pca

european journal of
postclassicalarchaeologies

volume 7/2017

SAP Società Archeologica s.r.l.

Mantova 2017

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Cover image: embankments at the Danube waterfront of Regensburg "Donaumarkt" made of re-used Roman material, probably Carolingian (S. Codreanu-Windauer, BLfD 2014).

"Post-Classical Archaeologies" is indexed in Scopus. It was approved on 2015-05-13 according to ERIH PLUS criteria for inclusion. Classified A by ANVUR (Agenzia Nazionale di Valutazione del sistema Universitario e della Ricerca).

DESIGN
Paolo Vedovetto

PUBLISHER
SAP Società Archeologica s.r.l.
Strada Fienili 39/a, 46020 Quingentole, Mantova
www.archeologica.it

PRINTED BY
Tecnografica Rossi, Via I maggio, Sandrigo (VI)

Authorised by Mantua court no. 4/2011 of April 8, 2011

For subscription and all other information visit the web site www.postclassical.it

ISSN 2039-7895

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european journal of
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PCA 7 (2017) ISSN: 2039-7895 (pp. 173-199)
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research

The Lower Tiber valley, environmental changes and resources in historical times

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In the Middle and Late Holocene, the coastal plain of Rome has been subjected to a very complex environmental evolution, in which the Tiber has played an essential role. In this article, the influence of the Tiber on the coastal landscape is considered for different historical periods, as well as the interaction between the river, the valley and the coastal plain on the one hand and the exploitation of the natural resources on the other. It is meant to be an updated overview based upon published material.
Keywords: Tiber valley, coastal plain, environmental evolution, natural resources, Holocene

Nel medio e tardo Olocene, la pianura costiera di Roma è stata oggetto di una evoluzione ambientale molto articolata, nella quale il Tevere ha svolto un ruolo fondamentale. In questo articolo, l'influenza del Tevere sul paesaggio costiero viene considerata per diversi periodi storici, così come l'interazione tra il fiume, la valle e la pianura costiera da un lato e lo sfruttamento delle risorse naturali dall'altro. È inteso di fornire un quadro aggiornato in base al materiale pubblicato.
Parole chiave: *Tevere, pianura costiera, evoluzione ambientale, risorse naturali, Olocene*

1. Introduction

The concept of "landscape" as used in this text refers to a set of terrestrial forms inseparable from the geological substrate, vegetation, climate, land use and its history. Such an approach is rather similar to some aspects of environmental archaeology, which is "about reconstructing the physicality of the landscape in which people lived, hunted and farmed. In other words, assessing where rivers and streams ran,

Received: 23-11-2016 - Accepted: 05-12-2016 - Revised: 15-02-2017

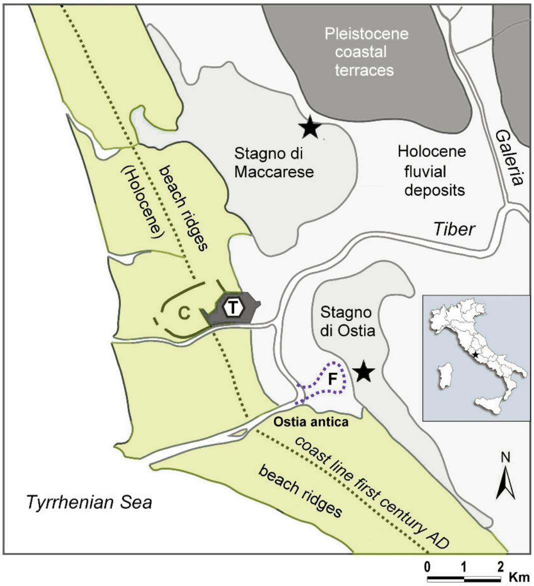

Fig. 1. Simplified topography and geology of the coastal plain of Rome; C. harbour basin of Claudius; T. harbour basin of Trajan; F. "Fiume Morto", the river course before 1557 AD; with a star are marked the known historical salt works.

the shape and slope of hills, the fertility of soils, the depth of lakes, the distance to the sea, and the countless other variables of the physical environment" (Wilkinson, Stevens 2003).

In reconstructing the past landscape, one should strive after distinguishing between those parts which, within the archaeological time span, have remained static in their morphology and environmental conditions, and the parts that were dynamic, i.e. underwent changes. And concentrate on the latter. The challenge in tracing the historical environmental record is to establish how much, how and when these factors changed (Arnoldus-Huyzendveld 2016).

The topics covered in this article and the references cited tend to favour the geoarchaeological approach. Apart from a voluntary bias in this sense, a critical selection of the bibliography has been applied, since the arguments referring to the environmental changes of the Lower Tiber valley are many and in continuous evolution.

The coastal area of Rome is divided in an external delta plain formed by beach ridges and a flat inner plain characterized by wide depressions that were occupied originally by two ponds, the *Stagno di Maccarese* and the *Stagno Ostiensis*, separated by the Tiber river. Landward the plain is delimited by dissected older (Pleistocene) coastal terraces (fig. 1).

In the last millennia, this plain has been subjected to a very complex environmental evolution, in which the Tiber has played an essential role, since the delta was formed practically due to its presence. During that time, the older landscape elements formed the static "backstage" of the events that occurred in the coastal belt.

In the following contribution, the influence of the Tiber on the coastal landscape will be considered for different periods, as well as the interaction between the river, the valley and the coastal plain on the one hand and the exploitation of the natural resources on the other.

It is meant to be an overview based upon published material, partly due to the investigations of the *Soprintendenza Speciale per il Colosseo, il Museo Nazionale Romano e l'Area Archeologica di Roma*.

As local natural resources can be considered in the first place water: groundwater (of which the dune belt is particularly rich), fresh or brackish lagoons for fishing and salt making, and the main rivers for transport. Another resource are the soils of the valley floors and the adjacent hills for agricultural production and animal husbandry.

The coastal area of Rome is poor in a primary resource like building stones to quarry. In historical times, with the exception of local river pebbles, stones have been imported from the nearby hills (*tufo lionato,* basalt, sand and pebbles), from the coastal areas more to the north unto Civitavecchia, and eventually from Rome and Tivoli.

The Tiber is the third river of Italy in length. It is characterized by a particular hydraulic regime, as stressed by Le Gall (2005, p. 20). Nowadays, the flow rate in Rome is 220-245 m^3/s, which is much higher than of the other main rivers reaching the Tyrrhenian coast, but not particularly high to national or European standards[1]. Its lower course is never completely dry in the summer, so always navigable. This feature is determined by the strong influence of its major tributaries, the Nera and the Aniene, flowing in porous limestone formations that absorb the irregular precipitations of the Mediterranean climate and thus regulate the water charge.

It is a meandering river, whose course has been subjected over time to significant lateral shifts, a process that has continued until relatively recent times. It's an ancient river, running already, more or less, in the present position from before the volcanic period. During the Middle Pleistocene volcanism, its course has undergone several major shifts, due to the disruption of the drainage network by the pyroclastic products (Marra, Rosa 1995). The evolution of the Tiber drainage network is also related to the sea level changes: during low stands incision of the valleys took place, at least when there was no the interference from volcanic sedimentation, and during high stands the filling in of the valley

[1] In comparison, the Po has an average flow rate of 1540 m^3/s and the Ticino at the confluence with the Po 350 m^3/s, but the Adige is similar, with an average of 235 m^3/s at the mouth.

floor. Due to the absence of directly preceding volcanic activity, the last valley incision, contemporaneous with the glacial peak of 20.000 years ago, was indeed much deeper than the former ones (Giordano, Mazza 2010).

With the late Pleistocene and Holocene increase in temperature, the sea rose stepwise from ca. -120 m until approximately the present level, and the lagoons and the Tiber valley began to fill in (Bellotti *et al.* 2007). This marine rise was due to the melting of the polar ice caps after the end of the last great glacial period of 20.000 years ago.

The sea level has been rising until approximately 6000 years ago, when a series of coastal barriers were laid in place, gradually isolating the lagoons from the sea (Bellotti *et al.* 2011). Geomorphological investigations revealed that the beach ridges were broken up a number of times during the last thousands of years, determining connections between the sea and the Maccarese pond (Giraudi 2004). The river system has continued to slowly fill in the lagoon and the valley with clayey and loamy sediments.

One should realize that generally, the position of a coastline is determined by two factors: 1) the marine water level; 2) the quantity of sediment that is transported to the sea by the rivers (Arnoldus-Huyzendveld 2005).

Geological research in the coastal area of Rome has proven that until about 5000-6000 years ago, the marine level played a major role in determining the position of the coastline, particularly leading to inland movement of the coastline by "drowning of the beach". After this "great prehistorical sea level rise", the coastline position was mainly governed by the balance between the sediment load of the river, the strength and direction of the marine currents and the force of the waves in the shore area, leading to increase, to standstill or to withdrawal of the coastline. Thus the intensity of river discharge and inundations, determined by climatic conditions or by erosion in the watershed, became potentially factors in the shoreline evolution.

Bellotti *et al.* 2011 provided a challenging and unitary model on the development of the river network of the coastal area of Rome over the last millennia, based upon drilling data analysed from the stratigraphic, faunistic and palynological viewpoint, sustained by carbon isotope datings, and upon the interpretation of aerial photographs and satellite imageries.

The several phases of migration of the Tiber are recorded by the different positions of the delta cusp (fig. 2).

In the first phase, from ca. 3000 BC until the 8th-7th century BC, a cusp spread out over the entire area from *Capo Due Rami* to the place

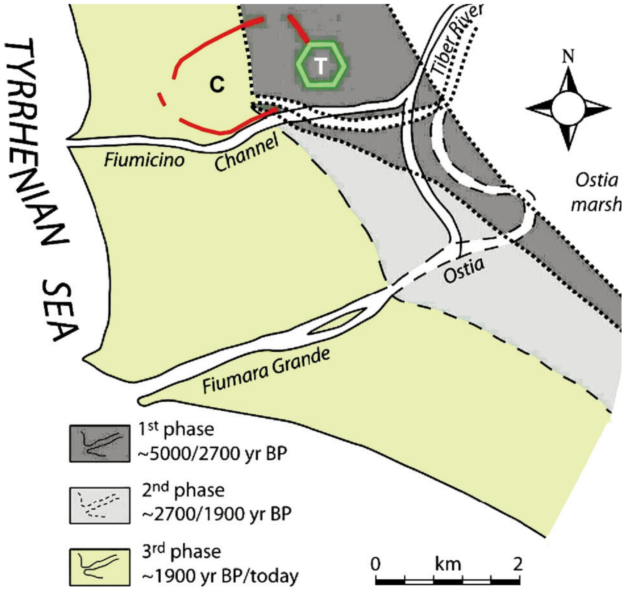

Fig. 2. The main changes of the Tiber river mouth location during the strand-plain evolution (modified from Bellotti *et al.* 2011); C. harbour basin of Claudius; T. harbour basin of Trajan. *Fiumicino channel* = channel of Trajan; *Fiumara Grande* = Tiber.

of the later imperial harbours, and unto the outer margin of the *Stagno di Ostia*. The transition to the second phase[2] coincided with the sudden migration of the Tiber to the south, at first flowing into the *Stagno Ostiensis,* which supposedly was the lowest point of the area. Being isolated from the sea through the coastal barriers, in a short time the lagoon level rose. Upon reaching the lowest point of the dune belt, the water broke through to the sea in a position near future Ostia and through an outlet more to the south (the *Foce dello Stagno*).

The hypothesis of a temporary presence of the Tiber mouth near the future imperial ports of Claudius and Trajan (figs. 2; 3, C, T) before its migration to the south, is now generally accepted. This hypothesis, first formulated by Segre in Dragone *et al.* 1967 and Segre 1986, has been confirmed by drilling data (Bellotti *et al.* 2007; Giraudi *et al.* 2009; Goiran *et al.* 2010; Di Bella *et al.* 2011; Arnoldus-Huyzendveld *et al.* 2015), and is also evident from the study of the direction of the coastal barriers by Bellotti *et al.* 2011. Several radiocarbon datings from drilling cores, both in the imperial harbour area and near Ostia, have established the period of lateral displacement between the 8th and 6th-5th centuries BC. The lateral migration is considered by Milli *et al.* 2013 as "brusque", and probably the result of a major flood.

[2] The sediments of the first two phases are called the "old" or "Holocene" dunes.

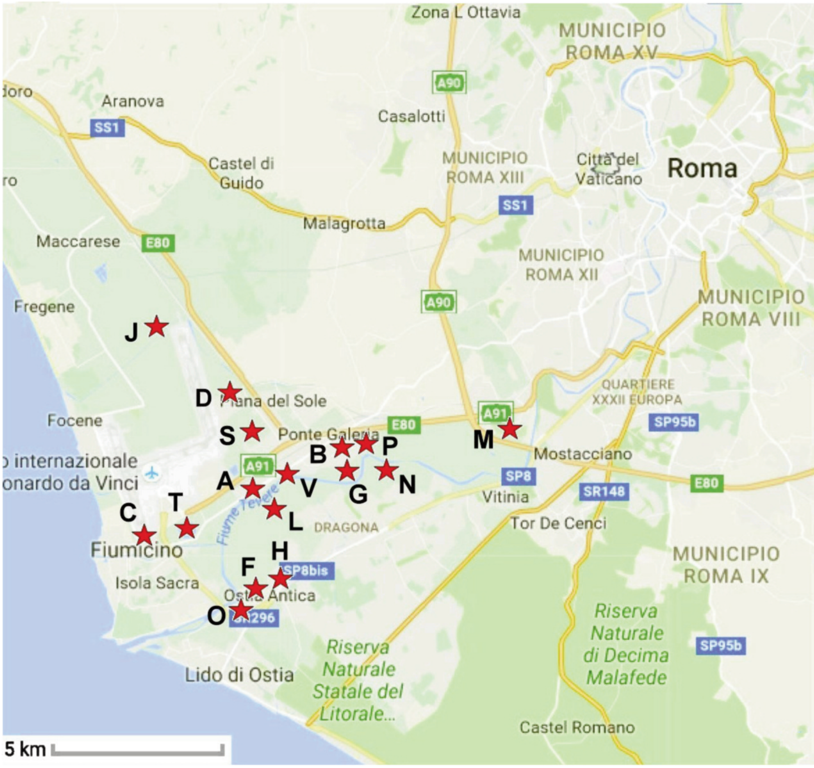

Fig. 3. Locations mentioned in the text: A-B. Late-Republican and Imperial salt storage buildings; C. harbour basin of Claudius; D. *amphorae* dam; F. "Fiume Morto"; G. area *Fiumicino-Ponte Galeria*; H. historical salt works of the *Stagno Ostiensis*; J. the Eneolithic site *Cerquete-Fianello*; L. the Final Bronze age site *Ostia Antica Collettore*; M. area *Magliana*; N. archaic town of *Ficana*; O. *Ostia Antica* romana; P. alluvial fan of *Ponte Galeria;* S. channels of the salt works of Maccarese; Final Bronze Age sites; T. harbour basin of Trajan and town of Portus; V. *Via Portuensis - Fiera di Roma* (modified from Google Maps).

With the opening of the channel of Trajan (early 2nd century AD) a new complex system of delta progradation developed, with two river branches active almost simultaneously (the third phase of Bellotti *et al.* 2011). In this period, the shore line near the Tiber outlet has migrated seawards several kilometres. Ostia was founded along the coast, and is now separated from the sea by a dune belt wide more than 2 km. The progradation has been initially relatively slow, later on more intense: about half of the growth occurred from the 16th century on (Dragone *et al.* 1967, pp. 62-65; Segre 1986, pp. 13-17; Servizio Geologico d'Italia 1967).

2. Pre-protohistorical times

The Holocene paleo-vegetational record from the *Stagno di Maccarese* indicates a sequence of abrupt landscape changes, driven by local geomorphic coastal processes and by variations of the sea level (Di Rita *et al.* 2010; 2011). So, between ca. 8300 and 5400 cal BP (calibrated date Before Present) it was a freshwater basin, surrounded by a forested landscape, which changed until 5100 cal BP in an open marshy environment, probably due to a lowering of the water table. Between 5100 and 2900 cal BP there has been a remarkable expansion of riparian trees, possibly triggered by an increased water influx. Until 2000 cal BP an unstable marshy environment is registered, "formed by ponds, wetlands, sedge fens and salted soils" (Di Rita *et al.* 2010, p. 64).

In pre-protohistoric times, the area around the Maccarese lagoon constituted an optimal habitat for human settlement due to the presence of fresh water. The first permanent settlement known in this area is the Eneolithic village of *Le Cerquete-Fianello*, located at the margin of the ancient lake, and dating back to 4.500 years ago (Manfredini 2002; fig. 3, J).

Close to *Le Cerquete-Fianello*, several Middle-Late Bronze Age settlements have been discovered (Di Rita *et al.* 2010).

Archaeological investigations carried out along the ancient south-eastern shore of the Maccarese pond have unearthed a series of slightly elevated working areas, probably only occupied during the summer season, dating to the late Final Bronze Age (XII-X centuries BC), with finds indicating the processing of milk and dairy products, and spinning and weaving (Ruggeri *et al.* 2010; Morelli, Forte 2014; fig. 3, S).

In the Tiber valley just north of the former *Stagno Ostiensis* was identified a settlement of the Final Bronze Age (*Collettore Ostia Antica*; fig. 3, L; Conti 1982; Alessandri 2013), probably originally located at the edge of the ancient lagoon.

3. The coastal belt in Roman times

In Antiquity, the sea level was slightly lower than nowadays, which must have influenced the water level of the lagoons. In the 1st century AD the marine level appears to have been more than one meter under the present level, and rising in the first centuries AD (Arnoldus-Huyzendveld *et al.* 2015). It was established at 0,80 m below present sea level in the 3rd-5th century AD (Goiran *et al.* 2009).

The Tiber course was broadly similar to the current one (if we exclude the natural cut off of the *Fiume Morto* meander, see figs. 2; 3, F; 11, which occurred much later), with the exception of a probably general smaller amplitude of the river bends. There are several indicators that support this hypothesis: the investigations carried out in the *Magliana* area (fig. 3, M; Catalli *et al.* 1995), the Tiber bend undercutting the *Via Ostiensis* near Ostia (see fig. 11), and the bend of the river course in the *Fiera di Roma* area (fig. 3, V) in a position that seems to cut off the *Via Portuensis* and the aqueduct of Portus. If we rule out for the latter case a slight curvature of the antique *Via Portuensis* in this location (Serlorenzi *et al.* 2004), we might be dealing with the same phenomenon reported for the river stretch in the *Magliana* area, i.e. an increase of the bend amplitude with respect to Roman times.

A model for such a river course development, referring to the Tiber meander east of ancient Ostia, is given in Salomon *et al.* 2016.

A level of the valley floor in Roman times of about one meter below the present level was encountered in the areas *Magliana* and *Fiumicino - Ponte Galeria* (fig. 3, G; Arnoldus, Pellegrino 2000). In the latter area, the antique surface was marked not only by the relicts of structures, but also by a distinct buried soil marker. These were often found covered by a clayey layer, testifying an initially slow accretion of the valley level, whereas the overlying layers were generally coarser (mainly loamy), thus indicating more intense flooding peaks for the later periods.

Near the Fosso Galeria tributary outlet, an alluvial fan with sandy sediments could be distinguished from the typical loamy Tiber sediments (fig. 3, P). Antique water distribution structures (canalizations) were excavated in the alluvial fan area (Petriaggi *et al.* 1995). The latter was apparently the preferential zone for settlement, both for water availability and quality as well as for the slightly higher elevation with respect to the main valley.

The aggradation of the valley floor cannot be disconnected from the advance of the coast line and the increase in amplitude of the river bends, since a meandering river like the Tiber is essentially a self-organising system, in which these phenomena are the expression of a new dynamic equilibrium along the whole water course (Brown 1997, pp. 33-34).

And it can neither be disconnected from the intensity and frequency of the floods. The Tiber inundations that occurred in the Roman period are well known (Le Gall 2005; Bersani, Bencivenga 2001): about thirty exceptional floods have been recorded. Traces of flooding from the Roman period have been recognized in many layer sets, but rarely dated like in the *Magliana* area: probably the years 15 or 16 AD (Catalli *et al.* 1995).

A natural resource of the dune belt of the coastal area of Rome has always been the presence of a fresh water aquifer close to the surface, also known in ancient Ostia (Scrinari, Ricciardi 1996).

4. The Roman salt works

An important environmental event that occurred, before or during the Etruscan period, with an almost stable sea level, is the transformation of the water of the Maccarese lagoon from fresh to salt/brackish (natural or artificially promoted?), enough to allow the construction of salt works. This change is recorded by Giraudi 2004, p. 485, to have occurred after 910-800 cal BC (calibrated ^{14}C dating). Di Rita *et al.* 2010 report an increased salinity of the Maccarese basin around 2600 cal BP, based upon pollen and carpological data. The cause of this transformation should have been the re-opening of the connection with the sea.

Following this "environmental revolution", the area of Maccarese became an important centre of salt production under both Etruscan and Roman domination. Although mentioned by the ancient sources, the Etruscan salt pans have never been found. After the conquest of Veio in 396 BC, the salt works came under Roman control and were used under the name *Campus salinarum romanarum* throughout the Republican and Imperial period.

It is probable that the *Via Campana*, connecting on the right bank of the Tiber Rome to the coast of Latium, was constructed, at least in this area, at the start of Roman control (Serlorenzi *et al.* 2004), and was still used for connection with the salt works, suitably adapted, until Claudius' and Nero's era. It was then substituted under Trajan's reign by a new, more efficient service road, the *Via Portuensis* (Arnoldus-Huyzendveld *et al.* 2009, p. 600).

The salt pans of Maccarese were exploited at long, and are mentioned in several documents at least until the end of the 15th century, under the names *Campus Maior*, *Campus salinarius* or *Campus Salinus Maior* (Morelli, Forte 2014; Lanciani 1888).

Recent trench prospection and excavation campaigns (Grossi *et al.* 2015) have brought to light Roman imperial salt works composed of a complex of canals dug into the earth used to channel and distribute salt water from the Maccarese Pond (fig. 3, S). Connected to the salt extraction systems was a structure composed of a one-kilometre string of 1.439 *amphorae* inserted upright into the muddy substrate (fig. 3, D; fig. 4, D). The row of *amphorae*, datable between the Augustan period and the middle of the 1st century AD, composed the framework of an earthen dam and was crossed by two canals in cement with *opus reticulatum* facing, each about 25 m long and provided with a sequence of two sluices. These canals have a characteristic funnel shape, with the opening to the west, which confirms their function as collectors of water from the lagoon.

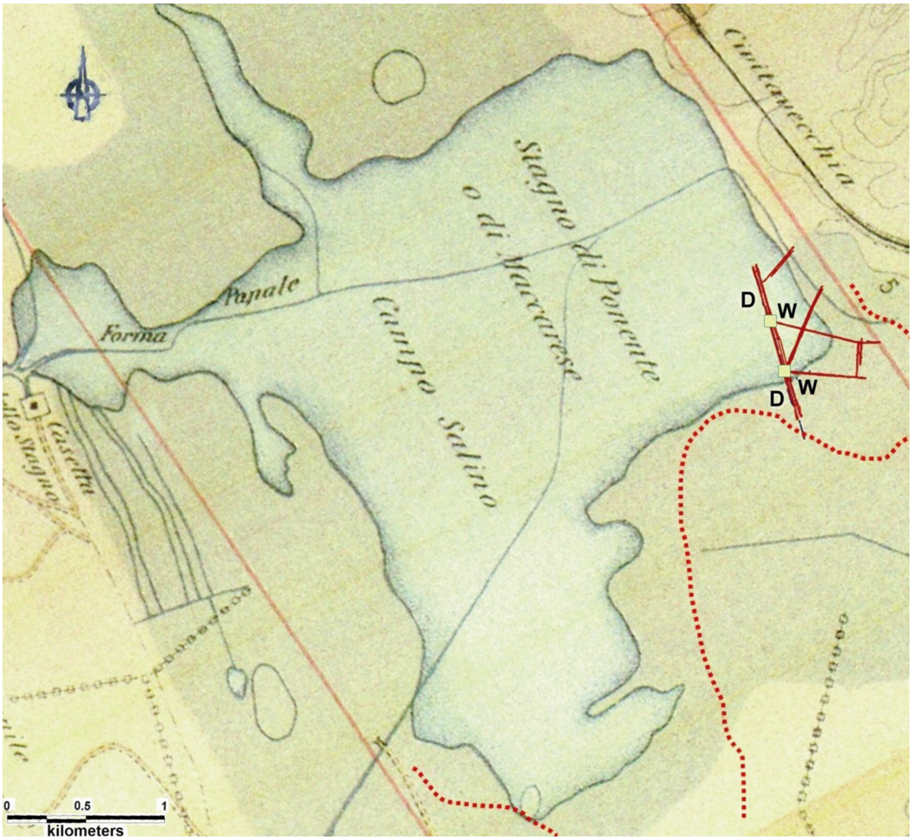

Fig. 4. Principal features of the Maccarese hydraulic system (1st century AD) overlain on the map of Amenduni 1884; a dotted line marks the historical lagoon shore. D. *amphorae* dam; W. ground canals departing eastward from the main walled channels; yellow squares mark the position of the masonry canals with sluices (modified from Grossi *et al.* 2015).

From the brick channels branch off to the east two long canals dug into the earth (fig. 4, W).

The system is completed by two ground channels or "basins" reinforced with rows of wooden poles (guaranteeing walkways), located parallel on both sides of the *amphorae* dam, and probably intended as water collectors. Their depth is shallow, max. 0,40-0,50 m, which coincides with the tidal range of these coastal plains.

The layout of the system suggests that the dam and the two masonry canals with sluices allowed to control the salt water flowing from the Maccarese Pond, which was then distributed over the vast territory behind the dam through canals dug into the earth. One or more times a year, from the start of the dry season, the salt water would have been let in during high tide. Then the sluices were closed, thus isolating, together with the *amphorae* dam, the system temporarily from the main body of the lagoon. Behind the dam, a shallow water surface would spread out over the flat areas between the canals, where salt concentrated and could be harvested.

Such a single-cycle process, without the use of interconnected basins to separate undesirable substances from the fine salt as indicated by Georgius Agricola 1556 and applied e.g. at the *La Trappola* salt works near Grosseto between the 14th and 18th century AD, might be similar to the system described by Rutilio Namaziano in the 5th century AD near Volterra[3]. It would imply that these salt works produced unrefined marine salt.

To the Roman phase belongs a large collector located along the eastern margin of the salt works, reused in medieval times. It was probably targeted at the protection of the salt works by deviating towards the Tiber the surface water running off the internal reliefs.

For service and salt storage activities, two building complexes have been identified, attributable to the late-Republican and Imperial age (fig. 3, A, B). Within the former, an inscription was found datable to 135 AD, of a dedication to Neptune made by two men identified as *conductores campi salinarum romanarum*, i.e. Roman salt work contractors (Morelli, Forte 2014).

To the south of the Tiber were located the salt works of Ostia (fig. 3, H). They have continued to function until the 19th century, and are still partially visible on the map of Amenduni 1884 (fig. 5) and on an aerial photograph taken from a balloon in 1911 (fig. 11; see Shepherd 2006).

The Roman age salt works of the *Stagno Ostiensis* have not been located exactly nor excavated. It is only possible to presume that the warehouses and wharfs of the harbour situated in the suburban zone of Ostia, along the later filled in meander of the Tiber (Arnoldus-Huyzendveld, Paroli 1995), were the points from which the salt was transported to Rome.

One of the most ancient salt deposits is recognizable in the late medieval building called *Casalone*, now incorporated in the modern township

[3] Morelli, Forte 2014, note 21. Rutilio Namaziano, *De redito suo*, I, 475-486, http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Rutilius_Namatianus/text*.html. "We find time to inspect the salt-pans lying near the mansion: it is on this score that value is set upon the salt marsh, where the sea-water, running down through channels in the land, makes entry, and a little trench floods the many-parted ponds. But after the Dog-star has advanced his blazing fires, when grass turns pale, when all the land is athirst, then the sea is shut out by the barrier-sluices, so that the parched ground may solidify the imprisoned waters. The natural incrustations catch the penetrating sun, and in the summer heat the heavy crust of salt cakes, just as when the wild Danube stiffens with ice and carries huge wains upon its frost-bound stream".

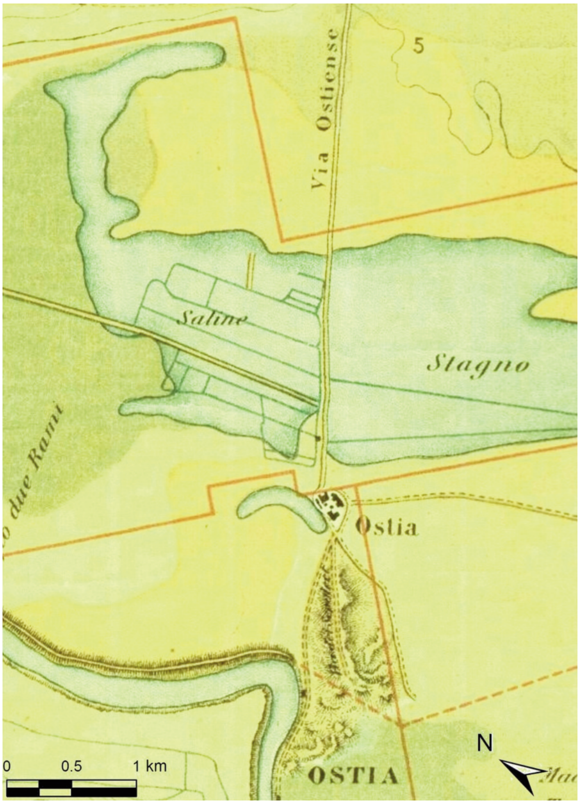

Fig. 5. The salt works of Ostia on Amenduni's general plan of the coastal plain of 1884. Visible are also the remains (*oxbow lake*) of the Tiber bend ("Fiume Morto") abandoned in the 16th century.

and close to the abandoned river course. After the cut off of the Tiber meander in the 16th century, salt storage occurred in the *Magazzino de Sali*, which is now the Museum of Ostia Antica.

The exact size of the lagoon of Ostia was partly defined thanks to recent archaeological excavations, which pinpointed most of the banks of the lagoon in the Roman period (Pannuzi 2013, fig. 2). The western limits of the perimeter of the basin were identified through the discovery of deposits of amphorae intended for soil drainage. The edges of the other banks were revealed thanks to the remains from different archaeological contexts (burial zones, rural buildings, factories, agricultural installations, roads).

The role of the Tiber was the transport over water to Rome of the goods arrived in the ports and of the salt.

Segre 1986 formulated the hypothesis that the original connection between the Tiber and the lagoon was reestablished by the Romans as a "navigable communication", as recognized by charred poles in the channel section of his 1962 excavations, of which unfortunately the location and dating are unknown. Pannuzi 2013 considers it more probable that this connection was at the service of the salt works, specifically to control the disposal of residual water of the salt production.

Important shipping and storage operations are known to have occurred in Ostia until the early 3rd century AD, when a gradual shift of all trade operations to Portus began. Based upon aerial photographs and geophysical survey, Heinzelmann, Martin 2002 confirmed the existence of a river harbour basin with an associated (navalia-) temple-complex, to the west of Ostia along the southern bank of the Tiber. Based on two sediment cores, stratigraphical investigations by Goiran *et al.* (2014) located here a lagoonal harbour functioning between the 4th and 2nd century BC, which was affected by strong siltation. At the same site, a river harbour was subsequently established from the 1st cent. AD onwards.

The Romans considered Ostia their first colony and they attributed its founding for the purpose of salt production to their fourth king, Ancus Marcius (second half of the 7th century BC), but no archaeological proofs have been found for this. In fact, the soil of Ostia (not even the Castrum, which is the first "urban" development), has so far delivered no findings dating back to the time of the Kings (Zevi 2001, p. 4). The nearest archaic site is the town of *Ficana* (fig. 3, N), which, according to written sources, was conquered by Ancus Marcius.

The paleo-environmental reconstruction of Bellotti *et al.* 2011 (see fig. 2) could clarify the discrepancy between archaeological and historical sources on the origin of Ostia. The Authors state that, just after the Tiber migration to the south, the coastal barrier belt separating the marsh of Ostia from the sea would have been still too narrow and insecure against storms to support a permanent human occupation. Therefore, in the 7th century BC there would have been only an outpost, with the aim of controlling the strategic river mouth and, eventually, to set up the first salt works in the marsh. In fact, the data of pollen and molluscs in the drilling core S5 in the marsh of Ostia, indicate around 600 BC a sudden intrusion of sea water, which would have allowed salt extraction. It is not clear if this is a natural event or a man induced breakthrough of the barrier belt. Only later, around 450 BC, when the cusp had expanded more than 1 km into the sea, following a progradation rate of about 5–6 m/year, the sandy substrate was supposedly large and safe enough to set up a fortified camp (the Castrum of Ostia) and to further develop the salt works.

The *Via Ostiensis* on the left side of the Tiber was realized supposedly from the foundation of Ostia on. It was paved for the first time in the 3rd century BC. The Ostian aqueduct was built during the early Empire, and rebuilt in the early 2nd century AD.

5. Other Roman Imperial infrastructures

In the coastal area north of the Tiber river, in the imperial period were realized the harbour basins of Claudius and Trajan, the channel of Trajan and other channels, the *Via Portuensis* and the aqueduct leading to the town of Portus. The Maccarese salt works seem to be part of this broad infrastructural development plan.

For the harbour of Trajan and the town of Portus, see specifically Keay *et al.* 2005, 2011; Paroli 2005.

In the Lower Tiber valley, the central part of the roman *Via Portuensis* was constructed on a viaduct (Morelli *et al.* 2011a, p. 278; Morelli 2014), which by means of thirteen bridges crossed water-filled depressions originated from hydrothermal activity, with gas and water leaking from the subsoil. Datings on the calcareous crusts attached to the structure and embedded in the alluvial sediments (Tuccimei *et al.* 2007) have confirmed its intermittent activity from pre-Roman times to the

Fig. 6. The extension of the harbour basin of Claudius, with in black the exposed part of the moles and in red the "hidden" parts; a dotted line indicates the Roman coast; modified from Google maps.

Fig. 7. Part of the northern mole of the harbour of Claudius exposed behind the *Museo delle Navi* of Fiumicino (photo Huissen).

present day. The hydrothermality is considered to represent a final expression of regional volcanism.

Next will be treated the harbour basin of Claudius, whose discovery is related to some geological aspects, specifically to the advance of the coastal dune belt in historical times.

The harbour of Claudius is located about 2 km north of Ostia, near the Roman town of Portus (fig. 6). Construction started in AD 42 and was completed by Nero in the year 64.

Even today, part of the southern breakwater is preserved, but it is hidden under the Tiber embankment. The landside part of the northern pier, instead, is still visible at the surface (fig. 7).

Further to the west no traces of the breakwater can be seen at the surface level. The burying of this part is due to the strong growth of the dune belt in historical times, particularly in the last centuries. The moles of the harbour of Claudius were buried by sandy sediments, and therefore the real size and orientation of the harbour basin were forgotten for centuries.

Only in the last decade a series of deep drillings[4] (see Morelli *et al.* 2011b) have confirmed, without a doubt, the hypothesis formulated by Castagnoli 1963 and further developed by Giuliani 1992, that the basin

[4] Between 2004 and 2007, by the *Soprintendenza Speciale per il Colosseo, il Museo Nazionale Romano e l'Area Archeologica di Roma.* The most recent drillings (2014-2016) executed within the Airport of Fiumicino confirm the location and base width of the buried part of the northern breakwater.

is east-west oriented and that the distance between the inland margin (Monte Giulio) and the lighthouse island is about 2 km.

Remains of structures were encountered in the drillings only from a depth of several meters on, being covered by dune and marine sediments.

The recent reconstruction shows two protruding breakwaters and a lighthouse island, separated by evident entrances. A third, narrower entrance (probably only a channel) was demonstrated to exist between the northern pier and Monte Giulio (Goiran *et al.* 2011).

This is in contrast with the reconstructions appearing from the first half of the 19th century on: a much smaller basin, with the central axis rotated 90 degrees towards an entrance in the north, and the lighthouse to the left of that entrance, but is in agreement with earlier hypotheses, e.g. by Antonio Labacco in the 16th century.

In the westernmost drillings the base of the breakwaters and the lighthouse island has been found resting upon the former sea bottom at a depth to 15-16 meter.

In the cores of the piers no hydraulic mortar was encountered, only large blocks of basalt and lithoid tuff embedded in coarse sand, forming a ridge-like rubble mound with a base width of at least 60 meters. This suggests that the mole was constructed by piling stones upon the seabed, which lines up with Pliny the Younger's description of the construction of the harbour at Civitavecchia[5].

In contrast to the hexagonal harbour basin of Trajan, which was completely excavated in the sand of the "old" dunes, for the basin of Claudius was exploited an indenture of the coast line left by the Tiber outlet before its southwards migration (the transition from the 1st to the 2nd phase of Bellotti *et al.* 2011), as was formulated by Segre in Dragone *et al.* 1967. By the onset of the Imperial times, this former outlet had been naturally transformed into a shallow lagoon, separated from the sea by a (probably) narrow dune belt.

Excavations and drillings executed along the *Monte Giulio*[6], forming the internal margin of the basin of Claudius, demonstrated that this quay was constructed upon a low dune ridge oriented parallel to the coast, dividing the lagoon in two parts: a major one before and a minor one behind the ridge (Arnoldus-Huyzendveld *et al.* 2015; see fig. 8), and that building upon it started only from Trajan on.

The hypothesis was developed that Claudius did not dredge the entire major lagoon, but may have done so only locally through the excavation of channels in the bottom, followed by cutting through the coastal barrier to

[5] Letters LXXI.

[6] Between 2007 and 2009, by the *Soprintendenza Speciale per il Colosseo, il Museo Nazionale Romano e l'Area Archeologica di Roma.*

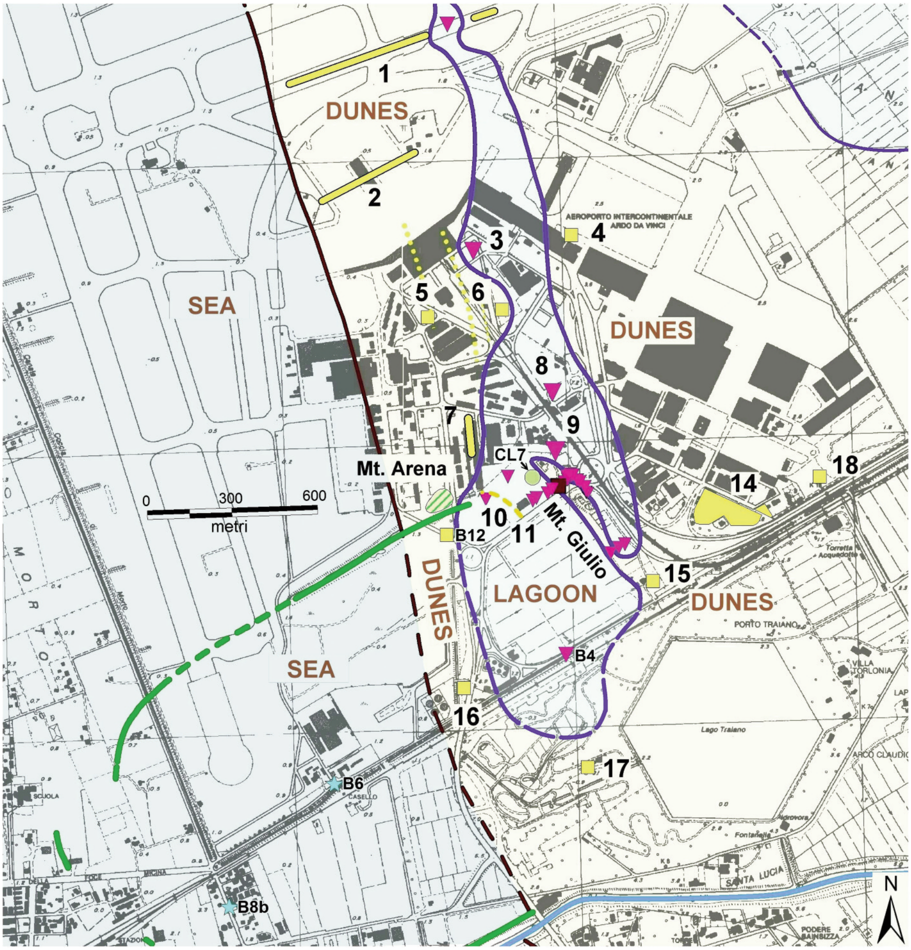

Fig. 8. Interpretation of the distribution of environments before the activities of Claudius, modified from Arnoldus-Huyzendveld *et al.* 2015. The numbers refer to the recently investigated areas and other published data; yellow symbols indicate the presence of *"old" dunes*, purple triangles lagoon environments and blue ones open sea; green lines mark the breakwaters of the harbour basin; a brown line marks the coast line (certain and alleged) directly prior to the imperial works.

let the sea enter. He then must have concentrated the maritime traffic on Portus through the creation of harbour structures along the original coast line of the outer lagoon and the sea. The internal lagoon was supposedly used as a dock for small and medium-tonnage vessels, which is indicated by the ramps located along the back side of the quay (see fig. 9).

The occupation of Monte Giulio has continued until the beginning of the 5th century (Arnoldus-Huyzendveld *et al.* 2015).

Fig. 9. Ramp of the “Capitaneria” directed to the small lagoon behind *Monte Giulio*, view towards west; to the left the north-eastern part of the harbour basin of Claudius where the drillings were executed; just visible in the background the *Museo delle Navi* (photo Huissen).

6. Late Antiquity

Environmental conditions were not stable after the first centuries AD.

At the beginning of the 5th century, Rutilius Namatianus describes how the final stretch of the Tiber is impractical due to the sandbanks, so that at one must follow the channel of Trajan to reach the sea.

“Then at length I proceed to the ships, where with twy-horned brow the branching Tiber cleaves his way to the right. The channel on the left is avoided for its unapproachable sands: its one remaining boast is to have welcomed Aeneas” (*De redito suo*, I, 179-182[7]).

The dune ridge pattern shows that the delta growth was interrupted by an erosion process, which occurred during the so-called Roman Warm Period, characterized by a decrease of the Tiber floods (Bellotti *et al.* 2011, p. 1114; Milli *et al.* 2013, p. 176). According to historical sources, this erosive process was underway in the 3rd century AD. After a description of the beach and the sea near the Porta Marina of Ostia, Minucius Felix writes: “Let us be seated on those rocky barriers that are cast there for the protection of the baths, and that run far out into the deep”[8]. So obviously at the time the sea was not only close by,

[7] http://penelope.uchicago.edu/Thayer/E/Roman/Texts/Rutilius_Namatianus/text*.html

[8] The Octavius of Minucius Felix, English Translation by Roberts-Donaldson. http://www.earlychristianwritings.com/text/octavius.html.

but also invading the coast and threatening the buildings of Ostia. This process is confirmed by an AD 238 epigraph which mentions stone blocks arranged as a protection of the seaward side of the Via Severiana south of the Tiber.

After this period, progradation restarted at the mouths of the "Fiumara Grande" (the main Tiber course) and the Fiumicino channel (Bellotti *et al.* 2011).

A similar sequence of events is suggested by the excavations of the Via Severiana between the *Terme di Porta Marina* and the Synagogue of Ostia (Pavolini 1980): defensive structures against the sea of the Decumanus Maximus were constructed in the 1st century AD, followed by

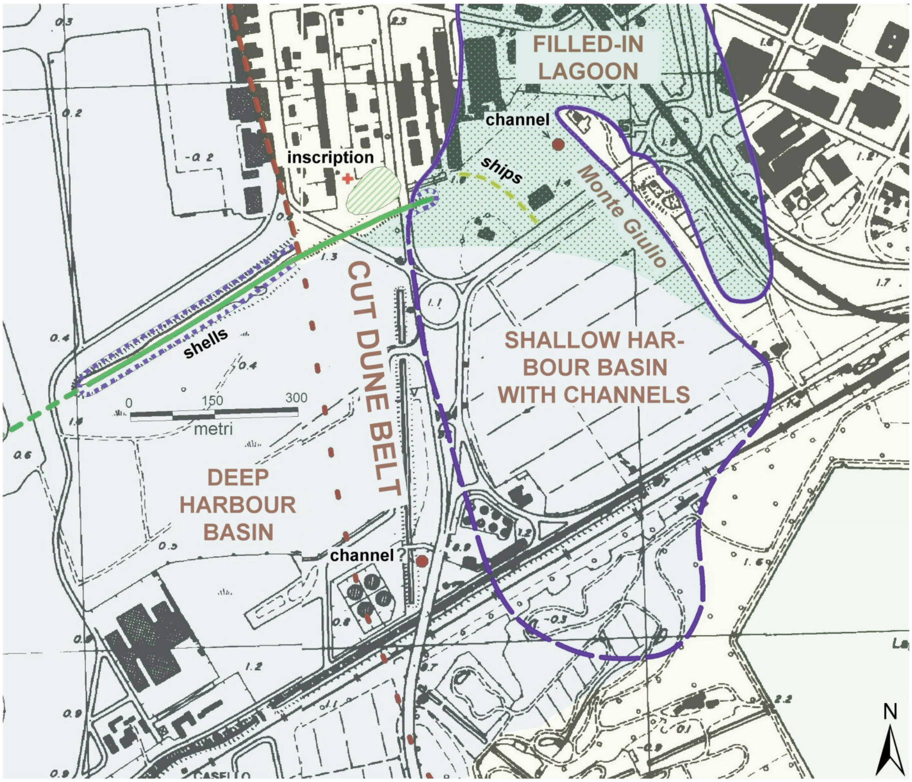

Fig. 10. Interpretation of the actions of Claudius, and the distribution of environments after the harbour construction and in first centuries AD (modified from Arnoldus-Huyzendveld *et al.* 2015). A dotted area marks the zone of late antique silting up; a brown line indicates the coast line (certain and alleged) directly prior to the imperial works; the text "shells" refers to the barnacles attached to the northern pier, dated in Goiran *et al.* 2009.

an embankment and quay of the 2nd century AD; next the Via Severiana was built at the beginning of the 3rd century, partially covering these structures and the newly accreted beach ridges.

As is well known, soon the harbour basin of Claudius has been subject to silting (fig. 10; Arnoldus-Huyzendveld *et al.* 2015). The early filling in of the northern corner of the basin, known from the discovery in the early sixties of the ships of Fiumicino (2nd-4th century AD, Boetto 2008), has been related to the presence of the piers protruding into the sea, in analogy to the effect of modern breakwaters placed transverse to the coast in order to protect the beach, which cause sand accumulation in front of the obstacle and a retraction of the beach behind it due to a minor sediment supply and to erosion by the sea currents (Arnoldus-Huyzendveld 2005). With a direction of the marine currents from south to north, this mechanism would also be perfectly consistent with the position along the coast, directly north of the basin, of an inscription of the 3rd century AD, referring to the regulation of sand quarrying (Testaguzza 1970, pp. 75-76).

In the first centuries AD, the sea level has still risen approx. 1 m with respect to the Republican period level (Goiran *et al.* 2009). This factor, together with the impact of the imperial structures and the frequent floods, has undoubtedly worsened the environmental conditions of the Tiber valley floor.

7. Middle Ages

There are relatively few reports of Tiber flooding between 500 and 1400 AD, on average only one per century. The flood of 589 was recorded in many other parts of Italy, so it must have been substantial. Later floods are memorized in particular through inscriptions on stone slabs preserved in several locations of Rome (Di Martino, Belati 1980; Bersani, Bencivenga 2001).

The harbour of Trajan functioned until the 9th-10th century (Paroli 2005), and, as a consequence, the *Via Portuensis* lost its importance thereafter.

In the areas investigated up to now, no traces of salt works were found for this period, although we know that those of Maccarese have functioned at least until the end of the 15th century. It is highly probable that the salt works of this period were structured in serial basins, like those of La Trappola known in the Grosseto plain, operative between 1386 and 1758. Georgius Agricola in 1556 (book XII) recommended to build salt pans by evaporation "near that part of the seashore where there is a quiet pool, and there are wide, level plains which the inundations of the sea do not overflow".

According to the indications, the brine is collected into shallow ponds and allowed to evaporate in the sun. A stepped process along a series of interconnected basins separates the undesirable substances from the fine salt. The basin should be moderately deep depressions, surrounded by embankments and separated by ditches with adjustable openings. The gentle drop down applied to the complex would allow the water to flow from one basin to another.

In the Maccarese plain there are rich archaeological testimonies of fish ponds from this period. The ^{14}C datings carried out on their wooden parts are concentrated in the period between the 11th and 13th centuries (Morelli *et al.* 2011a; Morelli, Forte 2014). There are also written records on fish farming in the medieval coastal plain of Rome (Vendittelli 1992), in particular documentation on the management of fishing facilities located along the Tiber river and in the delta from the 10th to the 13th century. These sources show how, at the time, the swamps were centres of an extremely vital fishing economy. The "piscarie" plants were quite elaborate wooden structures, which acted as labyrinths from which the fish, once entered, could not return to the sea. In most cases, evidence was found of connected channels to divert salt water into the fish ponds.

8. Renaissance and modern age

The 16th century is the period of the Tiber "unleashed", with more than six exceptional floods (Di Martino, Belati 1980). Those who recorded the highest levels ever reached by the Tiber in Rome occurred in the years 1530, 1557 and 1598. The flood of 1557 has also been reported in other parts of Italy: the Arno in Florence, the Ombrone near Grosseto. In the 17th century there have been still five exceptional floods, but the effects were less disastrous than from those of the previous century. In the century thereafter, no major inundations occurred.

Most floods were recorded in Rome, but only of the event of 1530 we have an eyewitness account from the coastal area, because at the time the papal court has made the trip from Ostia back to Rome.

Until 1557, the Tiber river near Ostia followed a tight meander, enclosing an area belonging in Roman times structurally to the city of Ostia, and known as *Trastevere Ostiensis*. The flood of 1557 has cut off this Tiber bend, leaving behind an imprint of the old course as a characteristic "oxbow" lake which still existed more than 100 years ago (fig. 5; Amen-

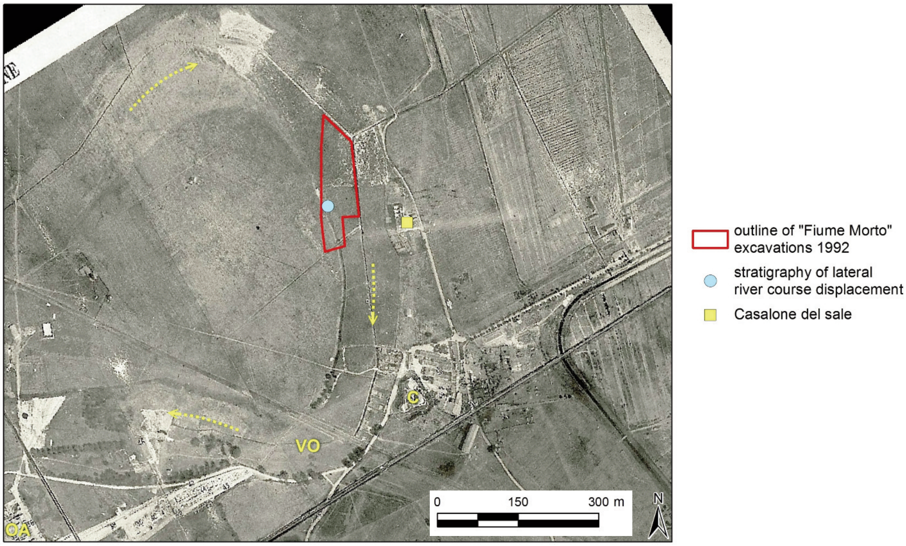

Fig. 11. "Fiume Morto", with the area investigated in 1992 overlain on a georeferenced cut of the *Topographical Survey of Ostia from a Balloon, 1911* (Shepherd 2006). In the centre and to the left, the river course abandoned in the 16th century, arrows indicate the stream direction; to the right, the remains of the salt works; OA, Ostia Antica; C, Castle of Ostia; VO, the abandoned Tiber bend undercutting the *Via Ostiensis*.

duni 1884), and also an isolated area, that since then carried the name *Fiume Morto* (Dead River). This event has completely isolated the castle of Ostia, built 60 years earlier, from its strategic position along the river mouth. The abandoned *Fiume Morto* is clearly visible on an aerial photograph taken from a balloon in 1911 (Shepherd 2006). During the excavation in 1992 of a section of the inner edge of the abandoned meander (fig. 11), traces of the lateral meander displacement during the floods of 1530 and 1557 were recognized (Arnoldus-Huyzendveld, Pellegrino 2000)[9].

Bellotti *et al.* 1989, p. 85 calculated an average shore line advancement of 0,8 m/year for the period 540-1420 and of 7,5 m/year between the latter moment and 1950. Simultaneous with the strong progradation of the coastline, the Tiber valley was further raised by flood sediments. Specifically, the severe flood of 1557 has caused the inaccessibility of the original Via Portuense, covering it with several decimetres of river sediment.

[9] Also was recognized a lateral displacement of several meters resulting from a flood of the 1st century AD. Today one may still be observe some traces of the former bend on the territory, e.g. in Via S. Massimo in the modern town of Ostia Antica (Rome), which near the *Casalone del Sale* crosses visibly the depression left behind by the abandoned Tiber meander.

A fresco of A. Danti of 1582 in the Vatican Museum (reproduced in Testaguzza 1970) demonstrates the visibility at the time of the remains of the lighthouse island and the mole extremities of the harbour basin of Claudius, before their burial by the sediments of the advancing coast. Contemporary writers also confirm the visibility of the ruins of the lighthouse in the sea. Giuliani 1992 mentions Biondo Flavio, who on that subject writes in 1558: "We still see a good part of this tower standing, although there is not much left of the marble with which it was covered"[10]. But it is Pius II, writing in 1614, who conveys the most useful information: "There are still traces of this tower which can be seen from far out at sea. Everything else has perished utterly"[11].

Between the 15th and 17th century the strongest environmental degradation in the coastal plain of Rome occurred. It seems that, on the whole, in this period there has been a change in the equilibrium of the river-sea system. The change of land use inland known to have occurred in Central Italy in the late Medieval and Renaissance period (Sereni 1987, pp. 201-204) may have been one of the triggering factors: ever steeper slopes have been cleared, causing increase of erosion, which, in turn, caused an increase in solid charge of the rivers, and thus of flood frequency and intensity, the rise of the valley level and the progradation of the coast line (fig. 12).

A secondary cause of the flood intensity would have been the presence of obstacles in the river in Rome (occluded passages of bridges, floating mills). The already mentioned increase in amplitude of the meanders can be seen as another consequence of the changed environmental balance. A contribution to the changed river balance may have been given by the start of a colder and rainier climate phase peaking in the 16th-19th centuries (the "Little Ice Age").

The salt marshes of Ostia have continued to function until the 19th century. By that time, the abandonment of the coastal plain is total; it is described by Carlo Fea in 1831 as an unhealthy marshy environment.

In the 19th century, in preparation of the land reclamation, the conditions of the coastal belt have been mapped by Amenduni 1884.

The sea level has resumed to rise again between 1884 and 1971 with an average annual value of 1.36 mm / year (Leoni, Dai Pra 1997).

In 1825 the new Via Portuense was constructed, in conjunction with the foundation of the town of Fiumicino. From 1875 on, the banks of the Tiber in Rome were built, and starting from 1918 along the stretch be-

10 *"... di questa torre ne veggiamo insino ad hoggi una buona parte in pie, se non che ne sono stati tolti i marmi, dei quali ella era incrustata".*

11 *"... ancora rimangono vestigi della torre le quali si vedono là nel mare; tutti gli altri monumenti sono periti interamente".* Original text: http://www.ostia-antica.org/~atexts/pius.htm.

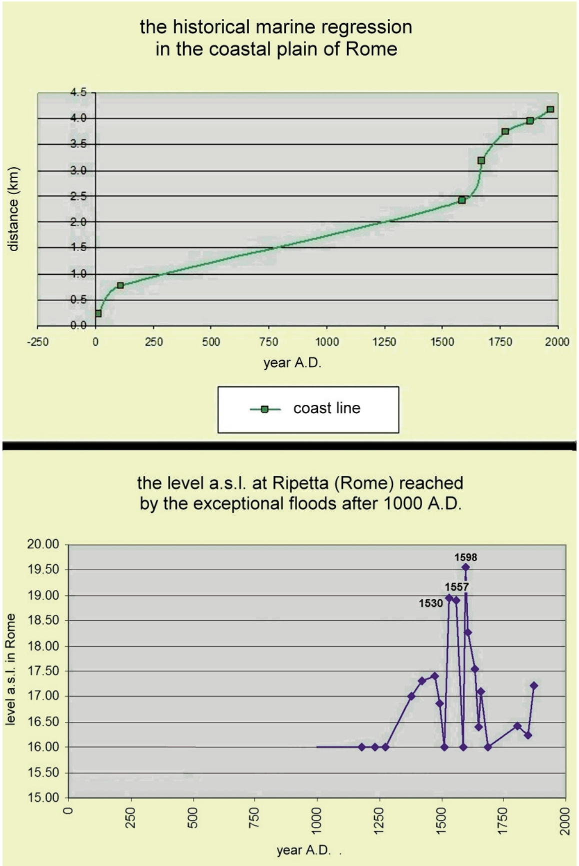

Fig. 12. Graphs showing the evident relationship between the accumulated coast line advance of the coastal plain of Rome and the flood levels reached after the year 1000 AD.

tween Rome and the mouth, actions which virtually isolated the river from the town and surrounding areas. The role and the "presence" of the river have become marginal.

There is nowadays a strong retreat of the coastline, undoubtedly related to the decrease in sediment load transported by the rivers to the sea.

In the twentieth century we have witnessed a strong urbanization, including the construction of the international airport of Fiumicino. Since 1992 the Lower Tiber valley is spread out over two Municipalities, Rome and Fiumicino, divided by the Tiber. But the newly founded (2016) *Parco Archeologico di Ostia Antica* has restored the historical unity of the archaeological sites on both sides of the river and the channel of Trajan, by including the excavations of Ostia Antica, the town of Portus, the larger part of the imperial harbours, the Necropolis of Isola Sacra, the temple of Isis and the *Museum of Roman Ships.*

Acknowledgements

I would like to thank Piero Bellotti and Carlo Citter for a critical review of this text, and Cinzia Morelli for supporting the geoarchaeological contribution to archaeological investigation.

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