185 Mastronuzzi, G., Sansò, P., 2002b. Holocene uplift rates and historical rapid sea-level
1186 changes at the Gargano promontory, Italy. Journal of Quaternary Science 17, 593–606.
1187 https://doi.org/10.1002/jqs.720

1188 Mazzini, I., Anadon, P., Barbieri, M., Castorina, F., Ferreli, L., Gliozzi, E., Mola, M., Vittori,
1189 E., 1999. Late Quaternary sea-level changes along the Tyrrhenian coast near Orbetello
1190 (Tuscany, central Italy): palaeoenvironmental reconstruction using ostracods. Marine
1191 Micropaleontology 37, 289–311. https://doi.org/10.1016/S0377-8398(99)00023-7

1192 Mazzini, I., Rossi, V., Da Prato, S., Ruscito, V., 2017. Ostracods in archaeological sites along
1193 the Mediterranean coastlines: three case studies from the Italian peninsula. In:

Williams, M., Hill, T., Boomer, I., Wilkinson, I.P. (eds), The Archaeological and Forensic Applications of Microfossils: A Deeper Understanding of Human History. The Micropalaeontological Society, Special Publications. Geological Society, London, pp. 121–142.

Meisch, C., 2000. Freshwater Ostracoda of Western and Central Europe. Spektrum Akademischer Verlag GmbH. Heidelberg, Berlin.

Mercuri, A.M., Bandini Mazzanti, M., Florenzano, A., Montecchi, M.C., Rattighieri, E., 2013. *Olea*, *Juglans* and *Castanea*: the OJC group as pollen evidence of the development of human-induced environments in the Italian peninsula. Quaternary International 303, 24-42. https://doi.org/10.1016/j.quaint.2013.01.005

Miall, A.D., 1985. Architectural-element analysis: A new method of facies analysis applied to fluvial deposits. Earth-Science Reviews 22, 261–308. https://doi.org/10.1016/0012-8252(85)90001-7

Miall, A.D., 2010. The Geology of Stratigraphic Sequences, 2nd ed. Springer, Berlin.

Moore, P.D., webb, J.W., Collinson, M.E., 1991. Pollen analysis. BlackWell Scientific Publications, London.

Muntoni, I.M., Delluniversità, E., Allegretta, I., Terzano, R., Eramo, G., 2022. Chert sources and Early to Middle Neolithic exploitation in the Tavoliere (Northern Apulia, Italy). Quaternary International 615, 43–65. https://doi.org/10.1016/j.quaint.2021.01.016

Natali, C., Bianchini, G., 2018. Natural vs anthropogenic components in sediments from the Po River delta coastal lagoons (NE Italy). Environmental Science and Pollution Research 25, 2981–2991. https://doi.org/10.1007/s11356-017-0986-y

Nichols, M.M., 1989. Sediment accumulation rates and relative sea-level rise in lagoons. Marine Geology 88, 201–219. https://doi.org/10.1016/0025-3227(89)90098-4

Noti, R., van Leeuwen, J.F.N., Colombaroli, D., Vescovi, E., Pasta, S., La Mantia, T., Tinner, W., 2009. Mid- and late-Holocene vegetation and fire history at Biviere di Gela, a coastal lake in southern Sicily, Italy. Vegetation History and Archaeobotany 18, 371–387. https://doi.org/10.1007/s00334-009-0211-0

1222 Orombelli, G., Pelfini, M., 1985. Una fase di avanzata glaciale nell'Olocene superiore,
1223 precedente alla Piccola Glaciazione, nelle Alpi Centrali. Rendiconti Società Geologica
1224 Italiana 8, 17–20.

1225 Patacca, E., Scandone, P., 2001. Late thrust propagation and sedimentary response in the
1226 thrust-belt—foredeep system of the Southern Apennines (Pliocene-Pleistocene). In:
1227 Vai, G.B., Martini, I.P. (eds.), Anatomy of an Orogen: The Apennines and Adjacent
1228 Mediterranean Basins. Springer Netherlands, Dordrecht, pp. 401–440.
1229 https://doi.org/10.1007/978-94-015-9829-3_23

1230 Pieri, P., Sabato, L., Tropeano, M., 1996. Significato geodinamico dei caratteri deposizionali
1231 e strutturali della Fossa bradanica nel Pleistocene. Memorie della Società Geologica
1232 Italiana 51, 501–515.

1233 Pieri, P., Festa, V., Moretti, M., Tropeano, M., 1997. Quaternary tectonic activity of the
1234 Murge area (Apulian foreland - Southern Italy). Annali di Geofisica XL, 1395–1404.

1235 Pieruccini, P., Susini, D., 2020. The Holocene sedimentary record and the landscape
1236 evolution along the coastal plains of the Pecora and Cornia rivers (Southern Tuscany,
1237 Italy): preliminary results and future perspectives. In: Bianchi, G., Hodges, R. (eds.),
1238 The NEU-Med Project: Vetricella, an Early Medieval Royal Property on Tuscany's
1239 Mediterranean. All'Insegna del Giglio, Firenze, pp. 161–168.

1240 Piva, A., Asioli, A., Trincardi, F., Schneider, R.R., Vigliotti, L., 2008. Late-Holocene climate
1241 variability in the Adriatic Sea (Central Mediterranean). The Holocene 18, 153–167.
1242 https://doi.org/10.1177/0959683607085606

1243 Pollegioni, P., Woeste, K., Chiocchini, F., Del Lungo, S., Ciolfi, M., Olimpieri, I., Tortolano,
1244 V., Clark, J., Hemery, G.E., Mapelli, S., Malvolti, M.E. 2017. Rethinking the history of
1245 common walnut (*Juglans regia* L.) in Europe: Its origins and human interactions. PLoS
1246 ONE 12, e0172541. https://doi.org/10.1371/journal.pone.0172541

1247 Primavera, D'Oronzo, C., Muntoni, I.M., Radina, F., Fiorentino, G., 2017. Environment,
1248 crops and harvesting strategies during the II millennium BC: Resilience and
1249 adaptation in socio-economic systems of Bronze Age communities in Apulia (SE Italy).
1250 Quaternary International 436, 83–95. https://doi.org/10.1016/j.quaint.2015.05.070

Primavera, M., Simone, O., Fiorentino, G., Caldara, M., 2011. The palaeoenvironmental study of the Alimini Piccolo lake enables a reconstruction of Holocene sea-level changes in southeast Italy. The Holocene 21, 553–563. https://doi.org/10.1177/0959683610385719

Reille, M., 1992. Pollen et spores d'Europe et d'Afrique du Nord. Laboratoire de Botanique Historique et Palynologie, Université d'Aix Marseille III, Marseille.

Reille, M., 1995. Pollen et spores d'Europe et d'Afrique du Nord – Supplément 1. Laboratoire de Botanique Historique et Palynologie, Université d'Aix Marseille III, Marseille.

Reille, M., 1998. Pollen et spores d'Europe et d'Afrique du Nord – Supplément 2. Laboratoire de Botanique Historique et Palynologie, Université d'Aix Marseille III, Marseille.

Reimer, P.J., Austin, W.E.N., Bard, E., Bayliss, A., Blackwell, P.G., Bronk Ramsey, C., Butzin, M., Cheng, H., Edwards, R.L., Friedrich, M., Grootes, P.M., Guilderson, T.P., Hajdas, I., Heaton, T.J., Hogg, A.G., Hughen, K.A., Kromer, B., Manning, S.W., Muscheler, R., Palmer, J.G., Pearson, C., Plicht, J. van der, Reimer, R.W., Richards, D.A., Scott, E.M., Southon, J.R., Turney, C.S.M., Wacker, L., Adolphi, F., Büntgen, U., Capano, M., Fahrni, S.M., Fogtmann-Schulz, A., Friedrich, R., Köhler, P., Kudsk, S., Miyake, F., Olsen, J., Reinig, F., Sakamoto, M., Sookdeo, A., Talamo, S., 2020. The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). Radiocarbon 62, 725–757. https://doi.org/10.1017/RDC.2020.41

Ruello, M.R., Cinque, A., Donato, V. Di, Molisso, F., Terrasi, F., Russo Ermolli, E., 2017. Interplay between sea level rise and tectonics in the Holocene evolution of the St. Eufemia Plain (Calabria, Italy). Journal of Coastal Conservation 21, 903–915. https://doi.org/10.1007/s11852-017-0558-9

Ruiz, F., Abad, M., Galán, E., González, I., Aguilá, I., Olías, M., Goméz Ariza, G.L., Cantano, M., 2006. The present environmental scenario of El Melah Lagoon (NE Tunisia) and its evolution to a future sabkha. Journal of African Earth Sciences 44, 289–302. https://doi.org/10.1016/j.jafrearsci.2005.11.023

1280 Russo, G., Strizzi, C, 2013. La vegetazione del Parco Nazionale del Gargano (Promontorio
1281 del Gargano e Isole Tremiti). Atti del Congresso "Stelvio '70" 09/2005. Colloques
1282 Phytosociologiques, XXIX, 577–603.

1283 Russo Ermolli, E., Romano, P., Ruello, M.R., Barone Lumaga, M.R., 2014. The natural and
1284 cultural landscape of Naples (southern Italy) during the Graeco-Roman and late
1285 antique periods. Journal of Archaeological Sciences 42, 399–411.
1286 https://doi.org/10.1016/j.jas.2013.11.018

1287 Russo Ermolli, E., Ruello, M.R., Cicala, L., Di Lorenzo, H., Molisso, F., Pacciarelli, M., 2018.
1288 An 8300-yr record of environmental and cultural changes in the Sant'Eufemia plain
1289 (Calabria, Italy). Quaternary International 483, 39–56.
1290 https://doi.org/10.1016/j.quaint.2018.01.033

1291 Russo, S., 1985. La bonifica del lago Salpi in Capitanata. L'Ambiente Storico, 119–135.

1292 Sabatier, P., Dezileau, L., Barbier, M., Raynal, O., Lofi, J., Briqueu, L., Condomines, M.,
1293 Bouchette, F., Certain, R., Van Grafenstein, U., Jorda, C., Blanchemanche, P., 2010.
1294 Late-Holocene evolution of a coastal lagoon in the Gulf of Lions (South of France).
1295 Bulletin de la Société Géologique de France 181, 27–36.
1296 https://doi.org/10.2113/gssgfbull.181.1.27

1297 Sacchi, M., Molisso, F., Pacifico, A., Vigliotti, M., Sabbarese, C., Ruberti, D., 2014. Late-
1298 Holocene to recent evolution of Lake Patria, South Italy: An example of a coastal
1299 lagoon within a Mediterranean delta system. Global and Planetary Change 117, 9–27.
1300 https://doi.org/10.1016/j.gloplacha.2014.03.004

1301 Sadori, L., 2013. Southern Europe. In: Elias, S.A. (ed.), The Encyclopedia of Quaternary
1302 Science, vol. 4. Elsevier, Amsterdam, pp. 179–188.

1303 Sadori, L., Giardini, M., Gliozzi, E., Mazzini, I., Sulpizio, R., van Welden, A., Zanchetta, G.,
1304 2015. Vegetation, climate and environmental history of the last 4500 years at lake
1305 Shkodra (Albania/Montenegro). The Holocene 25, 435-444.
1306 https://doi.org/10.1177%2F0959683614561891

1307 Sadori, L., Giardini, M., Giraudi, C., Mazzini, I., 2010. The plant landscape of the imperial
1308 harbour of Rome. Journal of Archaeological Science 37, 3294–3305.
1309 https://doi.org/10.1016/j.jas.2010.07.032

1310 Sadori, L., Mazzini, I., Pepe, C., Goiran, J-P., Pleuger, E., Ruscito, V., Salomon, F., Vittori,
1311 C., 2016. Palynology and ostracodology at the Roman port of ancient Ostia (Rome,
1312 Italy). The Holocene 26, 1502–1512. https://doi.org/10.1177/0959683616640054

1313 Sadori, L., Giardini, M., 2007. Charcoal analysis, a method to study vegetation and climate
1314 of the Holocene: the case of Lago di Pergusa, Sicily (Italy). Geobios 40(2), 173–180.
1315 https://doi.org/10.1016/j.geobios.2006.04.002

1316 Sangiorgi, F., Capotondi, L., Nebout, N.C., Vigliotti, L., Brinkhuis, H., Giunta, S., Lotter,
1317 A.F., Morigi, C., Negri, A., Reichart, G.-J., 2003. Holocene seasonal sea-surface
1318 temperature variations in the southern Adriatic Sea inferred from a multiproxy
1319 approach. Journal of Quaternary Science 18, 723–732. https://doi.org/10.1002/jqs.782

1320 Santacroce, R., Cioni, R., Marianelli, P., Sbrana, A., Sulpizio, R., Zanchetta, G., Donahue,
1321 D.J., Joron, J.L., 2008. Age and whole rock–glass compositions of proximal pyroclastics
1322 from the major explosive eruptions of Somma-Vesuvius: A review as a tool for distal
1323 tephrostratigraphy. Journal of Volcanology and Geothermal Research 177, 1–18.
1324 https://doi.org/10.1016/j.jvolgeores.2008.06.009

1325 Siani, G., Magny, M., Paterne, M., Debret, M., Fontugne, M., 2013. Paleohydrology
1326 reconstruction and Holocene climate variability in the South Adriatic Sea. Climate of
1327 the Past, 9, 499–515. https://doi.org/10.5194/cp-9-499-2013

1328 Siani, G., Paterne, M., Arnold, M., Bard, E., Métivier, B., Tisnerat, N., Bassinot, F., 2000.
1329 Radiocarbon Reservoir Ages in the Mediterranean Sea and Black Sea. Radiocarbon 42,
1330 271–280. https://doi.org/10.1017/S0033822200059075

1331 Simeoni, U., 1992. I litorali di Manfredonia e Barletta (Basso Adriatico): Dissesti, sedimenti,
1332 problematiche ambientali. Bollettino della Società Geologica Italiana 111, 367–398.

1333 Smit, A., 1973. A scanning electron microscopical study of the pollen morphology in the
1334 genus Quercus. Acta botanica neerlandica 22, 655–665.

1335 Spagnoli, F., Bartholini, G., Dinelli, E., Giordano, P., 2008. Geochemistry and particle size
1336 of surface sediments of Gulf of Manfredonia (Southern Adriatic sea). Estuarine,
1337 Coastal and Shelf Science 80, 21–30. https://doi.org/10.1016/j.ecss.2008.07.008

1338 Stevenson, R.J., 1996. An Introduction to Algal Ecology in Freshwater Benthic Habitats. In:
1339 Stevenson, R.J., Bothwell, M., Lowe, R., Thorp J. (eds), Algal Ecology. Freshwater
1340 Benthic Ecosystems. A volume in Aquatic Ecology. Academic Press, p. 30.

1341 Stockmarr, J., 1971. Tablets with spores used in absolute pollen analysis. Pollen et Spores
1342 13, 615–621.

1343 Tafuri, M.A., Robb, J., Belcastro, M.G., Mariotti, V., Iacumin, P., Di Matteo, A., O'Connel,
1344 T., 2014. Herding Practises in the Ditched Villages of the Neolithic Tavoliere (Apulia,
1345 South-east Italy) A Vicious Circle? The Isotopic Evidence. In: Whittle, A., Bickle, P.
1346 (eds.), Early Farmers: The View from Archaeology and Science, Proceedings of the
1347 British Academy, vol. 198. Oxford University Press, Oxford, pp. 143–158.

1348 Tinner, W., van Leeuwen, J.F.N., Colombaroli, D., Vescovi, E., van der Knaap, W.O.,
1349 Henne, P.D., Pasta, S., D'Angelo, S., La Mantia, T., 2009. Holocene environmental and
1350 climatic changes at Gorgo Basso, a coastal lake in southern Sicily, Italy. Quaternary
1351 Science Review 28, 1498–1510. https://doi.org/10.1016/j.quascirev.2009.02.001

1352 Tinner, W., Colombaroli, D., Heiri, O., Henne, P.D., Steinacher, M., Untenecker, J., Vescovi,
1353 E., Allen, J.R.M., Carraro, G., Conedera, M., Joos, F., Lotter, A.F., Luterbacher, J.,
1354 Samartin, S., Valsecchi, V., 2013. The past ecology of *Abies alba* provides new
1355 perspectives on future responses of silver fir forests to global warming. Ecological
1356 Monographs 83, 419–439. https://doi.org/10.1890/12-2231.1

1357 Totten, D.M., 2022. Life in the Late Antique town: *Salapia* in the 4th-6th c. CE. In: De Venuto,
1358 G., Goffredo, R., Totten, D.M. (eds.), Salapia-Salpi 1. Scavi e ricerche 2013-2016.
1359 Edipuglia, Bari, Italy, pp. 629–660.

1360 Tropeano, M., Sabato, L., Pieri, P., 2002. Filling and cannibalization of a foredeep: the
1361 Bradanic Trough, Southern Italy. Geological Society, London, Special Publications 191,
1362 55–79. https://doi.org/10.1144/GSL.SP.2002.191.01.05

1363 Vacchi, M., Marriner, N., Morhange, C., Spada, G., Fontana, A., Rovere, A., 2016.
1364 Multiproxy assessment of Holocene relative sea-level changes in the western
1365 Mediterranean: Sea-level variability and improvements in the definition of the
1366 isostatic signal. Earth-Science Reviews 155, 172–197.
1367 https://doi.org/10.1016/j.earscirev.2016.02.002

1368 Volpe, G., 1990. La Daunia nell'età della romanizzazione. Paesaggio agrario produzione e
1369 scambi. Adrias. Edipuglia, Bari.

1370 Vignola, C., Bonetto, J., Furlan, G., Mazza, M., Nicosia, C., Russo Ermolli, E., Sadori, L.,
1371 2022. At the origins of Pompeii: the plant landscape of the Sarno River floodplain from
1372 the first millennium BC to the AD 79 eruption. Vegetation History and Archaeobotany
1373 31, 171–186. https://doi.org/10.1007/s00334-021-00847-w

1374 Walker, M., Head, M.J., Berkelhammer, M., Björck, S., Cheng, H., Cwynar, L., Fisher, D.,
1375 Gkinis, V., Long, A., Lowe, J., Newnham, R., Rasmussen, S.O., Weiss, H., 2018. Formal
1376 ratification of the subdivision of the Holocene Series/Epoch (Quaternary
1377 System/Period): two new Global Boundary Stratotype Sections and Points (GSSPs)
1378 and three new stages/subseries. Episodes 41, 213–223.
1379 https://doi.org/10.18814/epiiugs/2018/018016

1380 Whitehouse, R., 2014. The chronology of the Neolithic ditched settlements of the Tavoliere
1381 and the Ofanto valley. Accordia Research Paper 13, 57–77.

1382 Whitlock, C., Higuera, P.E., McWethy, D.B., Briles, C.E., 2010. Paleoecological Perspectives
1383 on Fire Ecology: Revisiting the Fire-Regime Concept. The Open Ecology Journal 3, 6–
1384 23. http://dx.doi.org/10.2174/1874213001003020006

1385

List of figures:

Figure 1. Geological and geomorphological map of the study area modified from the on-line idro-geomorphological database of "Regione Puglia" (www.sit.puglia.it), and the National Geological Map from the "Istituto Superiore per la Ricerca Ambientale (ISPRA, www.isprambiente.gov.it). Datum: D_WGS_1984; GCS: WGS_1984_UTM_Zone_33N (as with all coordinates henceforth). Legend: 1) main towns; 2) boreholes; 3) archaeological sites; 4) water stream (natural/artificial channel); 5) alluvial fan; 6) carbonate Units (Mesozoic); 7) carbonate Units (Pliocene); 8) marine deposit – Middle Pleistocene; 9) alluvial deposit – Middle Pleistocene; 10) infralittoral deposit – Middle Pleistocene; 11) alluvial deposit – Middle/Upper Pleistocene; 12) alluvial deposit – Upper Pleistocene; 13) alluvial plain – Upper Pleistocene/Holocene; 15) beach deposit – Holocene; 16) reclamation deposit – Recent time; 17) artificial reservoir – Recent time (for interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article, as for all figures henceforth).

Figure 2. Salpi lagoon, location of the boreholes.

Figure 3. Selection of depositional environments and sedimentary facies recognised in the Salpi cores. a) SAM9 core – poorly drained floodplain environment (AF1); b) SAM9 core – poorly drained floodplain (AF1) and crevasse splay (AF2); c) SAM4 core – partially drained floodplain (AF1) and channel log (AF3); d) SAM9 core – swamp-marshy environments (SMF1); e) SAM9 core – non-vegetated lagoonal environment (LBF1) and marginal vegetated lagoonal environment (LBF2).

Figure 4. Grain size and micropalaeontological analyses of the SAM9 core. Densities of the identified ostracod species (using the OEG freshwater and euryhaline) and of the two most abundant foraminifera species *Hyanesina germanica* and *Ammonia tepida*. Occurrences of diatoms, carophytes, ephippia *Daphnia*-type and fish remains are also reported.

Figure 5. Salpi lagoon, core SAM9. Percentage diagram of selected pollen and NPP taxa. Curves are exaggerated by a factor of 5x.

Figure 6. Salpi lagoon, core SAM9. Concentration diagram of pollen, NPPs, and microcharcoals.

Figure 7. Stratigraphic sequence of the Salapia cores with indication of the facies association and associated depositional environments.

Figure 8. Comparison between pollen and micropalaeontological data from the SAM9 core. The ecological groups of pollen, NPPs, and ostracods are aligned with the main palaeoenvironmental changes of the Salpi lagoon and with archaeological data from the Tavoliere plain. Halophytic herbs: Amaranthaceae; Riparian trees: *Alnus*, *Populus*, *Tamarix*; Xeric herbs: Cichorieae; Erosion indicators: *Glomus*, *Pseudoschizaea*; Algae: *Botryococcus*, *Pediastrum*, Zygnemataceae.

Figure 9. Evolutionary model of the Salpi lagoon during the Holocene. a) Late Northgrippian (6.2ka – 4.2ka BP); b) Early Meghalayan (4.2ka – 2.4ka BP); c) Late Meghalayan (2.4ka BP – Present). Legend: 1) archaeological sites; 2) water streams; 3) alluvial fan; 4) carbonate Units – Mesozoic; 5) carbonate Units – Pliocene; 6) marine deposit – Middle Pleistocene; 7) alluvial deposit – Middle Pleistocene; 8) infralittoral deposit – Middle Pleistocene; 9) alluvial deposit – Middle/Upper Pleistocene; 10) alluvial deposit – Upper Pleistocene; 11) alluvial deposit – Upper Pleistocene/Holocene; 12) swamps deposit – Holocene; 13) Dune belts – Holocene; 14) Lagoon – Holocene.

List of tables:

Table 1. List of SAL and SAM boreholes.

Table 2. List radiocarbon dating. Dating with asterisk in SAM9 core has been used for the age-depth model.

Figure 1

Click here to download Figure Figure1.jpg

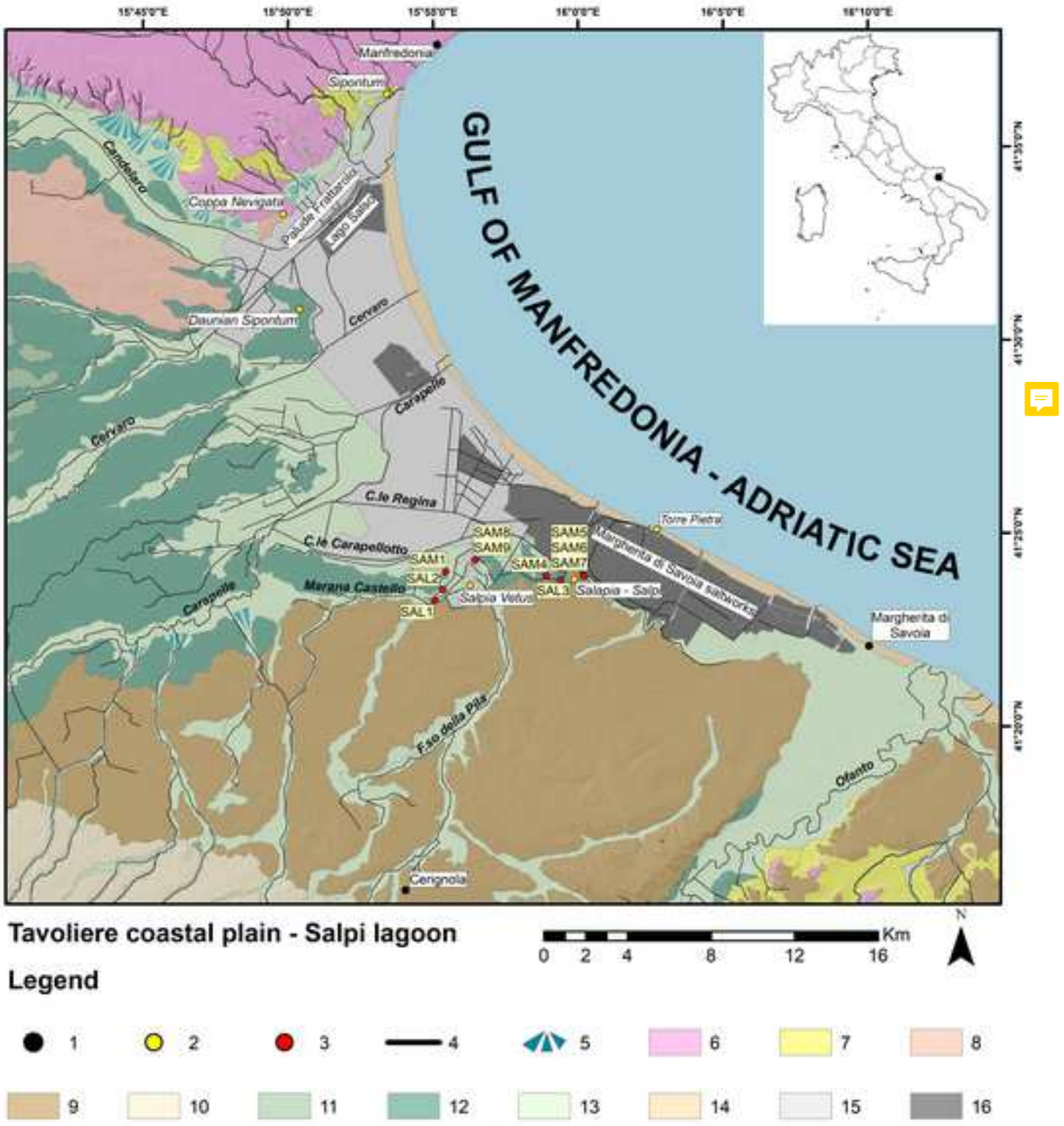


Figure 2

Click here to download Figure Figure2.jpg

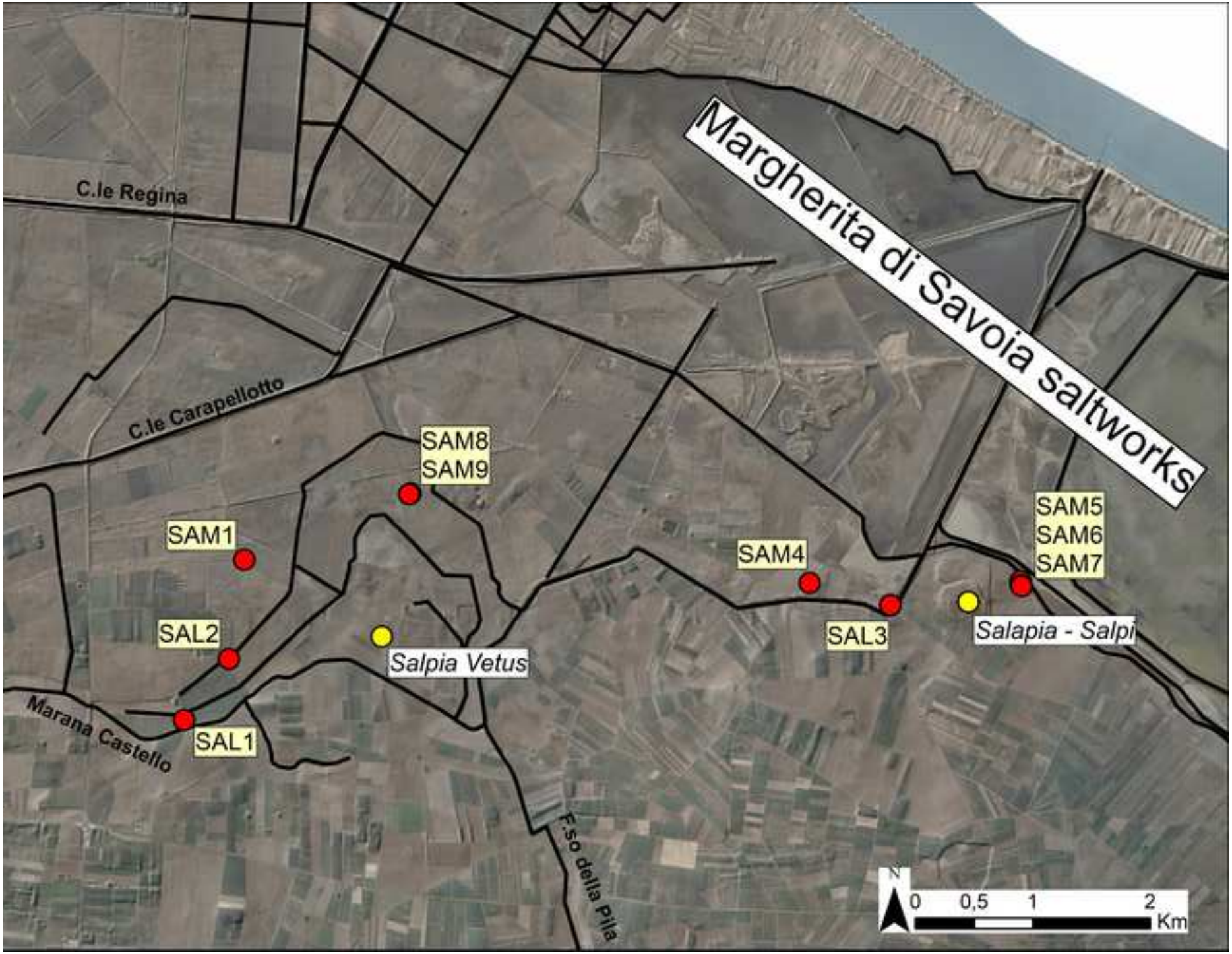


Figure 3

Click here to download Figure Figure3.jpg

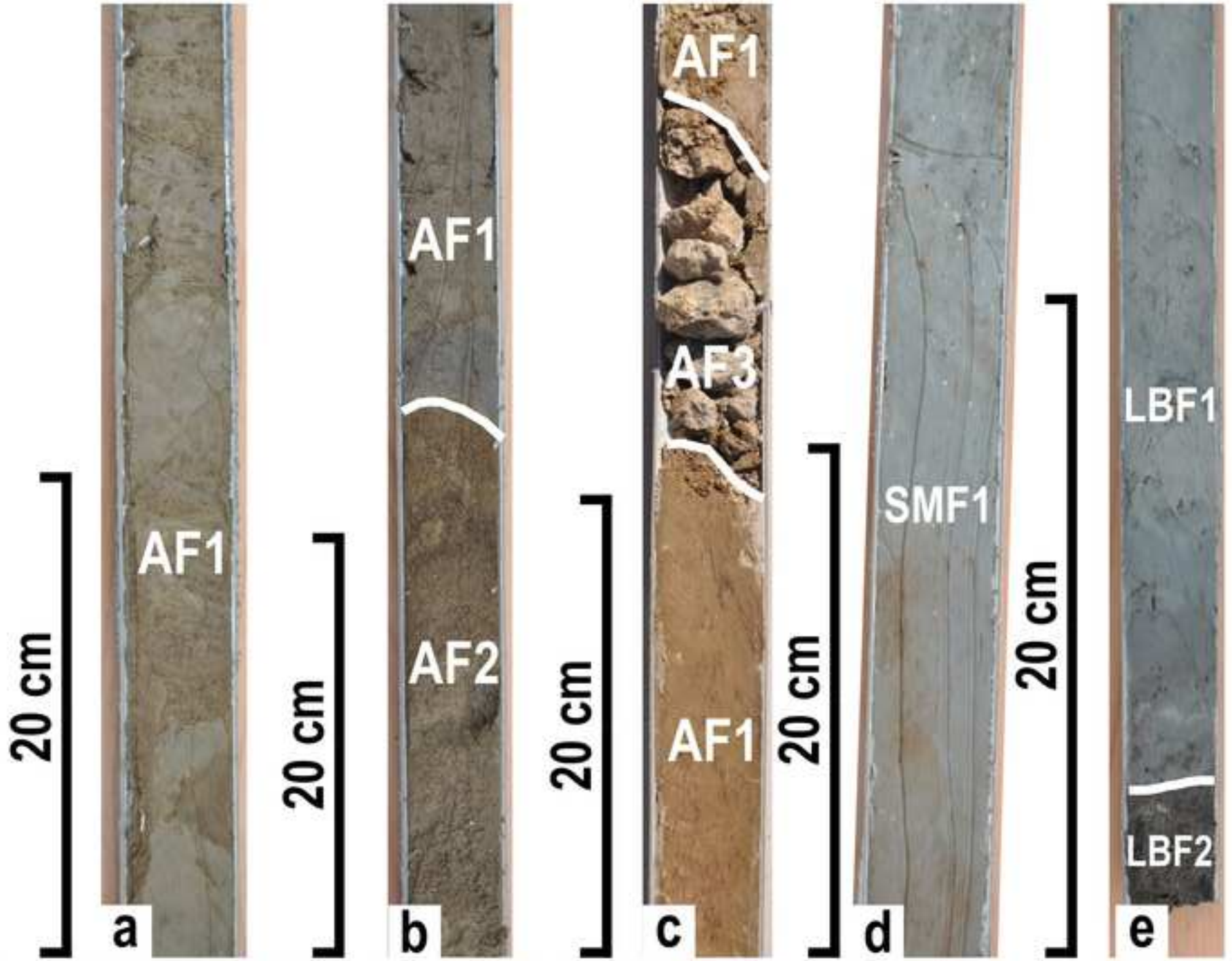


Figure 4

Click here to download Figure Figure4.jpg

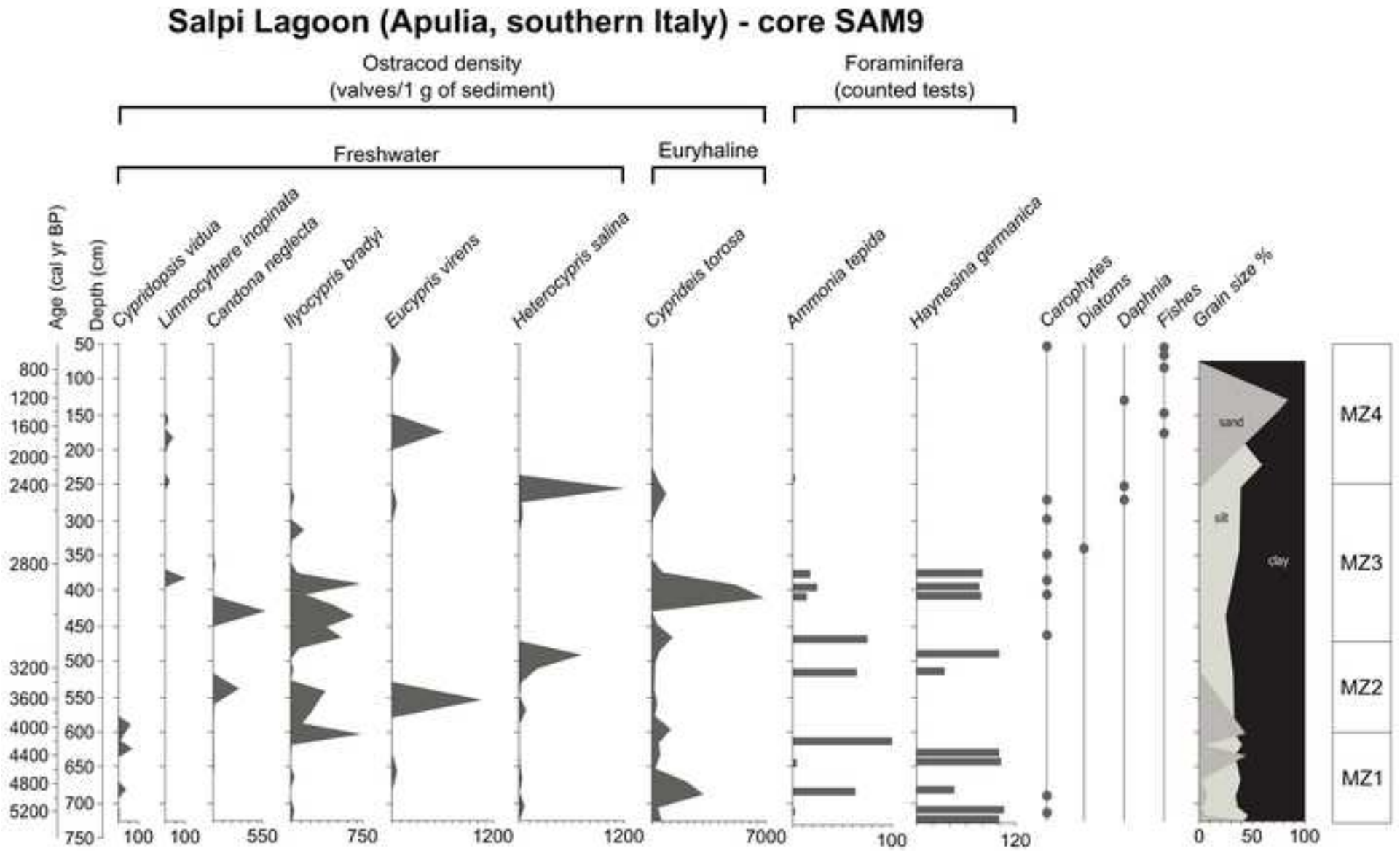


Figure 5

Click here to download Figure Figure5.jpg

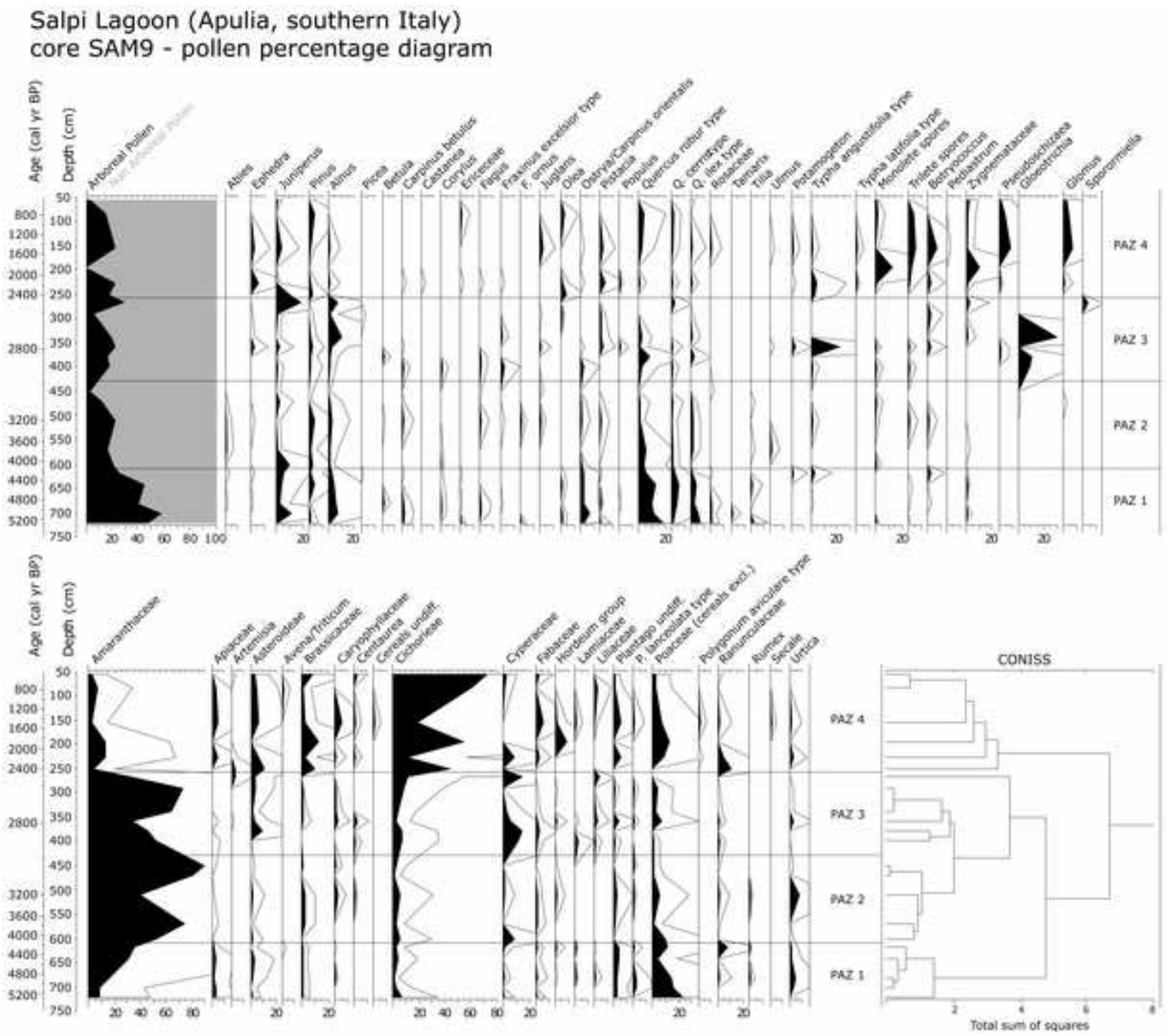


Figure 6

Click here to download Figure Figure6.jpg

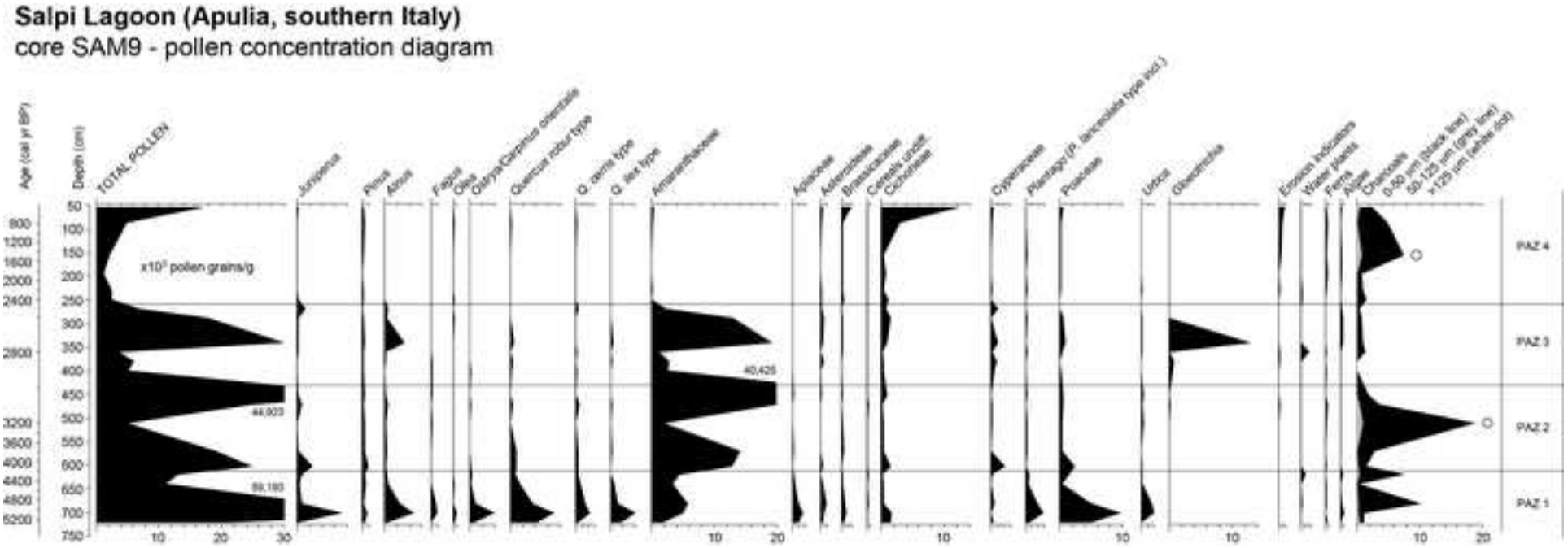


Figure 7

Click here to download Figure Figure7.jpg

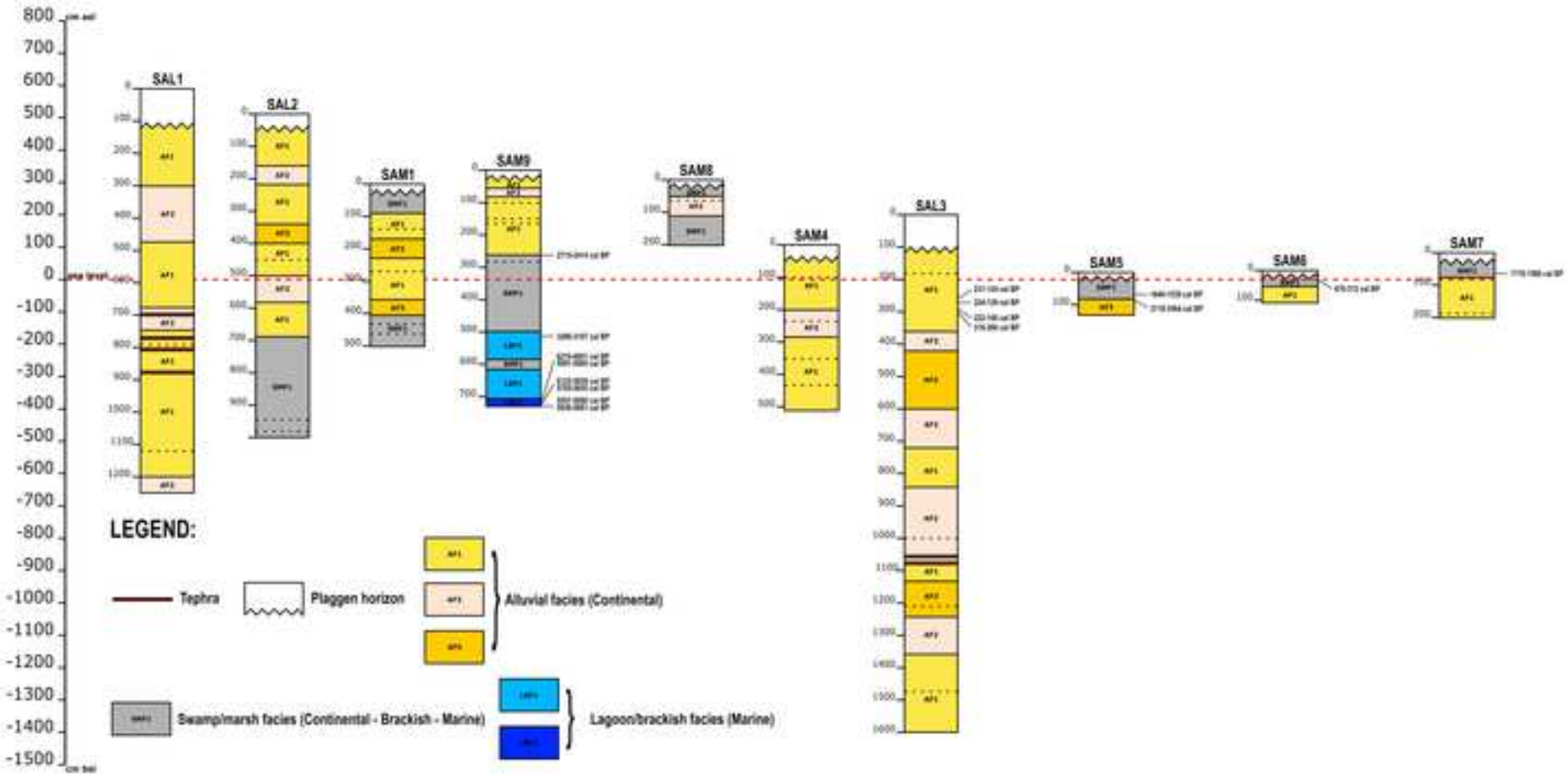


Figure 8

Click here to download Figure Figure8.jpg

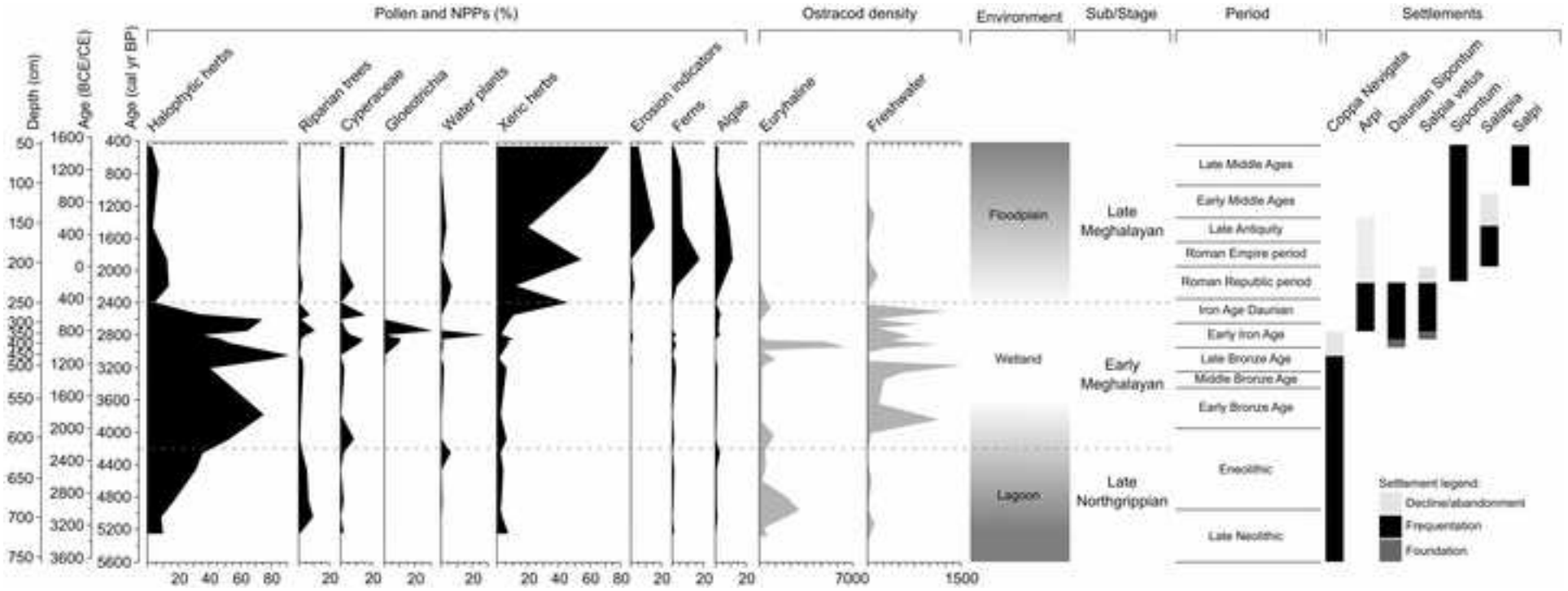
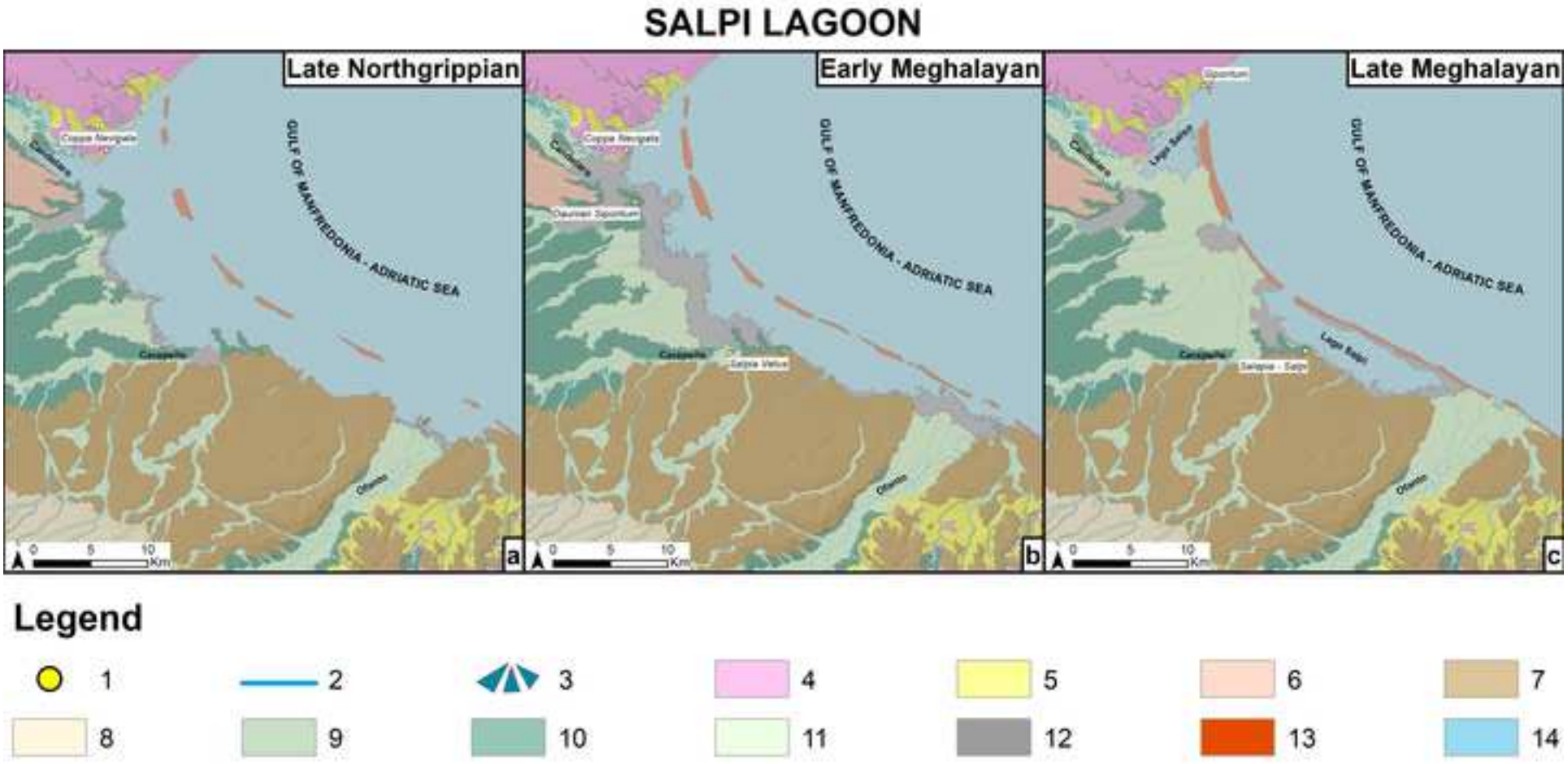


Figure 9

Click here to download Figure Figure9.jpg



ID Borehole	year	Coordinates	Elevation (m asl)	Depth (m)
SAL1	2017	15°54'57,59"E, 41°23'16,82"N	5,9 m	12,5 m
SAL2	2017	15°55'24,175"E, 41°23'33,767"N	5,02 m	10 m
SAL3	2017	15°59'30,058"E, 41°23'43,196"N	2 m	16 m
SAM1	2019	15°55'28,709"E, 41°24'3,234"N	3 m	5 m
SAM4	2019	15°58'43,74"E, 41°23'57,147"N	1 m	5,2 m
SAM5	2019	15°59'59,058"E, 41°24'1,991"N	0,3 m	1,4 m
SAM6	2019	15°59'59,215"E, 41°24'0,952"N	0,4 m	1 m
SAM7	2019	15°59'59,469"E, 41°24'0,658"N	0,8 m	2,1 m
SAM8	2019	15°56'14,971"E, 41°24'28,036"N	3,1 m	2,1 m
SAM9	2019	15°56'15,575"E, 41°24'28,161"N	3,4 m	7,35 m

Core	ID-core depth (cm)	Material	Lab. Code	Age (BP)	Age cal. (BP)	Age cal. (BCE/CE)
SAL3	SAL3_260	Charcoal	Beta - 509119	160±30 BP	231 – 124 cal BP	1719 – 1826 cal CE
	SAL3_270	Charcoal	Beta - 509118	180±30 BP	224 – 136 cal BP	1726 – 1814 cal CE
	SAL3_290	Charcoal	Beta - 509117	200±30 BP	222 – 140 cal BP	1728 – 1810 cal CE
	SAL3_300	Charcoal	Beta - 509116	240±30 BP	318 – 268 cal BP	1632 – 1682 cal CE
SAM5	SAM5_65	Sediment	Beta - 595402	1720±30 BP	1640 – 1539 cal BP	310 – 410 cal CE
	SAM5_86	Sediment	Beta - 595401	3400±30 BP	3718 – 3564 cal BP	1769 – 1615 cal BCE
SAM6	SAM6_38	Sediment	Beta - 595403	340±30 BP	476 – 312 cal BP	1474 – 1638 cal CE
SAM7	SAM7_68	Sediment	Beta - 595404	1750±30 BP	1710 – 1566 cal BP	240 – 384 cal CE
SAM9	SAM9_262*	Sediment	Beta - 598710	2470±30 BP	2715 – 2414 cal BP	766 – 465 cal BCE
	SAM9_513*	Ostracod shell	Beta - 528223	3010±30 BP	3266 – 3107 cal BP	795 – 385 cal BCE
	SAM9_724a	Charcoal	Beta - 530035	5180±30 BP	5991 – 5905 cal BP	4042 – 3956 cal BCE
	SAM9_724b	Sediment	Beta - 528224	5340±30 BP	6210 – 6001 cal BP	4261 – 4052 cal BCE
	SAM9_727a	Charcoal	Beta - 528225	5010±30 BP	5765 – 5655 cal BP	3816 – 3706 cal BCE
	SAM9_727b	Sediment	Beta - 531708	5270±30 BP	6125 – 5939 cal BP	4176 – 3990 cal BCE
	SAM9_730a*	Ostracod shell	Beta - 531709	5180±30 BP	5557 – 5068 cal BP	3608 – 3119 cal BCE
	SAM9_730b	Sediment	Beta - 528226	5130±30 BP	5939 – 5861 cal BP	3990 – 3912 cal BCE

1