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LANDSCAPE DIACHRONIC RECONSTRUCTION IN THE TIBER DELTA DURING HISTORICAL TIME: A HOLISTIC APPROACH

Abstract: Bellotti P., Davoli L. & Sadori L., *Landscape diachronic reconstruction in the Tiber delta during historical time: a holistic approach.* (IT 0391-9838, 2018).

The sensitivity of deltas in response to evolutionary factors makes them important archives of the events that occurred in the entire river basin. Detailed knowledge of the stratigraphy and morphology, combined with a set of archaeological, palaeobotanical and historical information, make possible to reconstruct the diachronic changes of the landscape in the Tiber delta plain over the past 3000 years taking into account natural and anthropic forcing. The main factors that contributed to the delta landscape change are considered following a temporal scansion. Among the natural factors, we considered climate, sea level rise, tectonic and local subsidence. Among the human factors we considered the population density and several human activities, such as farming and breeding practices, reclamation, construction of ports, canals and salt works. To evaluate the amount of sediment involved in the delta evolution during different periods, the BQART model was used. Prior to Roman times anthropogenic forcing had a lower influence than natural forcing on the landscape evolution. During the Roman period (between third century BC-fourth century AD), the delta landscape was severely conditioned by the human activity. Throughout the Middle Ages and until the first half of the nineteenth century, a more natural landscape evolved in the delta, gradually and partially replacing the previous landscape. With the arrival of the new Italian State a new and impressive landscape change occurred. The evolution of the Tiber delta landscape appear particularly affected by anthropogenic forcing when socio-political organization allowed the control and planning of policy actions.

Key Words: Landscape change, Delta evolution, Tiber River, Human impacts, Climate forcing, River discharge.

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Per la grande sensibilità ai fattori evolutivi, i delta costituiscono importanti archivi geologici degli eventi naturali e antropici intervenuti nei relativi bacini fluviali e paraggi costieri. Considerando l'insieme dei dati stratigrafici, morfologici, archeologici, paleobotanici e storici, ampiamente disponibili per l'area romana, si è cercato di individuare quali fattori evolutivi abbiano pesato maggiormente nella definizione del paesaggio della piana deltizia del Tevere in diversi intervalli temporali degli ultimi 3000 anni. Tra i fattori naturali sono stati considerati: clima, sollevamento del livello marino, tettonica e subsidenza locale. Tra i fattori antropici sono stati inclusi la densità di popolazione e diverse attività umane quali la costruzione di porti, saline, canali, dighe, sviluppo del pascolo e bonifiche. Al fine di stimare la quantità di sedimento coinvolto nell'evoluzione deltizia è stato utilizzato il modello BQART. In due intervalli temporali, periodi pre-romano e medioevale, l'evoluzione sembra essere determinata essenzialmente da fattori naturali mentre i fattori antropici risultano particolarmente influenti in periodo romano e in quello moderno a partire dalla seconda metà del diciannovesimo secolo. L'evoluzione del paesaggio deltizio, nel periodo storico, appare dunque maggiormente influenzata dai fattori antropici solo in presenza di una ben definita organizzazione socio-politica capace di programmare importanti interventi sul territorio.

Parole chiave: Evoluzione del paesaggio, Evoluzione deltizia, Fiume Tevere, Impatto umano, Forzanti climatiche, Apporto fluviale.

INTRODUCTION

Deltas are sedimentary bodies that respond to changes in natural factors, such as climate, tectonic activity and relative sea level rise, in geologically short time periods (even <1000 years). Deltas are also the meeting point of a drainage network with the sea and have been particularly suitable areas for human settlements since the Neolithic. Human action in river catchments is another evolutionary factor of landscapes in most deltaic plains. The impact of human action has gradually increased through historical time. The evolution of the main Mediterranean delta areas, where important human settlements developed, is well known during the Holocene (Oomkens, 1970; Rodriguez-Ortiz & *alii*, 1978; Morhange & *alii*, 2003; Vella & *alii*, 2005; Stanley & Bernasconi, 2006; Marriner & Morhange, 2007; Amato & *alii*, 2013; Milli & *alii*, 2016). In particular, along the Italian coasts, studies have been carried out

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near ancient towns located next to river mouths at Luni and Apuo-Versilian Plain (Bini & *alii*, 2012; 2013; Baroni & *alii*, 2015), Pisa (Amorosi & *alii*, 2013), Rosellae (Innocenti and Pranzini 1993; Bellotti & *alii*, 2004), Ostia/Portus (Bellotti & *alii,* 2007; Milli & *alii*, 2013; Goiran & *alii*, 2014; Sadori & *alii*, 2010; 2016b; Arnoldus-Huyzendveld, 2017), Minturnae (Bellotti & *alii*, 2016), Cuma (Stefaniuk & Morhange, 2005), Pestum (Amato & *alii*, 2012), and Thurii/Copiae (Bellotti & *alii*, 2003; Stanley & Bernasconi, 2009). Moreover, Anthony & *alii* (2014) proposed an overview of the relationship between anthropogenic and natural forcing in the evolution of several Mediterranean coastal areas.

The sensitivity of deltas in response to evolutionary factors makes them important sedimentary archives of the events that occurred in the entire river catchment. Disentangling natural and anthropogenic forcing, especially for earlier periods, is a difficult task (Anthony & *alii,* 2014). The distinction is easier to identify in the last two centuries since measured data have become available and made the relationship between natural and anthropogenic forcing clearer. Detailed knowledge of the stratigraphy and post-glacial evolution of the Tiber delta (Belluomini & *alii*, 1986; Bellotti & *alii*, 1989; 1994; 1995; 2007; Giraudi, 2004; Giraudi & *alii*, 2009; Goiran & *alii*, 2009; Milli & *alii*, 2013) is combined with a set of archaeological, palaeobotanical and historical information describing a time span of over 2500 years and concerning not only the delta area but also much of the connected river basin. With local exceptions, landscape changes during historical time have often dealt with natural and anthropogenic forcing separately.

The aim of this paper is to relate natural and human diachronic regional changes in the landscape of the Tiber delta plain over the past 3000 years and assess their weight, if possible. The Tiber delta, due to the abundance of historical data available for the last 2000 years, allows a good evaluation of human-environmental interaction. This can provide a further element for time limits of the Anthropocene.

GENERAL SETTING OF THE TIBER SYSTEM

The Tiber River basin is located on the western side of the central Apennines. Evolution of the Tiber River basin has mainly developed since the early Pleistocene, following a significant regional uplift (De Rita & *alii*, 1995). The eastern side of the Tiber River basin consists mainly of calcareous and terrigenous formations of the central Apennines, while on the western side, the volcanic products from the Roman comagmatic province prevail (Locardi & *alii*, 1976). (fig. 1). The development of the Alban volcano dammed the Tiber River more than 500,000 years ago (Faccenna & *alii*, 1994) and led to the westward shift of the downstream part of the river. Since then, the lower valley of the Tiber generally cuts through pyroclastic products of the Sabatino and Albano volcanic systems and clastic sediments older than the volcanic activity (Conato & *alii*, 1980).

The interaction between glacioeustatic cycles, volcanic activity and Pleistocene tectonics has produced a series of depositional sequences that can be observed along the lower Tiber River valley (Milli, 1997), the most recent of which includes the sediments of the present Tiber River delta. This depositional sequence is known in the literature as the Tiber depositional sequence (TDS), an evolving fourth-order depositional sequence (Bellotti & *alii*, 1994; 1995; Milli & *alii*, 2013; 2016). Its evolution (fig. 2) has mainly been driven by postglacial relative sea level rise between 18,000 and 6000 years ago and successively by Tiber River sediment load. Consequently, the morphology of the river mouth area changed considerably over time (fig. 3).

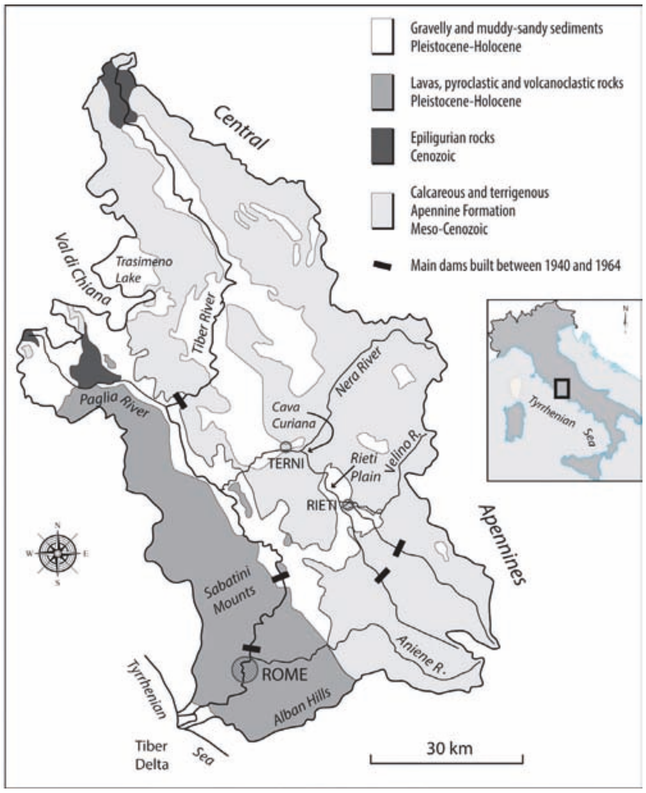

FIG. 1 - Location and lithological features of the Tiber River basin.

– The erosive lower boundary of the TDS formed during the sea level fall at the end of the Last Glacial Maximum (LGM). During the LGM, the landscape between the current urban area of Rome and the Tyrrhenian Sea was characterized by the Tiber palaeo-valley that was oriented in the E-W direction. At that time, the Tiber River flowed approximately 3-5 km north of its present course (Milli & *alii*, 2013).

– The lowstand system tract (LST) of the TDS developed following a slow sea level rise (18,000-14,000 years ago). Fluvial sands and gravels were deposited along the valley axis, which transition upward to floodplain muddy-peaty sediments approximately 85 m below the present topographical surface.

– Sediments of the transgressive system tract (TST) were deposited during the main and rapid phase of postglacial sea level rise (14,000-6000 years ago). The TST shows a complex architecture of shallowing-upward cycles derived from fluctuating rate of relative sea level rise. The first phase of rapid sea level rise triggered the drowning of the valley forming an open lagoon and barrier island

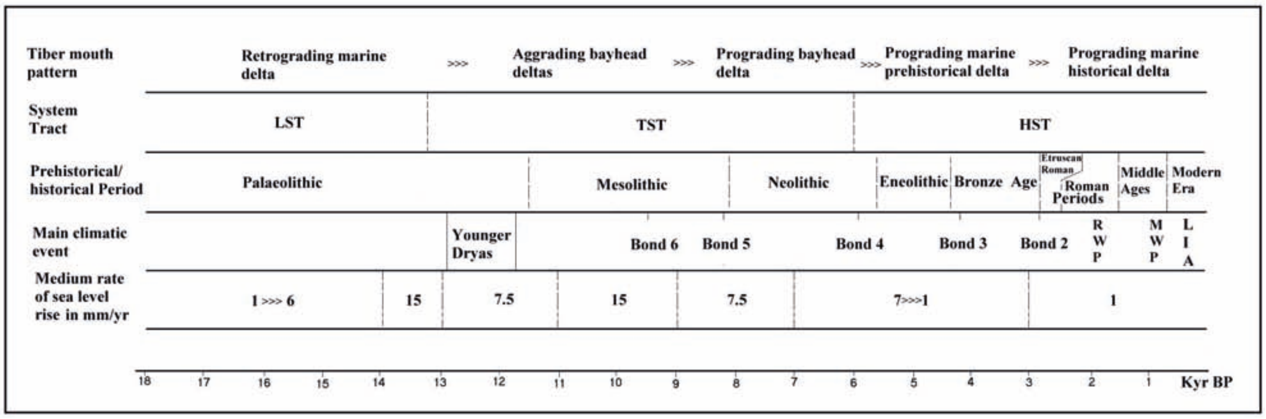

FIG. 2 - Tiber mouth pattern change through historical and climatic periods.

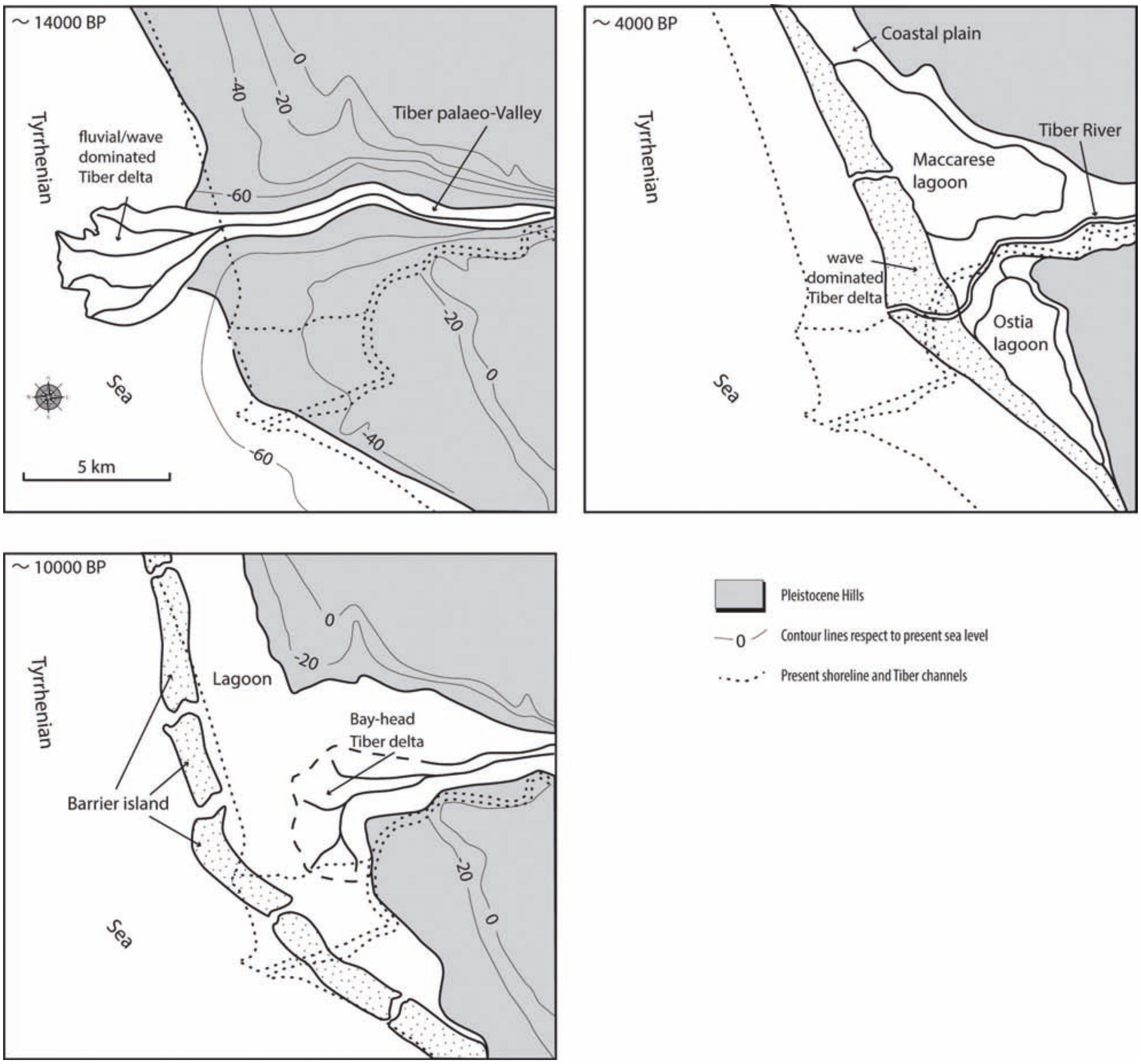

FIG. 3 - Evolutionary steps of the Tiber delta between 14000 and 4000 BP (modified after Milli & *alii*, 2016).

developed. Due to a progressive sea level rise, the coastal barriers and lagoons migrated landward, and the Tiber River mouth was permanently located inside the lagoon. Bay-head delta developed into a wave-dominated estuary. The most recent bay-head delta quickly prograded to the coastal barriers before 6000 years ago, when the Tiber River flowed into the sea.

– The highstand system tract (HST) has developed within the last 6000 years. Due to a reduced rate of sea level rise (Lambeck & *alii*, 2010), the Tiber River sediment load was adequate to trigger the formation of a wave-dominated delta (Galloway, 1975). In an early stage of the HST, coalescing coastal barriers transformed the estuary into two lagoons separated from the river course. In the northern lagoon (Maccarese lagoon), abundant organic sedimentation developed until approximately 5000 years ago. Clastic sedimentation, mainly due to Tiber River flooding events, became prevalent later. The water, mostly fresh until the ninth-eighth century BC, overtime became brackish (Giraudi, 2011; Di Rita & *alii*, 2010) for a better lagoon-sea connection. In the southern lagoon (Ostia lagoon), sedimentation of organic matter persisted until the eighth century BC, and then, the water became brackish, and clastic sedimentation became prevalent (Bellotti & *alii*, 2011). The Holocene Tiber delta (fig. 4) is currently a sandy-silt lenticular body 25 m thick, and its delta plain extends for 3 km (toward the sea), with a shoreline length of 35 km. The main hydrological and morphological characteristics of the present Tiber River are reported in tab. 1.

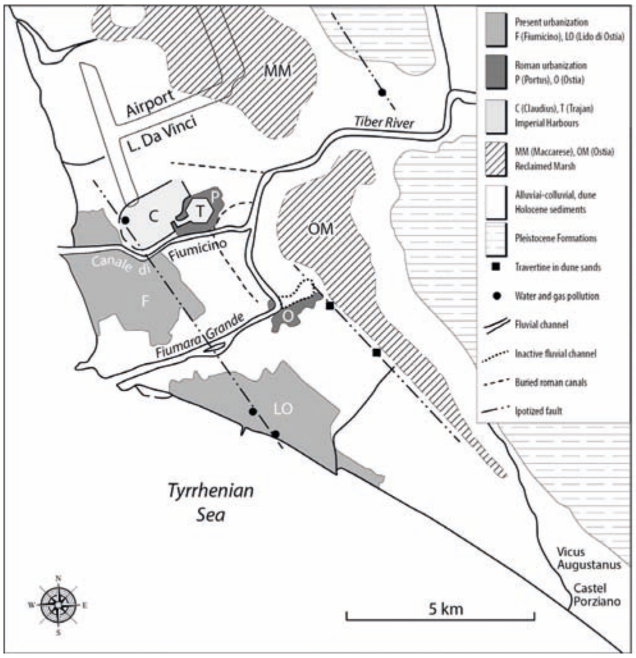

FIG. 4 - Main features of the Tiber delta landscape.

MATERIALS AND METHODS

The multi-proxy approach takes into account both environmental data and cultural sources available from the area. We used several sediment drillings, geomorphological data, palynological and archaeological data as well as considered historical sources. For the methods of the physical proxies, we referred to published studies (sediment drillings: Bellotti & *alii,* 2007; Milli & *alii,* 2013; geomorphological setting: Bellotti & *alii*, 1989; 1994; palynology: Pepe & *alii*, 2013; 2016; Sadori & *alii*, 2010, 2016b). For archaeology, we particularly considered: Broccoli, 1984; Pavolini, 1996; Baldassarre, 2001; and Keay, 2012. For the historical sources (see later), we particularly considered Latin literature (for the Roman period), Vatican documents (for the Medieval-Renaissance and post-Renaissance periods) and documents of the Italian State (since 1870). Historical maps (fig. 5), bathymetric data, and hydrological data related to the past two centuries were also considered. To evaluate the amount of sediment involved in the delta evolution during different periods, the BQART model (Syvitski & Milliman, 2007; Syvitski & Kettner, 2011) was used. BQART model is the evolution of ART model (Syvitski & *alii*, 2003) that considers the amount of river sediment load mainly a function of the river basin area (A), of the maximum relief (R) present into the basin and of the local climate. The latter element is evaluated by the mean temperature (T) of the basin. In the BQART model, element B is added. It takes into account glacial erosion, basin lithology and the trapping efficiency of the natural and artificial lakes. The element B, also takes account of human-induced erosion based on population density and on the development of sheep farming and agricultural activity. BQART model is applied through the equation [1]

TABLE 1 - Main features of the Tiber River system. Data from AbT and Bersani and Piotti(*) (1994).

Catchment area	17,375 km^2
Fluvial length	405 Km
Annual average water discharge	230 m^3/s
Annual average (1985-2005) sediment load (*)	≈ 1 MT/yr
Water discharge triggering sediment load (*)	350 m^3/s
Max measured water discharge/water level (AD 1937)	2750 m^3/s / 16.84 m
Min measured water discharge (AD 1986)	50 m^3/s
Catchment annual average precipitation	≈ 1200 mm
Max elevation catchment	2487 m

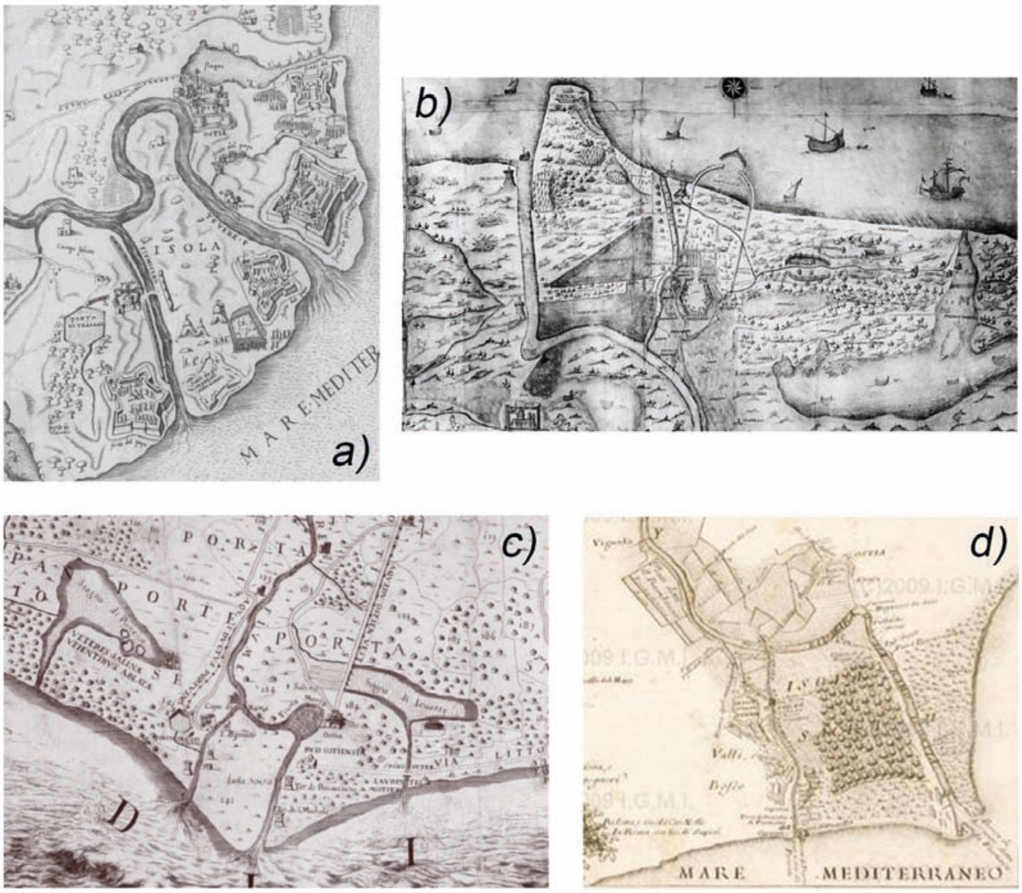

FIG. 5 - Historical maps: a) 1557 (Anonimous); b) 1603 (O. Torriani); c) 1704 (G.B. Cingolani della Pergola); d) 1744 (Chiesa and Gambarini).

$$Q_s = \omega\ [IL(1-T_E)E_h]Q^{0.31}A^{0.5}RT \qquad [1]$$

where

Q_s = sediment load in MT/yr
ω = a coefficient = 0.0006
I = glacial erosion factor
L = lithological factor
T_E = trapping efficiency of the natural and artificial lakes
E_h = human-influenced soil erosion factor
Q = water discharge in km^3/yr
A = catchment area in km^2
R = maximum relief in km
T = average basin temperature in °C

The glacial erosion in the Tiber basin is negligible (I = 1). The value of L is based on interpretation of the national geological mapping and on Tiber Basin Authority (AbT) data. For T_E, reference was made to Brune (1953). For estimating E_h, we followed Syvitski & Milliman (2007) and considered the population density from the Roman period to the present (Barbiera & Della Zuanna, 2007; ISTAT, 2016), per capita income (GNP) (Breschi & Malanima, 2002), and the development and organization of grazing activities (Morcone, 2016; Bombai & Boncompagni, 2002). The Q value, for periods without direct measurements, was based on the reconstruction of precipitation (Pauling & *alii*, 2005; Büntgen & *alii*, 2011) and descriptions of the chroniclers from different periods. The values of A, R and T are provided by the AbT.

FACTORS INFLUENCING THE LANDSCAPE EVOLUTION

In order to understand the landscape change in the Tiber River Delta, both environmental (i.e. climate, sea level change, tectonic) and anthropogenic factors (i.e. town and port construction, reclamations, management of coastal basin as saltpans, agricolture and farming activity) were considered.

Main Natural Events

CLIMATE – The climate controls water and solid river discharge and the energy of the sea. Over the past 3000 years, detailed data of climatic change have not been recorded for either the Tiber basin or the central Tyrrhenian Sea. However, we believe that the climatic changes in these areas are comparable to those reconstructed for the central Mediterranean zone. The Mediterranean area, influenced by changes in the North Atlantic Oscillation (NAO). This is commonly characterized by high subtropical pressure in the summer and by subpolar low pressure in the winter.

Sometimes there is an increase in the baric gradients that lead to seasonal weather anomalies. The persistence and intensity of these cyclonic and anticyclonic areas changed over time according to the seasonal migration pattern of the InterTropical Convergence Zone (ITCZ). Over the past fifteen years, many studies have highlighted Rapid Climate Changes events; lasting several centuries during the Holocene (Alley, 2000; Bond & *alii*, 2001; Mayewsky & *alii*, 2004; Ribeiro & *alii*, 2012; Nieto Moreno & *alii*, 2013; Zalasiewicz & *alii*, 2015) and paid particular attention to the solar forcing (Ineson & *alii*, 2011; Dietrich & *alii,* 2011; Wang & Dickinson, 2013). The different climatic periods in the central Mediterranean area, characterized by intense floods (Benito & *alii*, 2015), frequent storms (Sabatier & *alii*, 2012; Kaniewsky & *alii*, 2016; Ghilardi & *alii*, 2017) and the alternation of warm/cold (Margaritelli & *alii*, 2016) and arid/humid periods (Sadori & *alii*, 2016a) urge us to frame the Tiber delta evolution in a more defined climatic context.

According to Margaritelli & *alii* (2016), approximately 1000 BC, a cold event terminated the Bronze Age Warm Period, and drier climate persisted until approximately 500 BC. Other Mediterranean marine and terrestrial records register a change nearly 1000 BC (e.g., Sadori & *alii*, 2011; 2013). This finding could be evidence of the Bond event 2 (2.8 cal. BC), cold and drought period recorded in the North Atlantic (Bond & *alii*, 2001). A warmer/wetter climate followed, starting in different centuries and named either the Roman Humid Period (RHP) (650 BC-350 AD, Goudeau & *alii*, 2015) or Roman Warm Period (RWP) (100 BC-350 AD, Grauel & *alii*, 2013, Piva & *alii*, 2008). All records describe strong climate changes until the fourth century AD.

Historical sources reported that particularly cold winters occurred between 450 and 150 BC, with partial freezing of the Tiber River in Rome (Livii *Historiae*, V,13,1-2; Sant'Agostino *De Civitate Dei*, III, 17.34-5; Lamb, 1977). During the warmest phase, which occurred between the first century BC and the second century AD (Chen & *alii*, 2011), rains, which normally fall abundantly in winter, fell abnormally also in the summer, especially in the southern Mediterranean area (Lamb, 1977; Reale & Dirmeyer, 2000; Büntgen & *alii*, 2011). This produced frequent floods in the Rhône, Arno and Tiber basins (Benito & *alii*, 2015; Camuffo & Enzi, 1995; Bersani & Bencivenga, 2001). Three short cold and dry periods characterized the final period of the RWP (Margaritelli & *alii*, 2016).

After the RWP, a short arid (Büntgen & *alii*, 2011) and warm phase (Margaritelli & *alii*, 2016) preceded a widespread cooling period that caused an increase in rainfall between 350 and 450 AD, as evidenced in the western Mediterranean (Martin-Puertas & *alii*, 2010) and in central-southern Europe (Grauel & *alii*, 2013). In Sicily (Sadori & *alii*, 2016a), a longer humid period (Dark Age Cold Period) from 450-750 AD was interpreted from oxygen isotopes.

Since approximately 950 AD, a mostly dry period lasting approximately three centuries, with temperatures comparable to those of today, was recorded (Despart & *alii*, 2003; Guiot & *alii*, 2010; Lamb, 1977; Lebreiro & *alii*, 2006; Martin-Chívelet & *alii*, 2011; Piva & *alii*, 2008; Reale & Dirmeyer, 2000; Sadori & *alii*, 2016b). This period is commonly called the Medieval Warm Period (MWP) or Medieval Climate Anomaly (MCA).

There was later a climate cooling called Little Ice Age (LIA) is accompanied by humid fluctuations, which resulted in three wet phases in the western Mediterranean (1250-1450, 1350-1600 and 1700-1800 AD) between by dry phases (Rodrigo & *alii*, 2000; Nieto Moreno & *alii*, 2013). Also the winter and summer temperatures decreased at least 1°C and 0.6°C, respectively. In the Mediterranean, rainfall increased in the winter and summer (Barriendos, 1997; Rodrigo & *alii*, 2000; Grove, 2001; Pauling & *alii*, 2005), with a consequent increase in river discharge (Glaser & *alii*, 2010). The main rivers of the Tyrrhenian side of the Apennines show an increase in the frequency and intensity of floods as early as the fourteenth century (Camuffo & Enzi, 1995). After a short, less cold interval in the early seventeenth century, a widespread cold phase continued between the second half of the seventeenth century and early nineteenth century (Benito & *alii*, 2015; Margaritelli & *alii*, 2016). On the Rome hydrometer, the Tiber floods reached 17 m during the fourteenth century, exceeded 19 m during the sixteenth century and after 1606 AD water level never reached 18 m. In 1870 AD, the Rome hydrometer exceeded 17 m for the last time.

With the decline of the LIA, the regional climate gradually warmed up, with short fluctuating cold and wet periods until the 1960s. In the last 30 years, a warm and dry climatic fluctuation has occurred, due to the persistence of high subtropical pressure (positive NAO) (Hurrell, 1995; Rodò & *alii*, 1997), with a consequent decrease in rainfall especially in the winter (Rodwell & *alii*, 1999; Rodrigo & Trigo 2007; Gallego & *alii*, 2011). After 1870, the Tiber water level exceeded 16 m in three events only.

The analysis of storm deposits in the Mediterranean area from the last 3000 years seems to match some of the wave highly energetic phases (Sabatier & *alii*, 2012; Kaniewsky & *alii*, 2016) between 850 and 650 BC, 50 BC and 150 AD, 300 and 500 AD and 1550 and 1850 AD. These phases mostly coincide with either warm or cold humid periods, as in the RWP (Chen & *alii*, 2011) and LIA (Trouet & *alii*, 2012; Narranjo & *alii*, 2012), respectively.

Local sea level change – Lambeck & *alii* (2010) estimated that the relative sea level had risen along the Latium coasts 1.5-2.0 m in the past 3000 years, similar to other Italian coastal areas considered tectonically stable. Based on the levels of vermetids identified on the northern pier of the ancient Claudius harbour, Goiran & *alii* (2009) suggested that the sea level during the third-fifth century AD is 0.80 m below the current sea level. This means that sea level arose at a rate between 0.7 and 0.5 mm/yr**.**

Local tectonic and subsidence - The Tiber delta is spread over a Pliocene passive margin (Bartole, 1990). Normal faults have been documented along this margin, beginning in the Plio-Pleistocene, and the activity of the N-S oriented strike-slip faults are inferred until the late Pleistocene (Barberi & *alii*, 1994; Conti & *alii*, 2013; Faccenna & *alii*, 1994). General isostatic re-equilibrium of the Apennine chain uplifted the central Tyrrhenian coast (Barberi & *alii*, 1994; Bordoni & Valensise, 1998). Moreover, the existence of local volcanic activity suggests an acceleration of the tectonics in the Middle Pleistocene and uplift of the coastal margin of Latium (De Rita & *alii*, 1995). An earlier interpretation of a seismic line in this area suggested that some normal faults, with an average slip rate of 2 mm/yr and mainly dipping to the west, affected the sediments deposited after the LGM (Bigi & *alii*, 2014). An Apenninic fault system (trending about N40°W) runs through the delta area, possibly increasing fluid flow related to the Albano volcanism. Hydrothermal systems were active in the inner part of the delta between 900 BC and the Roman period (Arnoldus-Huyzendveld & *alii*, 2005) due to the extension of a fault present on the Pleistocene terraces immediately to the north of the delta (Rosa & Pannuzi, 2017).

Also the travertine concretions in dune sands, detected along an alignment N40°W near Ostia Antica (Rosa & Pannuzi, 2017) and close the western side of the Ostia marsh (Bellotti & *alii*, 2011), testify the rising of fluids along tectonic lines in the historical period. The rising of fluids along tectonic lines is still active as demonstrated by sudden deep gas eruption at Fiumicino (Ciotoli & *alii*, 2013; 2016) and the contemporary outcrops of water observed at Lido di Ostia in August 2013. Even these last events are aligned according to an Apennine trend (fig. 4).

Salomon (2013) compared the stratigraphic position of the lagoon peat layers and sea level rise curves and hypothesized a vertical dislocation downthrowing the southern delta area. Subsidence due to compaction appears to vary locally (Manassero & Dominijanni, 2010). Interferometric surveys showed subsidence rates greater than 20 mm/yr where sediments are rich in peat (Maccarese and Ostia lagoons) and less than 3 mm/yr where sandy sediments are dominant (Ministero dell'Ambiente, 2014).

MAIN ANTHROPOGENIC ACTIVITIES - During the tenth-eighth century BC, near the freshwater Maccarese and Ostia lagoons, a few scattered settlements were sporadically used (Morelli & Forte, 2014). In the Tiber catchment, around the mid-eighth century BC, the synechism of some tribes settled on the hills at the left side of the Tiber River, approximately 30 km from the mouth, giving rise to the town of Rome (Giraudi, 2004; Bellotti & *alii*, 2011; Salomon & *alii*, 2018).

Between seventh and fourth century BC, close the Tiber River mouth Ostia was founded. Latin literature indicates 630 BC as the date of the first Roman settlement at the Tiber River mouth (Livii "*Ab Urbe Condita*" 1, 33). However, the most ancient Roman ruins, established by the *castrum* of Ostia, date back to the fourth century BC (Torelli & Zevi, 1973). In this time interval, to the north of the Tiber River, Etruscan saltpans were active under the control of Veii (Plutarch, *Romolus* 25; Dionysius of Halicarnassus, Roman Antiquities 2, 55, 5; Cingolani, 1774). Around the fifth century BC, in the first development of Rome, the local topography was artificially modified to gain useful space for the expansion of towns (Ammerman & Filippi, 2004). In 397 BC, the basin of the Albano Lake (6 km^2) was artificially connected to the Tiber River basin (Livii "*Ab Urbe Condita*" 5, 15-16).

During the fourth-first century BC, the town of Ostia mainly developed along the left bank of the Tiber River between the last meander and the mouth (Pavolini, 1996). The town had a harbour (Quintus Ennius "*Annales*" 2, 76-77) inside the river channel, with a boat dock next to the mouth (Fea, 1824; Canina, 1830; Heinzelmann & Martin, 2002; Goiran & *alii*, 2014; Sadori & *alii*, 2016a; Goiran & *alii*, 2017). Additionally, the Ostia lagoon saltworks may have developed at this time (Livii "*Ab Urbe Condita*" 1, 33). In the Tiber catchment, the consul Marcus Curio Dentato (271 BC) ordered a canal to be dug to drain *Lacus Velinus* (in the Rieti plain). This work (named *Cava Curiana*) caused the release of huge floods of the Velino River in the Tiber catchment (Cicero, "*de Reatinorum Causa*"). In the entire Tiber basin, agricultural organization gradually increased, as well as the utilization of timber, which was transported to Rome by the river (Strabo "*Geographica*" 5, 2, 5; Pliny the Younger "*Epistules*." 5, 6).

Between 42 and 64 AD, the Emperor Claudius built a harbour approximately 3 km north of Ostia, with two piers jutting into the sea (Pliny the Elder "*Naturalis Historia*"; Suetonius "*Claudius*"). The detailed reconstruction of the local environmental changes following the construction of the Claudius harbour, are described in Arnoldus-Huyzendveld (2017). Between 100 and 112 AD, Trajan built a hexagonal inner harbour connecting it with the adjacent Claudius harbour (Pliny the Younger "*Panegyricus*"). Some canals connected the harbours to both the Tiber River and the Tyrrhenian Sea. (Goiran & *alii*, 2010; Salomom & *alii*, 2014) Around this harbour complex (the largest of the ancient world), the town of *Portus* developed. Dams were built with amphorae, and canals were built in the Maccarese lagoon (Morelli, 2008; Grossi & *alii*, 2015). In the second half of the first century AD, most of the walking surfaces in Ostia, were raised about one metre (Zevi, 1970; Pavolini, 1996). During the first-second century AD, the agricultural organization in the Tiber valley changed from small and medium rural properties to latifundium (Pliny the Younger "*Epistules*" 5, 6; Strabo 5, 4, 11). This process limited the earlier restrictions to animal movement and thus favoured breeding and transhumance (Mengarelli, 2010).

In the long interval between the fifth and the fourteenth century AD, with the decline of the towns of Ostia and Portus (Février, 1958), the territory was gradually abandoned. Near Ostia, under the papacy of Gregory IV (IX century) (Broccoli, 1984), a fortified village *(Gregoriopoli)* was built to protect the remaining inhabitants. The gradual silting up of the imperial ports and the existence of a minor mouth of the Tiber were witnessed by the *Liber Pontificalis* 23 (mid-ninth century) and the papal seals of John XV (992) and Benedict IX (1037). The minor Tiber River mouth was created by a canal (*Fossa Traiana*) dug, in the second century AD, for the construction of the imperial harbours flanking the southern pier of the Claudius harbour (Keay, 2012). This channel no longer maintained after the abandonment of the ports had intermittent activity. Some documents dating back to the twelfth century testify to the presence of saltpans in the Ostia lagoon (Pannuzi, 2013). In the Tiber catchment the *Cava Curiana* suffered a partial obstruction due to a lack of maintenance, and the marsh extended back into the Rieti plain (fig. 1) (Camerieri

& Mattioli, 2014). The agricultural and grazing organization deteriorated due to both the population decline and less extensive latifundia that were mostly connected to the properties of the Catholic Church until the twelfth century. In the fourteenth century, the establishment of the customs of the sheep movement allowed greater development of the pasture economy (Mengarelli, 2010). The considerable amount of timber previously requested for construction, furnaces and heating of *termae* was no longer gathered.

During the fourteenth-eighteenth century AD, the minor Tiber River mouth, now named *Canale di Fiumicino*, was definitively reopened (Fea, 1824) after five centuries of intermittent functionality. Several towers were built to control both mouths that were quickly prograding in this period. The Maccarese and Ostia lagoons evolved into two marshes (Bellotti & *alii,* 1989). Saltpans in the Ostia lagoon developed, although since the sixteenth century, there has been no news of saltpans in the Maccarese lagoon (Pannuzi, 2013). In the Tiber river basin, the drainage of the Rieti plain (formerly *Cava Curiana*) was progressively reactivated, and then, part of the Val di Chiana (approximately 1000 km^2) disconnected from the Tiber basin (Biagianti, 1990). In central Italy grazing was re-developed and well organized.

In the nineteenth century, reclamation work started in the Ostia and Maccarese marshes. Near the minor Tiber River mouth, the village of Fiumicino was built and along the Tiber River, the embankments were built from Rome to the river mouths.

In the last century, the reclamation of the two marshes was completed. The residential centre of Lido di Ostia expanded south of the Tiber River mouths, and a busy tourist industry developed there. The Fiumicino International Airport was built on the northern bank. Significant hydroelectric reservoirs were built along the Tiber River and some of its tributaries. In the Tiber catchment, the population density doubled respect to precedent century. A synthesis of the main elements which contributed to the evolution in historical Tiber delta landscape, is drawn in fig. 6.

VEGETATION CHANGES

Anthropogenic effects are often hard to distinguish from climate effects (Mercuri & Sadori, 2012), and past vegetation studies alone are not able to solve the dilemma of which of the two was the main agent of environmental change (Mercuri & *alii*, 2013; Oldfield & *alii*, 2003; Roberts & *alii*, 2011; Sadori & *alii*, 2004; 2013) since the Bronze Age, when humans started to consistently shape the landscape. Palynology has often been misused to assess either the degree of climate change or the level of human involvement. Palynology alone cannot be used to determine the difference; for example, both human impact and aridification can produce forest clearance (Sadori & *alii*, 2011). The same issue applies to climate reconstructions of the last millennia based on pollen (Li & *alii*, 2014) as the cause of wood opening can be twofold.

A clear and simple pattern of vegetation changes over the Mediterranean region therefore not only is difficult to find but also probably does not exist, as vegetation dynamics are highly determined by regional exploitation of the territories. The best way to solve this problem is to combine palynology with other environmental proxies (Sadori & *alii*, 2016a). This combining is one of the aims of this study.

The last three millennia are recorded in few Mediterranean pollen records due to the difficulty of sampling recent soft sediments from extant lakes and of finding pollen in the cultivated fields of drained lakes. Most central Italian records have evidence of forest opening soon after 3000 years ago (Sadori & *alii*, 2011). If this landscape change is found at the transition from the Bronze to Iron Age, it

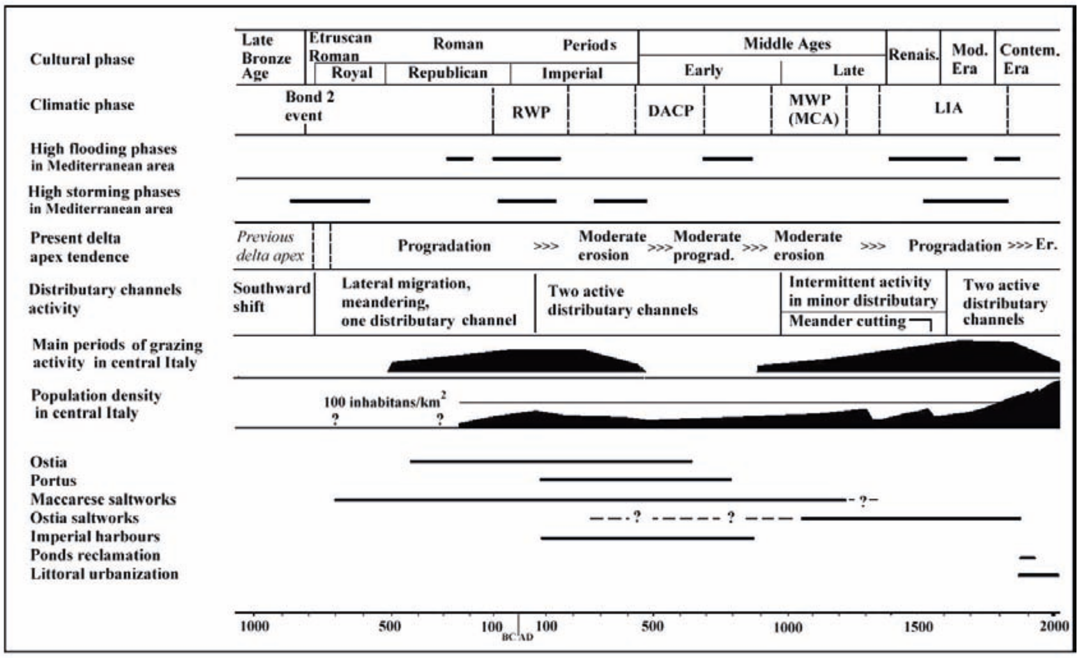

FIG. 6 - Summary of the main elements that contributed to the evolution in Tiber delta landscape through cultural and climatic phases in the last 3000 years.

could also have a global climatic cause, as an important and sudden climate change is recorded in the Northern Atlantic records approximately 2800 years ago (Bond event 2, Bond & *alii*, 2001). Clear signs of increasing cultivation, pasture, and land use are found in many central Italian records soon after 3000 years ago (Drescher-Schneider & *alii*, 2007; Magri & Sadori, 1999; Mercuri & *alii*, 2002). We lack data in the whole Tiber river catchment, as pollen records are available from Latium volcanic lakes (e.g. Albano and Nemi: Lowe & *alii*, 1996; Mercuri & *alii*, 2002; Vico: Magri & Sadori, 1999; Mezzano: Sadori & *alii* 2004).

For the Tiber delta area, mid-Holocene natural archives have also been palynologically investigated. The investigated cores outside the harbour areas are from the Maccarese lagoon/marsh (Di Rita & *alii*, 2010); *Fiume Morto*, a cut-off Tiber River meander (Pepe & *alii*, 2016); and Ostia lagoon/marsh (Bellotti & *alii*, 2011). The ancient Ostia riverine harbour (Goiran & *alii*, 2014; Sadori & *alii*, 2016b) and Claudius (Giardini & *alii*, 2013; Pepe & *alii*, 2013, Sadori & *alii*, 2013) and Trajan basins records cover the period between the ninth century BC to present. Discontinuity cannot be ruled out for most records, and this is particularly true for the two records located close to the Tiber River (namely, the *Fiume Morto* and ancient Ostia records). We have also a good record along the central and (partly) southern Italian marine coast and the last couple millennia are well represented in the sediments of the ancient Italian harbours of Naples, Pisa, and Rome (Sadori & *alii*, 2015). In the ancient harbours of Rome, many cores have been studied using a multiproxy approach including palynology (Mazzini & *alii*, 2011; Pepe & *alii*, 2013; Sadori & *alii*, 2010; 2016b).

In the last three millennia, the period we are mainly focusing on, a complex mosaic of natural vegetation and human landscapes established the plant environment of the delta. Deciduous coastal plain forest, Mediterranean evergreen and riparian arboreal formations are present. The two marshes seem to record different environments. In the Maccarese marsh (Di Rita & *alii*, 2010), lacustrine and perilacustrine vegetation was widespread and is probably masking the regional arboreal pollen rain. In the Ostia marsh (Bellotti & *alii*, 2011), both deciduous and evergreen oaks were spreading. This colonization was related to the new land made available by the accretion of the delta cusp. The vegetational landscape near the Ostia harbour (Sadori & *alii*, 2016b) was also characterized by deciduous and evergreen oaks, as well as high percentages of olive trees. Very high percentages of pine were found in low-concentration pollen samples and related to river erosive phases. In the cores from ancient Ostia area, human impact is clearly detected in the last few centuries BC.

Saltwork activities were historically and palynologically documented in the area since the sixth century BC (Di Rita & *alii*, 2010). These activities are detected in the records of the *Fiume Morto* (Pepe & *alii*, 2016), Ostia marsh (Bellotti & *alii*, 2011) and harbour (Sadori & *alii*, 2016), and Claudius basin (dock core, Sadori & *alii*, 2010) by chenopod pollen spreads. Tamarisks, probably planted in the Roman imperial period to stabilize the dunes and protect the imperial harbour (Sadori & *alii*, 2010), could also be used to evaluate the distance from the sea and thus the evolution of the coastline.

Environmental changes are rather strong along the river in the area of Ostia and do not provide a direct climate signal. In fact, the *Fiume Morto* and Ostia cores show complex trends, with significant pollen changes that probably mirror the Tiber River dynamics and are evidence of floods during the Republican/Imperial age, Renaissance and modern ages. In this last period, intense floods historically documented (Bersani & Bencivenga, 2001) were the expression of the Little Ice Age. The most recent pollen data are from *Fiume Morto* core (Pepe & *alii*, 2016) and record the presence of quite reduced arboreal vegetation.

APPLICATION OF THE BQART MODEL

To evaluate the applicability of the BQART model to the Tiber basin, four periods were considered; for each period, the values of Q, Qs, Te, Eh and T are known. Given the constant values of ω = 0.0006, I = 1, L = 1.5, and R = 2.487, we compared the measured Qs values and those estimated by the model for each period. The evolutionary trend of the delta apex is known. The first two periods (1873-1878 and 1932-1942) precede the construction of hydroelectric reservoirs, but in the second period, the population density and urbanization are greater in the catchment. The third period (1948-1964) is marked by the construction of the main hydroelectric reservoirs, and the fourth period (1965-1994) considers a catchment with a further increase in population, GNP and urbanization. The values are given in tab. 2.

Although the first three intervals are short, for a good statistical calibration, it can be assumed that the model provides acceptable accuracy in estimating the values of Qs.

The BQART model was then applied to three different periods before the Val di Chiana disconnection, during which the Tiber River was considered to have a wider catchment.

For the sixteenth-seventeenth centuries (part of the LIA), we considered a rainfall increase of approximately

TABLE 2 - Measured Qs versus BQART estimated Qs and effect in delta shoreline

Period	Qs measured in MT/yr	Qs estimated in MT/yr	Trend of the delta shoreline
1873-1878	10.5	9.9	moderate progradation
1932-1942	7.6	6.9	quasi stability
1948-1964	4.2	4.2	retreat
1965-1994	1.5	1.8	severe retreat

6% from the present day (Pauling & *alii*, 2005; Büntgen & *alii*, 2011), with a water discharge of approximately 300 m^3/s. The average temperature of the Tiber catchment was assumed to be 1°C less than the present-day average temperature. The model used a value of Eh = 1.4, slightly greater than that used for the end of the nineteenth century due to the lower GNP and the greater grazing development and organization. The value of Qs predicted by the model is 11 MT/yr.

For the MCA (tenth-thirteenth centuries) we estimated that the rainfall was approximately 8% less than present-day rainfall (Büntgen & *alii*, 2011), with a water discharge of approximately 225 m^3/s, a temperature equal to the present-day temperature, and Eh = 1 due to the low population density and poor grazing organization. The Qs value predicted by the model is approximately 7.6 MT/yr.

For the RWP (first century BC-second century AD), we estimated that the rainfall was approximately 4% greater than present-day rainfall (average water discharge 290 m^3/s), and the average temperature was the same as the present-day average temperature. Considering a greater population density in the Middle Ages and Renaissance periods and the progressive development of agriculture and pastoralism, a value of Eh = 1.2 was used. The Qs value predicted by the model is approximately 10 MT/yr.

CHANGES IN THE DELTA LANDSCAPE AND PROBABLE CAUSES

Tenth-sixth century BC (fig. 7a) – In this period, natural processes were dominant. The fluvial or backdune facies older than 2900 years near Fiumicino and the coeval facies with marine influence near Ostia suggest that the Tiber River mouth was to the north of its current position during the tenth century BC (Giraudi, 2004; Bellotti & *alii* 2011; Di Bella & *alii*, 2011; Goiran & *alii*, 2014; Salomon & *alii*, 2012; 2018). Between the ninth and sixth centuries BC, a crevasse in the left bank or a local tectonic movement caused the sudden southward migration of the Tiber River mouth. The river flowed toward the Ostia lagoon, and the new river mouth was established near the lagoon. The deactivation of the northern mouth produced a local shoreline retreat allowing seawater input into the Maccarese lagoon, which then became brackish (Di Rita & *alii*, 2010). The settlements present near the lagoon shore in the final Bronze Age were abandoned in this period. The Ostia isolated lagoon was influenced by fluvial sediments and seawaters (Bellotti & *alii* 2011). Due to the new river mouth position, a cusp developed that highlighted the different orientations of the new beach ridges (Bellotti & *alii*, 2011). This development agrees with the presence of preportual marine to brackish lagoonal ostracod assemblages (radiocarbon dated at the base between 895-798 years BC) in the area of ancient Ostia harbour (Goiran & *alii*, 2014; Sadori & *alii*, 2016b).

Fifth-fourth century BC (fig. 7b) – The new mouth quickly prograded (rate ≈ 6 mm/y) by the juxtaposition of beach ridges, locally separated by ephemeral interdunar lagoons. The *castrum* was built on the enlarged cusp. A meander upstream of Ostia developed and lapped the outer edge of the Ostia lagoon (Bellotti & *alii* 2011; Vittori & *alii* 2015). In the Maccarese lagoon, now brackish with fewer deep areas (Di Rita & *alii*, 2010; Giraudi, 2011), the Etruscan saltpans developed. Pollen data from both the Ostia lagoon (Bellotti & *alii,* 2011) and riverine harbour (Sadori & *alii*, 2016b) suggest the presence of mesophilous vegetation with typical elements of the deciduous oak plain forests. Near the river mouth, cultivated taxa such as olive, cereals and grape vine and a concentration peak of total charcoals (a proxy for fire) are found, together with sorrel, which is an indicator of pastureland according to most authors (Florenzano & *alii*, 2013; Sadori & *alii*, 2004). Local use of fire, detected by bigger fragments of ash preserved in the sediments, is recorded, confirming an anthropic pressure. Besides natural fires, microcharcoals in fact can record the use of wood for heating, building, or producing metals. The increased land use in the area (forest clearance and grazing) left also hints for soil erosion (*Glomus* spores and *Pseudoschizaea* cists) in the pollen record. For the first time, the local landscape is significantly influenced by anthropogenic forcing due to both the development of saltpans and the town of Ostia.

Third-first century BC (fig. 7c) – Human activity became progressively more important in the landscape evolution especially for the expansion of Ostia. The progradation of the cusp was probably due to also the opening of the *Cava Curiana*, the canal excavated at the end of the third century BC, to reclaim the Rieti plain. This connection allowed easier transit of the Velino river water discharge (about one-fifth of the total Tiber water discharge) and sediments that were previously largely trapped in the Rieti plain (Mensing & *alii*, 2015 Camerieri & Mattioli, 2014). The BQART model estimates that the lake could trap sediment at a rate of approximately 0.8 MT/yr. Even the development of agriculture in the Tiber basin increased sediment availability. The town of Ostia developed with its harbour around the *castrum*. In the first century BC, the access into the river had been described as easy, large and not affected by sand deposits (Dionysus of Halicarnassus "Roman Antiquities" 3, 46). The meander that laps the Ostia lagoon, gradually assumes a flattened shape (Salomon, 2013; Salomon & *alii* 2017). This morphology could be due to the erosion resistance of the cohesive lagoon sediments or conditioned by anthropic structures (e.g., docks) built on the left riverbank (Salomon & *alii*, 2016). Considering that the meander is located probably along a fault running on the western edge of Ostia lagoon (see fig. 4), the tectonic influence cannot be ruled out. The Maccarese lagoon is a largely swampy area, unsuitable for human settlements, with only a partial utilization for salt extraction (Di Rita & *alii*, 2010). As already mentioned possible olive intense cultivation is detected at the Tiber mouth (Sadori & *alii*, 2016b) but an increase in land-use for trees and herbs cultivation is also found at the more inland Ostia saltpan (Bellotti & *alii*, 2011). Mesophilous vegetation still appears rather preserved and mixed with Mediterranean and riparian elements.

First-fourth century AD (fig. 7d) – Historical sources (Carcani, 1875; Camuffo & Enzi, 1995; Bersani & Bencivenga, 2001) indicate the occurrence of 13 Tiber flood

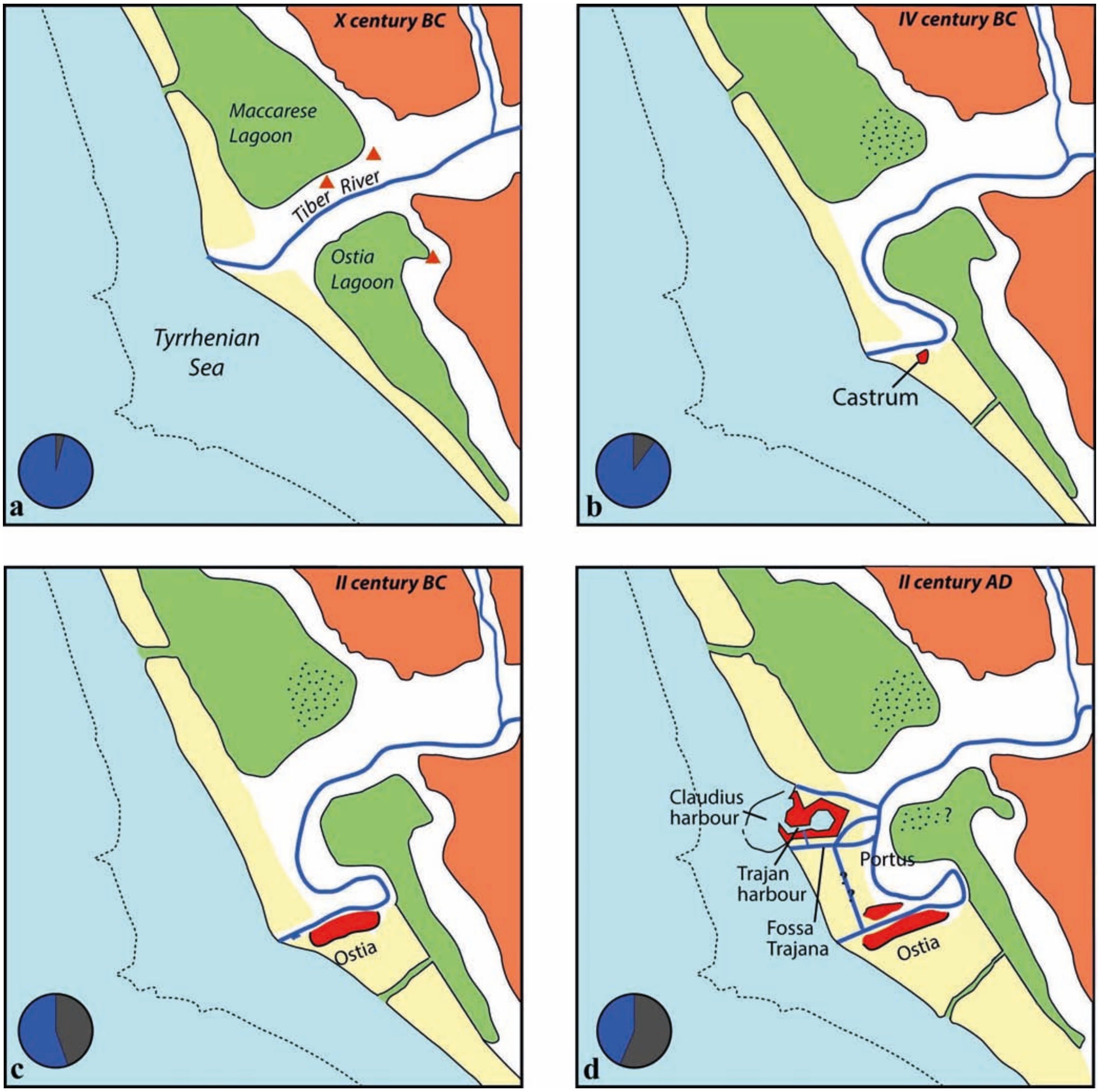

FIG. 7 - Schematic bidimensional landscape reconstruction of the Tiber delta between the tenth century BC and the Roman period. The dotted line marks the current shoreline. The circular diagram indicates a valuation of the relative weight of natural (blue) and anthropic (gray) evolutionary factors. For the legend, see fig. 8.

events between the second half of the first century BC and the end of the first century AD. At the Ostia harbour (Sadori & *alii*, 2016b), a very low pollen concentration, the presence of damaged pine pollen grains transported by the river from the inland drainage basin, and peaks of palynomorphs indicating soil erosion are evidence of these floods. We can assume that these floods were particularly intense because the walking surface in the Roman Forum was raised from 10 m (in kings period) to 12.70 m a.s.l. (in the Augustan-Trajan period) (Bianchi & Antognoli 2014). In addition, flood-associated sediments made the use of the harbour of Ostia more difficult (Goiran & *alii*, 2014). In fact, Cassius Dio (*Historia Romana* 60, 11, 1) described the phenomenon as “close to the mouth the Tiber River banks did not provide enough protection for the vessels any more”. Since the foundation of the town of Ostia, the water table in the sands of Ostia raised by approximately 30 cm due to sea level rise. In addition, the frequent flooding of the Tiber in the first century likely created some problems for the town. This flooding was probably an element that led to the raising of the Ostia walking surfaces before building renovation started by Emperor Domiziano.

The BQART model estimates show that the water discharge was at that time, greater than the current one and this is consistent with the events described above. However, the progradation rate of the delta apex did not increase and underwent a first erosional phase in the third century (Bellotti & *alii*, 2011). This event is consistent with a phase of high energy of storms (Kaniewsky & *alii*, 2016), one of which occurred in 62 AD and is described by Tacit (*Annales* 15, 18). Under these conditions, the sediments easily migrated from the apex to the delta wings, which explains why at *Vicus Augustanus*, approximately 12 km south of Ostia, the progradation appears to continue throughout the Roman period (Bicket & *alii*, 2009). The town of Ostia, which extended to the right of the Tiber River, reached its maximum expansion due to delta progradation. One of the canals dredged for construction of the imperial harbours created a second Tiber River mouth (*Fossa Traiana*), which, together with the Claudius harbour jetties, changed the hydrodynamics of the area. The opening of the second mouth shifted part of the fluvial sediment deposition approximately 3 km to the north of the apex and contributed to the delta apex erosion starting in the third century AD (the data indicate that currently 20% of the Tiber River sediment load flows into the minor mouth). The Tiber delta is still characterized by a mosaic of different vegetation types: deciduous, evergreen oaks and riparian elements still surround the intensely exploited areas. Between first and fifth century AD, the delta landscape was characterized by two important and contiguous towns (Ostia and Portus) closely interconnected, by roads and waterways, with a complex harbour system. In addition, the extensive development of saltpans in the Maccarese lagoon and perhaps the Ostia lagoon (Pavolini, 1983; Morelli & *alii*, 2011) is another indication of the strong anthropic control of the delta landscape. Toward the end of this period, landscape changed due to climate change and less anthropic control. The silting up of the Claudius harbour become more prominent, and the first wetlands developed. Human activity largely determined the landscape evolution, although the natural processes related to the frequency of the Tiber floods are not negligible. The second river mouth and the remains of the imperial harbours still mark the landscape of the area today.

Fifth-tenth century AD (fig. 8a) **–** The influence of human activity gradually declined. The Dark Age Cold Period (Ker, 1904) coincides with the progressive abandonment of the Roman agricultural organization and maintained land in both the Tiber delta and catchment. The largely abandoned delta areas became swampy and more sensitive to the Tiber floods. The Procopius description (*De Bello gotico* I, 26, relative to 537 AD) testifies to the land degradation and suggests limited recovery of the cusp progradation and sufficient functionality of the Trajan harbour. Later, the Claudius harbour quickly silted (Di Bella & *alii*, 2011), and the Trajan harbour was no longer useable from the ninth century on (Gallina Zevi & Turchetti, 2004). In this cold-humid climatic phase (Martin-Puertas & *alii*, 2010) the progradation was probably limited by greater development of the vegetation cover in the basin (due to reduction of agricultural practices and reduced use of timber) and the partial obstruction of the *Cava Curiana*.

In the two cores (Pepe & *alii*, 2013) of the Claudius harbour, the co-occurrence of ostracods from different palaeoenvironments is evidence of the presence of a salinity wedge and indicates the occurrence of regular discharge events distinct from historical floods from the fourth to fourteenth centuries. Around Portus, the human impact was lower during the first centuries AD than during late antiquity and the Middle Ages (Pepe & *alii*, 2013; Sadori & *alii*, 2010).

Eleventh-fourteenth century AD (fig. 8b) – In the first part of this period, coinciding with the MWP/MCA, the BQART model estimates a significant reduction in both the sediment and water Tiber River discharge. The delta apex was subject to an erosive phase. The southern pier of the Claudius harbour intercepted the sediments coming from the main outlet and directed northward by prevailing longshore current. Therefore, sediment accumulation was produced near the mouth of the Fossa Traiana area that could not be completely removed due to the limited channel water discharge. Therefore, the minor Tiber River mouth had intermittent activity and was not navigable from the beginning of the twelfth century. It is believed that for some centuries, the Tiber delta predominantly had a single mouth.

Fifteenth century - 1850 AD (fig. 8c) – The last significant environmental change, primarily driven by natural forcing, occurred during this period. The frequent summer rainfall in the sixteenth and seventeenth centuries, saturating the soil, caused the huge floods easier in subsequent autumn periods. A rapid progradation (maximum rate 9 m/yr) at the main Tiber River mouth (Bellotti & De Luca, 1979) started in the sixteenth century due to the four major floods that occurred between 1530 and 1606 AD (Bersani and Bencivenga, 2001). The value of the sediment load estimated by the BQART model (11 MT/yr) does not explain this fast progradation. This rate can be explained considering that, the estimated water discharge ($\approx 300\ m^3/s$) is very close to the sediment load trigger value ($\approx 350\ m^3/s$). This sediment load trigger value may have been frequently exceeded, producing a sediment load greater than that predicted by the model. At Fiume Morto, an oxbow lake created after the Tiber meander cutoff of 1557, pollen data (Pepe & *alii*, 2016) indicate the presence of synanthropic taxa and chenopods (Amaranthaceae) that are typical of marshy areas and saltworks. The sediments of the small oxbow lake recorded the occurrence of episodes related to the floods that are also documented during the Little Ice Age. Additionally, foraminifera associations in the external margin of the prodelta (Di Bella & *alii*, 2013) indicate an influence of fluvial inputs not identified in previous wet climatic phases.

The delta became strongly cusped (Salomon, 2013) and the Tiber River assumed the current flow path, abandoning the meander of Ostia, after the flood of 1557 AD. In 1612 AD, the secondary river mouth was artificially reopened and

FIG. 8 - Schematic bidimensional landscape reconstructions of the Tiber delta from the Middle Ages to the present. Coloured areas indicate: Pleistocene hills (brown), lagoon/marsh/pond (green), strand plain (yellow), main reclaimed zone (violet), alluvial/colluvial zone (white), fluvial and artificial channels (blue), urbanized zones (red). The dotted areas indicate the saltpans; the red triangles indicate the remnants of Late Bronze Age settlements.

named Canale di Fiumicino. Since then, the delta has two mouths that are permanently active. The secondary river mouth is rapidly prograding, while the main river mouth is partially dismantled, and a relative shoreline rectification between the mouths has begun. The shoreline evolution of the north delta wing was affected in an early phase by the remains of the Claudius harbour jetties that interfered with the northernward littoral drift. Only when the shoreline migrated seaward beyond the Claudius harbour jetties did the delta shape become an asymmetrical cusp (Chiesa & Gambarini, 1744). The intense progradation, favoured also by the gradual reactivation of the Rieti plain drainage, produced the Claudius harbour filling, the change of the Trajan harbour into a lake and of the Maccarese and Ostia lagoons in ponds (the Maccarese Pond in the north and Ostia Pond in the south). Coinciding with this environmental transformation, malaria, already widespread in the area became particularly intense since 1590 AD on (http://media.

accademiaxl.it/pubblicazioni/malaria). The decrease in the progradation rate in the eighteenth century is coincident with a lower intensity of the Tiber floods and the amplitude reduction of the Tiber basin due to the disconnection of the Val di Chiana. In the same period, a wide pinewood (*Pinus pinea*) was implanted in the southern delta wing and left a clear mark in the most recent samples of the PO1 core at Ostia (Sadori & *alii*, 2016b).

1850 AD – today (fig. 8d) – Human action was crucial in the delta landscape evolution**.** The end of progradation followed the end of the LIA and the beginning of an intense management in the lower Tiber River alluvial valley. At the end of the nineteenth century, two reclaimed and intensively cultivated depressed areas (previous Maccarese and Ostia ponds) was separated from the sea by a broad strand plain. In the first half of the twentieth century, a new erosive phase produce an increase in the slope of delta apex submerged beach (Tarragoni & *alii*, 2015) without substantial change in shoreline position. This erosive phase is linked to a decrease in the fluvial inputs caused by both climate improvement and the Tiber basin management that occurred after the annexation of Rome by the Kingdom of Italy. In the second half of the twentieth century, the construction of important hydroelectric reservoirs in the Tiber catchment, along with the growth in population density, drastically reduced the fluvial bed load. These events, along with the dune belt destruction due to the intense littoral urbanization, produce a severe shoreline retreat in the delta apex (Mastronuzzi & *alii*, 2017). During the erosive phase of the third century AD, the beach of the former *Vicus Augustanus* (today Castelporziano) was stable or in a limited progradation stage. Presently, the apex delta beaches are maintained and stable only because of breakwater or artificial nourishment. The Fiumicino airport building at the Tiber River delta provides the connection between Rome and the world as the Roman harbours had done in the past.

CONCLUSIONS

Natural and anthropogenic forcing drove diachronic changes in the Tiber delta landscape during the last 3000 years. The natural forcing was essentially due to climatic changes and, to a lesser extent, related to the vertical tectonic movements. The shoreline progradation changes in the Tiber final channel may have responded not only to more humid sub-Milankovian climatic oscillations but also to variations in seastorm strength. In warm-arid periods, shoreline retreat phases and the uncertain functionality of the Tiber minor mouth are identified. Anthropogenic forcing has contributed to delta landscape change by acting both on the coast and in the river catchment.

During the Roman period, in the catchment area, reclamation works, progressive spread of the agricultural/breeding organization and timber use increased the availability of river sediment. Along the coast, human activity was characterized by harbours and towns construction, artificial opening of a second river mouth and the management of coastal basins as saltpans. The delta landscape in this phase was severely conditioned by the anthropic activity.

Between the Roman period and the modern era, anthropogenic forcing seems less important than natural forcing. Throughout the Middle Ages and until the first half of the nineteenth century, in a very fragmented socio-political fabric, a more natural landscape evolved in the delta, gradually and partially replacing the previous landscape.

With the arrival of the new Italian State and reclamation of the Maccarese and Ostia ponds that characterized the delta for 3000 years, a new and impressive landscape change occurred, which preceded the intense urbanization of the twentieth century.

It is evident that the evolution of the delta landscape has been particularly affected by anthropogenic forcing when past socio-political organization allowed the control and planning of policy actions, as in Roman times and in the establishment of the Italian State. Recently, the development of modern technology has clearly allowed anthropogenic forcing to become prevalent.

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