DOI: 10.4408/IJEGE.2019-02.O-01

NEW MAPS RELATIVE TO THE SPECIAL PROTECTION AREA OF THE "PALUDE DI TORRE FLAVIA" (CENTRAL TYRRHENIAN SEA - ITALY) PRONE TO SEVERE COASTAL EROSION

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EXTENDED ABSTRACT

Il presente lavoro rientra nel progetto di Ateneo Sapienza di Roma "*Cliff slope failures in the coastal morpho-dynamics: from back-to forward-analysis of processes through monitoring and multi-modelling approaches*". Lo studio si prefigge di individuare le principali problematiche di erosione costiera dell'area protetta nota come Palude di Torre Flavia, sita fra i comuni di Ladispoli e Cerveteri a circa 35 km a NW di Roma.

L'area di studio è uno degli ultimi relitti di paludi costiere, largamente presenti in passato nell'Agro Romano. Attualmente la palude è ampia 0.16 km^2 e presenta una forma pressoché triangolare, essa risulta separata dal mare da un sistema spiaggia/duna che si allunga da Torre Flavia verso nord-ovest per circa 1 km. Quest'area naturale in passato aveva una estensione maggiore. Recentemente è stata bonificata e trasformata in parte in zona coltivata e parzialmente urbanizzata, in parte preservata come area umida protetta (Zona di Protezione Speciale ZPS IT 6030020, in accordo con le Direttive Comunitarie sulla Conservazione degli Uccelli 79/409/CEE e 2009/147/CE) gestita dalla Città Metropolitana di Roma. Questa zona attualmente è fortemente minacciata da fenomeni di erosione della spiaggia e della duna costiera antistanti la Palude. Nonostante la sua importanza naturalistica a livello nazionale, l'area non appare sufficientemente protetta e alta è la probabilità che essa possa essere ulteriormente ridotta o finanche essere soggetta alla totale scomparsa.

Studi sull'area sono stati essenzialmente centrati sulle caratteristiche ecologiche, poco sulle caratteristiche geologico- geomorfologiche e di dinamica costiera; specifici studi risalgono agli anni '80 nell'ambito dell'Atlante delle Spiagge Italiane e a monografie a scala regionale che hanno consentito di ricostruire l'evoluzione storica del paraggio costiero. La dinamica litorale mostra, fin dal 1950, un intenso e progressivo processo erosivo che diventa ancor più cospicuo a partire dagli anni '70. Questo sembra essere connesso con la forte riduzione del carico solido a mare del Fiume Tevere, principale fonte di alimentazione sedimentaria delle coste centrali del Lazio. Per contrastare il fenomeno erosivo sono state costruite circa venti anni fa opere di difesa di tipo convenzionale rigido (pennello e barriera longitudinale) che hanno prodotto un pascimento (tombolo) localizzato solo nella parte meridionale (in corrispondenza di Torre Flavia) senza migliorare la situazione a nord. Negli ultimi anni l'arretramento del litorale antistante la palude si è fatto sempre più cospicuo e la riduzione/scomparsa della spiaggia sta causando l'erosione anche del cordone dunare, oramai smembrato da diversi varchi. Conseguentemente, la palude retrostante rischia di perdere le proprie peculiari caratteristiche ambientali.

Il lavoro è stato svolto attraverso: 1) rilievi morfobatimetrici stagionali effettuati nell'anno 2017, 2) rilievi LiDAR del 2010, 3) rilievi morfologici di campagna 2017-2018, 4) analisi sedimentologiche della spiaggia sommersa/emersa 2017, 5) analisi di dati anemometrici di lungo periodo (1961-2010) relativi alle stazioni di Civitavecchia e di Fiumicino. I risultati sono presentati essenzialmente attraverso carte tematiche, in particolare: 1) due carte batimetriche stagionali, 2) una carta morfologica di grande dettaglio ove sono riportati dati morfometrici e morfodinamici del paraggio. Appare evidente, dai dati rilevati, che il sistema spiaggia/duna nel tempo è migrato verso terra, riducendo l'area palustre che attualmente risulta fortemente vulnerabile soprattutto nell'area centro-settentrionale. Durante le recenti, frequenti e intense fasi di tempesta l'erosione della spiaggia ha messo a nudo il fondo della palude su cui il sistema spiaggia/duna è nel tempo trasgredito. Inoltre localmente e saltuariamente il mare supera il sistema dunare penetrando nell'area protetta. L'aumentata frequenza di tali fenomeni rende particolarmente elevata la probabilità di danni ai caratteri ecologici della palude.

E' stato inoltre considerato l'atteso arretramento della linea di riva relativo al previsto innalzamento del livello marino all'anno 2050. Si è inserita, pertanto, una carta che mostra l'arretramento stimato ed evidenzia che il solo sollevamento del livello marino produrrebbe la distruzione, nella parte centrale, del sistema dunare con conseguente connessione permanente fra il mare e la Palude.

L'innalzamento del livello del mare non potrà che incrementare la probabilità di onde anomale , con conseguente rischio di erosione e inondazione; ciò potrà causare l'intrusione del cuneo salino e ulteriore degrado della palude retrostante. Il paraggio della Palude di Torre Flavia andrebbe, dunque, salvaguardato con adeguate difese costiere che provvedano 1) al controllo della pendenza della spiaggia sommersa 2) al ripristino dell'ampiezza della spiaggia emersa e 3) alla ricostruzione del cordone dunare.

ABSTRACT

This paper is aimed at Palude di Torre Flavia (SPZ IT 6030020) within the Natura 2000 Network including a coastal sector of central Tyrrhenian Sea (Italy) located about 35 km to the NW of Rome along the right sector of the Tiber River Delta, Italy. This site has a high naturalistic value because it includes a wetland area today threatened in particular by coastal erosion and partly by climate change in progress.

The analysis of the shoreline evolution shows that in the past, the wetland should be wider than the current one and, during the time, it was susceptible to an ongoing reduction due to a prevailing erosive trend. This erosive character resulted in reduced backshore width and the steepening of the shoreface. Seasonal morphological profiles show that the winter profile resembles much more a summer beach profile, while the summer profile is in part characterized by winter features. This anomalous climate regime occurring during 2017 belongs to a series of climate irregularity occurring in the last years along the Italian peninsula that testify an ongoing climate change at global scale.

Two objectives are proposed: i) understanding the coastal dynamics processes that induce erosion phenomena; ii) editing the geomorphological map using the ISPRA-AIGeo legend recently applied for several Italian coastal sites. It is proposed to identify, characterize and map the forms of the coastal landscape with the purpose of providing a useful tool to evaluate the coastal hazard and to support future land planning and management.

Keywords: *beach erosion, wetland, geomorphological map, wave climate, Tyrrhenian Sea*

INTRODUCTION

Recently the world's coastal areas are increasingly under pressure because they are (i) inhabited by a high percentage of citizens, (ii) an important source of food and raw materials, (iii) a vital link for transport and trade, (iv) host some sensitive habitats and, finally, (v) are favorite destinations for leisure time. The reduced carrying capacity and the lack of space create conflicts among different use of the land caused by significant seasonal variations in population and employment. All these factors threat an coastal natural ecosystems and are amplified by the effects of climate changes (Calise *et alii*, 2018). Sea-level rise increases the probability of anomalous waves, erosion processes, flooding, intrusion of the salt wedge and further endangers natural buffer zones such as wetlands (EUROSION, 2007). All these significant aspects, highlighted in the Integrated Coastal Zone Management Recommendation in Europe (2002/413/EC), are reflected, at a local scale, at the Palude di Torre Flavia site that is subjected to a severe erosive crisis and at risk of disappearing due to coastal erosion. Laws officially protected the study area since 1997, managed by the "Protected areas and Regional Parks" Office of the Province of Rome authority. The environmental value of this site is testified by the numerous regulatory protections since 1997 (Battisti, 2006). It is: i) a Site of Community Importance (SIC IT 60000009) in the Natura 2000 Network; ii) a Special Protection Area (SPA IT 6030020) in the official list of the Ministry of the Environment; and iii) a site included in the Ministry of Agriculture quality of International Long Term Ecological Research Station (ILTER). Moreover it is a Natural Monument (D.P.G.R. 613/1997) (hereafter TFNM) and a Special Area of Conservation, according to the Directives on the Conservation of Wild Bird 79/409/EEC and 2009/147/EC (SPZ code IT6030020).

The aim of this study is to provide a new map of the area to represent coastal dynamics processes and for planning future sea defenses (Miccadei *et alii*, 2012; Buosi *et alii*, 2017). It is the result at an interdisciplinary sea-land approach that is a key tool for the development of sustainable and successful management of Special Protection Sites. In this perspective, the geomorphological map applies the updated legend elaborated by the Italian Association of Physical Geography and Geomorphology (AiGeo) and the Italian Institute for Environmental Protection and Research (ISPRA) for several Italian coastal sites (Mastronuzzi *et alii*, 2017; Chelli *et alii*, 2018). Moreover an evaluation of shoreline retreat related to future sea level rise in 2050 is mapped.

STUDY AREA

The protected area belongs both to the continental transitional water and to the coastal water portion: it includes a coastal sector of central Tyrrhenian sea (41°58'N; 12°03'E) located about 35 km to the NW of the Tiber River mouth (NW Rome, Italy). The study area is characterized by flat sandy coast counting, proceeding from east to west, three main morphotypes: wetland, dune and beach. Moreover the site includes a medieval tower (Flavia Tower) built on the remains of a Roman villa located in the southern sector of the studied site (Fig. 1).

The wetland shows a triangular shape 0.16 km^2 wide (16 ha) and is fragmented into small brackish water basins (Fig. 2). This biotope is a relict of a larger heterogeneous littoral

Fig. 2 - Landscape of the Palude di Torre Flavia. It is shown how the basin is fragmented into smaller basins that can coalesce for periodic water oscillations

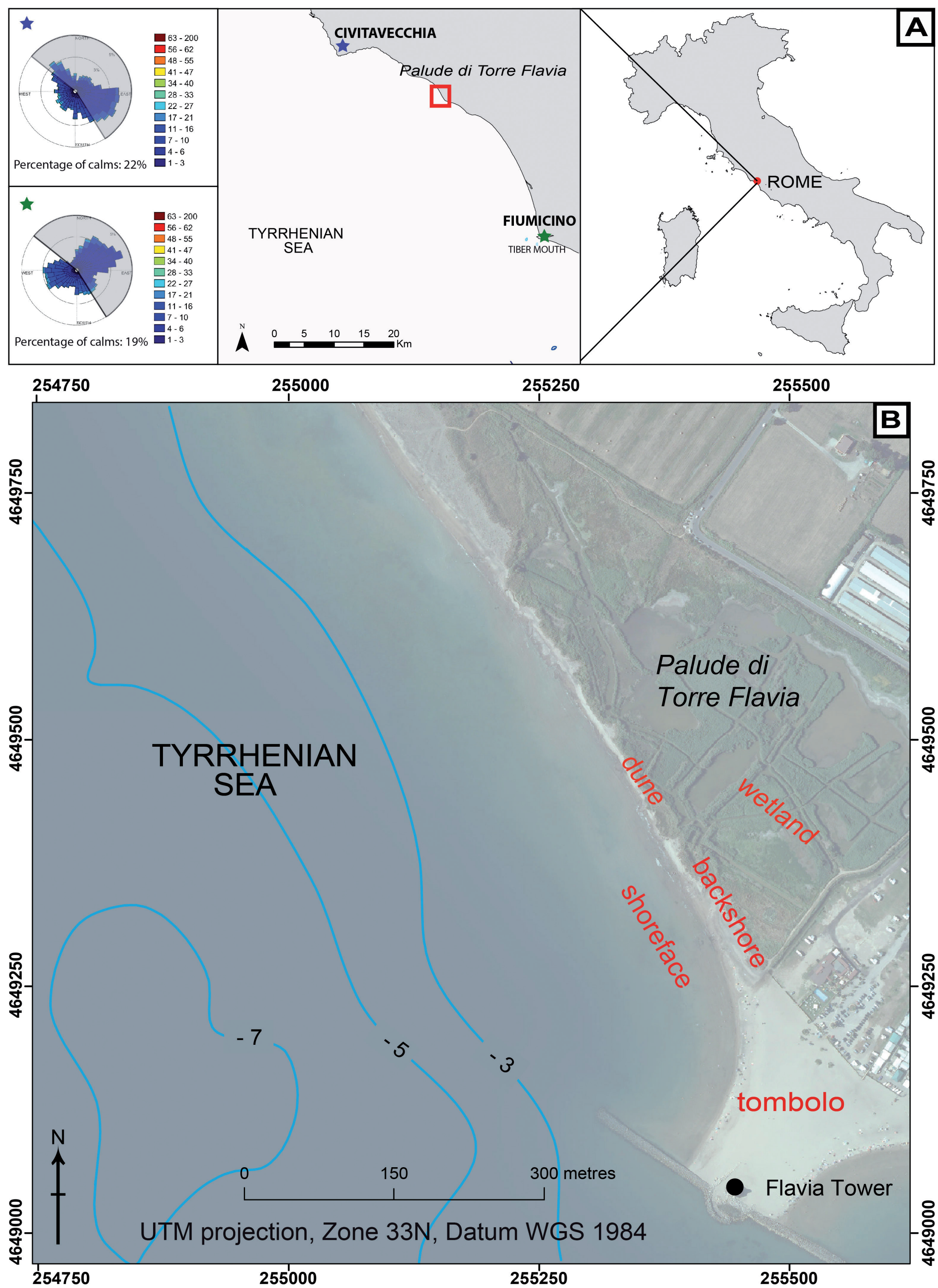

Fig. 1 - (A) Location map of the study area (square) included between Fiumicino and Civitavecchia cities. Anemometric data (1961-2010) from the Fiumicino (green star) and Civitavecchia (blue star) stations expressed by Beaufort scale. (B) Palude di Torre Flavia map based on orthophoto 2012; wetland, dune and backshore/shoreface are indicated

wetland area extended until 1960-1970 for about 100 ha, and successively drained and transformed by land reclamation. It is a sandy coast where, thanks to aeolian processes, a dune ridge is formed isolating brackish basins. The dune stretches for about 1 km parallel to the coast and constitutes a boundary towards the sea of the wetland, protecting it from coastal erosion. The backshore (Short, 1999) stretches from the Flavia Tower for about 1 km towards the NW. Its dynamics is strongly subjected to a sedimentary balance directly regulated by the main wave regime. The shoreface morphology (Short, 1999) appears uniform and constituted of sandy bottom except for the so-called "Secche di Torre Flavia", an arc shaped bedrock outcrop that extends from the tower towards the NW. According to the Köppen Climate System, the climate of this coastal sector falls within the mesothermal climates (C), Mediterranean type with very hot dry summer (Csa) (Bramati *et alii*, 2014), with scarce rainfall (593-811 mm annually). Rainfall shows a maximum in November-December and a minimum in July with a classic Mediterranean trend. Aridity characterizes a time interval ranging from May to August (sub-aridity period in April). Mean yearly temperatures are between 12 and 16°C (max: 30-35°C) while the mean temperatures of colder months range between 3.7 and 6.8°C. The prevailing winds blow from the W.

The shoreline dynamics shows, since the mid-1950's, an erosive phase; starting from the 1970's beach erosion was induced by a reduction of sediment transported by the Tiber River and several sea defenses recently built south of the study site. Today the site and its typical wetland ecosystem have strong chance to disappear and/or to be largely reduced in area.

METHODS

A long-term (1961-2010) anemometric analysis was conducted to define wave climate by mean of data from two meteorological stations (Civitavecchia and Fiumicino stations), located north and south of the investigated area, respectively (Fig. 1A). For the waves, we used data collected from the buoy of Ponza of the Italian Wave Measurement Network. The buoy provides data covering a time interval from 1989 to 2010. These data were used to obtain information regarding the wavelength, wave period and closure depth.

Coastal evolution has been investigated by means of maps since 1874, aerial photographs since 1954, orthophoto maps since 1994, LiDAR (2010) and GPS (2017) surveys and direct field survey (2016-2018). Geodetic data were acquired relating to the WGS84 Geographic Coordinate System, and elevation above mean sea level and depth were reported too.

Morphological and sedimentological data were recorded along 12 transects perpendicular to the shoreline obtained during two campaigns held in March and September 2017. In particular, two seasonal bathymetric maps are obtained by SINGLEBEAM

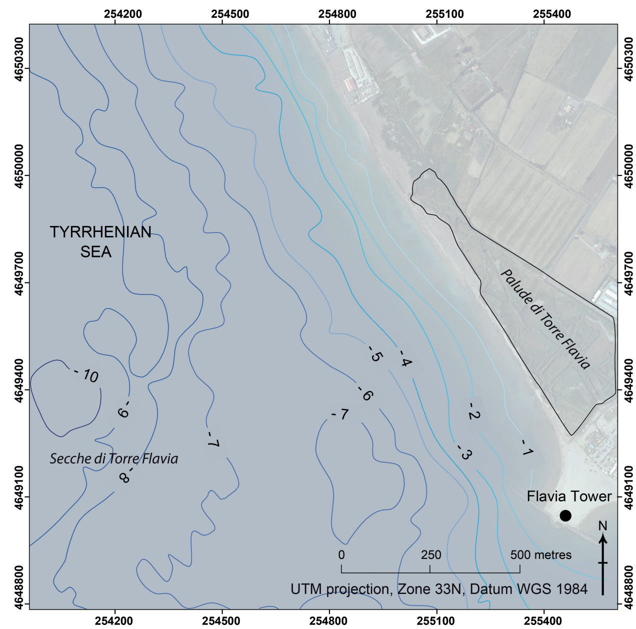

Fig. 3 - Reconstruction of the shoreface bottom of Palude di Torre Flavia based on March 2017 survey data. Isobaths in metres b.s.l.

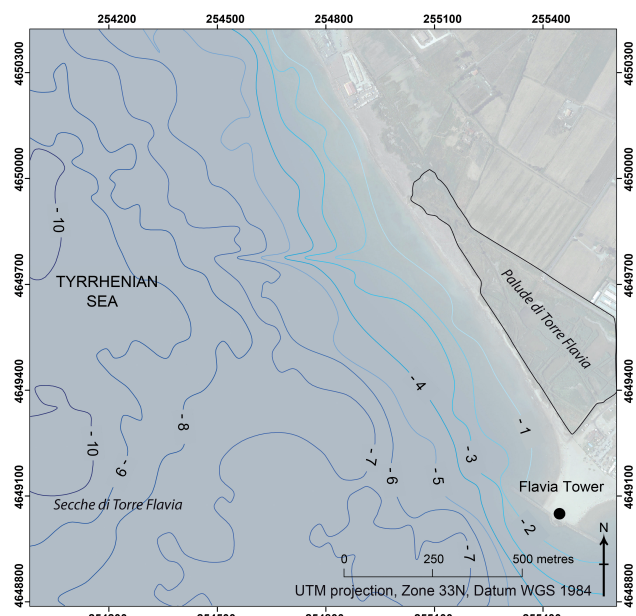

Fig. 4 - Reconstruction of the shoreface bottom of Palude di Torre Flavia based on September 2017 survey data. Isobaths in metres b.s.l.

surveys (Figs. 3-4); these data were compared with 1981 and 2011 survey findings. The wetland depth was measured during June 2017.

The geomorphological map was drawn using the updated legend of the Geomorphological Map of the Italian Coast (Mastronuzzi *et alii*, 2017; Chelli *et alii*, 2018), recently

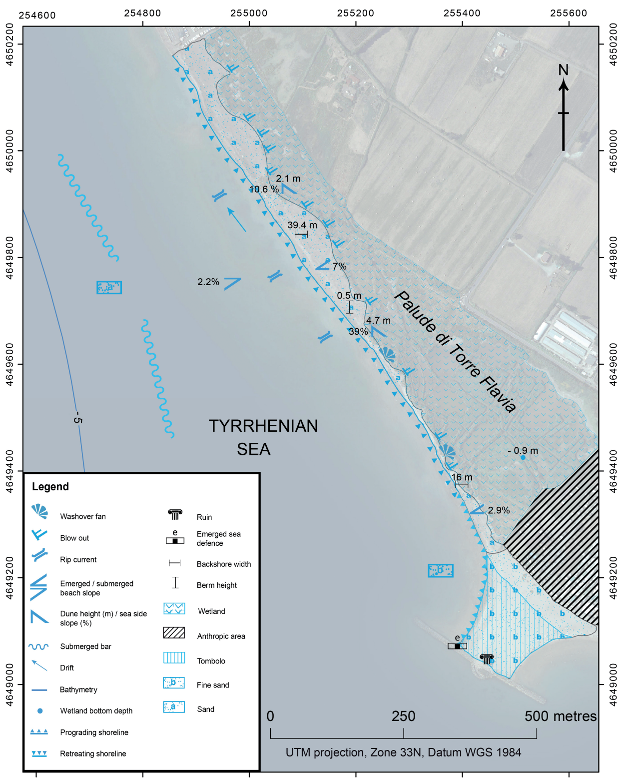

Fig. 5 - Morphological and morphometric map after the Italian Association of Physical Geography and Geomorphology AiGeo

applied for several Italian coastal sites. The proposed legend allowed the mapping of each landform of the study area for its genesis as well as its evolution and current dynamics, and provided information of morphological and morphometric characteristics (Fig. 5).

An evaluation of shoreline retreat was based on the sea level rise expected for the Tyrrhenian Sea to 2050 (Antonioli *et alii*, 2017). For this purpose according to Bruun (1962), the following equation was applied:

$$R = XS / (B + h)$$

where R is shoreline retreat, X is the distance between the closure depth and the top of the first dune, S is the hypothesized sea level rise for 2050, B is the altitude of the first dune and h is the closure depth calculated according to Hallermeier (1981) (Fig. 6).

RESULTS

The anemometric data for 1961-2010 (Fig. 1A), considering the totality of data, display prevailing winds from the third quadrant (N225° - 270°, west south-west), with an intensity reaching the 7th Beaufort class at Civitavecchia Station. Civitavecchia or Fiumicino stations both recorded similar total calm percentages, ranging between 19% and 22%. The area has an effective fetch for a sector of traversal 145° wide, of 394 km

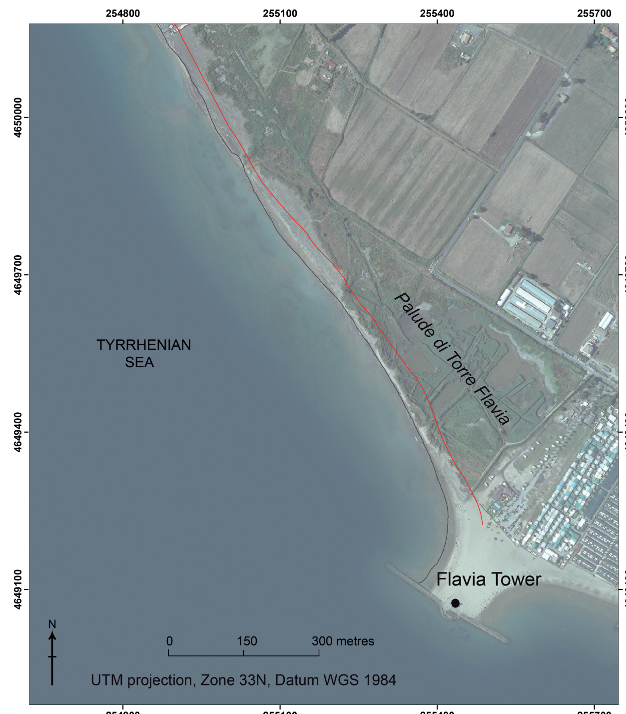

Fig. 6 - Map based on orthophoto 2012: the black line indicates the shoreline related to 2017; the red line indicates the expected shoreline related to 2050

Fig. 7 - View of present damaged dune

and a maximum fetch of over 600 km from the N210° direction. The wave data show significant height (H_s) equal to 3.9 m, wave period (T) equal to 9 s, and closure depth at -7.6 m. The coastal area is characterized by a microtidal regime, with maximum syzygial tide amplitude of 0.4 m.

The wetland shows a flattened bottom at 0 m a.s.l. with local depressions at -0.9 m a.s.l. and evidence of washover fans.

The dune has a maximum height of 4.7 m with a seaside slope on average between 39.0% and 10.6%, is broken up and incised by several blow-outs (Fig. 7). The embryo dunes are only found closest to the Flavia Tower.

Fig. 8 - View of the backshore subjected to severe erosion

The backshore stretches from the tower for about 1 km towards the NW. The width of the beach ranges from 16 to 40 m and the slope reflects both sediment size (sand and gravel) and beach width: the minimum value (2.9%) is recorded at the south, while the maximum (7%) is attained along the intermediate portion of the study area. A sea defense produces a 150 m stretched tombolo (Fig. 5). The study of the morphological evolution of the backshore at Palude di Torre Flavia carried out from 1874 to 2017 has evidenced a general prevailing erosional trend, variable in intensity in time and in space. In particular, during the more recent period 1950-2017, shoreline retreat between 50-150 m occurred along the central and northwestern part (Fig. 8), while an opposite trend occurred in the southeast caused by the coastal defences built near the tower. These erosive phenomena produced a progressive beach-dune system landward migration, reducing the extension of the wetland from 0.5 km^2 wide (in 1874) to 0.16 km^2 (in 2017).

The shoreface widens for about 1.2 km, from the shoreline to the estimated closure depth (-7.6 m). Around the depth of 4-5 m, 300 m from the shoreline, the presence of an outermost bar is detected while an inner one, extremely mobile, is on average at -2 to -3 m depth. Off the Flavia Tower, beyond the closure depth, a rocky platform called Secche di Torre Flavia is present.

The northern and central sector is incised by erosive channels, like gullies, perpendicular to the shoreline and extended beyond the closure depth. Seasonally, the bathymetry detected in March, shows, in the northern sector (up to 3-4 m depth), a steeper profile than the profile found in the southern part of the area, close to the tombolo (Fig. 3). Moreover during the September survey, in the northern sector, more accentuated erosive gullies than those of the winter season (March survey) were highlighted (Fig. 4). In this same northern sector, the shoreface, resembling the winter bathymetric profile, appears steeper if compared to the slope of the southern portion of the submerged beach.

The data analyzed made it possible to prepare the morphographic, morphometric and morphodynamic map (Fig. 5).

Finally a map is drawn showing the hypothesized shoreline retreat at 2050. Considering the shortcomings of the Bruun rule (Pilkey *et alii*, 1993; Davidson-Arnott, 2005) regarding beaches affected by longshore-currents (Brunel & Sabatier, 2009), in this case, this method was considered suitable for the limited local coastal stretch extension and the presence of sea defense close to Flavia Tower. The values used are: S = 0.34 m; h = 7.6 m; whereas B and X values were measured along six normal transects to the coast. The presence of rocky platform, although beyond the closure depth, and the irregularity of the sea floor could determine variability and decrease in h values (Sabatier *et alii*, 2004), but it is believed that these variations may scarcely affect regarding to the shoreline retreat value ranging between 19 and 44 m with respect to the current shoreline (Fig. 6).

FINAL REMARKS

The erosive phase during the last century that affected the area under study is widespread throughout the delta Tiber coast and is mainly due to the severe reduction of the Tiber solid load (Bersani & Piotti, 1994; Bersani & Moretti, 2008). The drift, induced by predominantly western waves and directed northwest ward from the Tiber mouth is also partially intercepted by the sea defenses located south of the study area. Sediments are further partially lost through rip current action that periodically triggers and produces a series of gullies on the central and northern shoreface. The erosive crisis appears more conspicuous in the northern part where the backshore width is reduced and the shoreface slope is steeper, consequently the dune ridge is more frequently damaged by storms that are becoming frequent (Calise *et alii*, 2017).

The information obtained from LiDAR, bathymetric and sedimentological surveys all together allowed us to draw up a morphological coastal map. The legend collects recent research advances carried out by the community of Italian coastal geomorphologists as well as the results of an articulated scientific discussion developed by the Coastal Morphodynamics Workgroup established by AIGeo in 2013. Unlike the vast majority of existing coastal maps, this paper suggests a new mapping approach, replacing the descriptive method of "morphographic" maps with that based on morphogenetic, morphometric, and morphodynamic data. The new "morphodynamic" maps are enriched by hydrodynamic features, sedimentology and can facilitate their input into a Geographical Information System (GIS), to carry out evolutionary trends. Therefore the new legend may be considered more useful for coastal planners and stakeholders because it describes both the genesis and evolution of coastal landforms. The morphological and morphodynamic legend reported in Fig. 5 represents only a small part of a more complex and wider geodatabase because it delineates and maps the present coastal landforms as point, line, and polygonal elements at scales ranging from 1:5000 to 1:50,000.

In conclusion, the study area is vulnerable likely to Tiber delta coast (Tarragoni *et alii*, 2014) and has a strong disappearance risk due to sea ingression in the wetland (Tarragoni *et alii*, 2011). Coastal vulnerability is mainly due to two different processes. The first is the dynamics induced by wave action concomitant to scarcity of sediment supply. The second is due to expected sea-level rise. The first process being rapid and impulsive represents the greatest threat; it can in fact produce a rupture of the coastal barrier system (beach+dune) that protects the Palude di Torre Flavia, with consequent introduction of water and marine sediment in the protected area. The second process is more gradual and can produce landward migration of the beach +dune system and amplify the effects of the first process. In particular in the central sector of the studied coast, the expected shoreline to 2050 would be positioned behind the current dune system (Fig. 6). The partial dismantling of this system would allow a permanent connection of the wetland with the sea and the consequent change in the environmental parameters of the Palude di Torre Flavia (Mikhailova *et alii*, 1999).

The Palude di Torre Flavia must be safeguarded through adequate coastal defenses that will provide for the control of shoreface slope, backshore width and dune ridge reconstitution.

SOFTWARE

Software Surfer13 was utilized to elaborate bathymetric and GPS data and to generate the bathymetric contour lines; while ArcGis 10.1 was utilized to manage all data and base maps and elaborate the geomorphological legend. The design of the final map was performed using Adobe Illustrator suite.

ACKNOWLEDGEMENTS

This paper was funded by the Sapienza University of Rome Project "Cliff slope failures in the coastal morpho-dynamics: from back-forward analysis of processes through monitoring and multi-modeling approaches" (Responsible Prof. S. Martino).

REFERENCES

Antonioli F., Anzidei M., Amorosi A., Lo Presti V., Mastronuzzi G., Deiana G., De Falco G., Fontana A., Fontolan G., Lisco S., Marsico A., Moretti M., Orru' P.E., Sannino G.M., Serpelloni E. & Vecchi A. (2017) - *Sea-level rise an potential browning of the Italian coastal plains flooding risk scenarious for 2100*. Quaternary Sciences Reviews, **158**: 29-43.

Battisti C. (2006) - *La Palude di Torre Flavia. Biodiversità, gestione, conservazione di un'area umida del litorale tirrenico.* Gangemi Editore. 493 pp. ISBN 88-492-1145-0.

Bersani P. & Piotti A. (1994) - *Correlazioni tra portata liquida e trasporto solido deel Fiume Tevere a Roma.* Idrotecnica, **2**: 69-78.

Bersani P. & Moretti D. (2008) - *Evoluzione storica della linea di costa in prossimità della foce del Tevere*. L'Acqua, **5**: 77-87.

Bramati M.C., Tarragoni C., Davoli L. & Raffi R. (2014) - *Extreme rainfall in coastal metropolitan areas of Central Italy: Rome and Pescara case studies*. Geografia Fisica e Dinamica Quaternaria, **37** (1): 3-13.

Brunel C. & Sabatier F. (2009) - *Potential influence of sea-level rise controlling shoreline position on the French Mediterranean Coast.* Geomorphology, **107**: 47-57.

Bruun P. (1962) - *Sea-level rise as a cause of shore erosion.* Proceedings of the American Society of Civil Engineers. Journal of the Waterways and Harbors Division, **88**: 117-130.

Buosi C., Tecchiato S., Pusceddu N., Frongia P, Ibba A. & De Muro S. (2017) - *Geomorphology and sedimentology of Porto Pino, SW Sardinia, western Mediterranean*. Journal of Maps, **13** (2): 470-485. Doi: 10.1080/17445647.2017.1328318

Calise, G., Jonia Lasinio, G., Mastrantonio, G., Bruschi, A. & Davoli L. (2018) - *Short term change of sea climate and influence on the littoral of Belvedere Marittimo (Cosenza - Italy)*. Italian Journal of Engineering Geology and Environment, **1**: 5-24.

Chelli A., Aringoli D., Aucelli P., Baldassarre M.A., Bellotti P., Bini M., Biolchi S., Bontempi S., Brandolini P. L., Davoli L., Deiana G., De Muro S., Devoto S., Di Paola G., Donadio C., Fago P., Ferrari M., Furlani S., Ibba A., Lupia Palmieri E., Marsico A., Melis R.T., Milella M., Mucerino L., Nesci O., Orrù P., Panizza V., Pennetta M., Piacentini D., Piscitelli A., Pusceddu N., Raffi R., Rosskopf C. M., Sansò P. & Stanislao C. (2018) - *Morphodynamics of coastal areas represented in the new geomorphologic map of Italy: draw the landforms of the past to outline the future.* Quaternary: Past, Present, Future - AIQUA Conference, Florence, 13-14/06/2018. Alpine and Mediterranean Quaternary, **31**: 17-21.

Council Directive 2009/147/EC of the European Parliament and of the Council. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009L0147

Council directive 79/409/EEC of 2 April 1979 on the conservation of wild birds. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM%3Al28046

Davidson-Arnott R.G.D. (2005) - *Conceptual model of the effects of sea level rise on sandy coasts*. Journal of Coastal Research, **21**: 1166-1172.

EUROSION (2007) - *Vivere con l'erosione costiera in Europa : Sedimenti e spazio per la sostenibilità.* A cura di: Doody P., Ferreira M., Lombardo S., Lucius I., Misdorp R., Niesing H., Salman A., Smallegange M.,. Cipriani L.E., Lanza S., Pranzini E. & Randazzo G. 21 pp.

Hallermeier R.J. (1981) - *A profile zonation for seasonal sand beaches from wave climate.* Coastal Engineering, **4**: 253-277.

Mastronuzzi G., Aringoli D., Aucelli P., Baldassarre M.A., Bellotti P., Bini M., Biolchi S., Bontempi S., Brandolini P., Chelli A., Davoli L., Deiana G., De Muro S., Devoto S., Di Paola G., Donadio C., Fago P., Ferrari M., Furlani S., Ibba A., Lupia Palmieri E., Marsico, A., Melis R.T., Milella M., Mucerino L., Nesci O., Orrù P., Panizza V., Pennetta M., Piacentini D., Piscitelli A., Pusceddu N., Raffi R., Rosskopf C. M., Sansò P., Stanislao C., Tarragoni C. & Valente A. (2017) - *Geomorphological map of the Italian Coast. From a descriptive to a morphodynamic approach.* Geografia Fisica e Dinamica Quaternaria, **40**: 175-178. Doi: 10.4461/ GFDQ 2017.40.11.

Miccadei E., Orrù P., Piacentini T., Mascioli F.& Puliga G. (2012) - *Geomorphological map of the Tremiti Islands (Puglia, Southern Adriatic Sea, Italy), scale 1:15,000.* Journal of Maps, **8** (1): 74-87. Doi:10.1080/17445647.2012.668765.

Mikhailova, M.V., Bellotti, P., Valeri, P. & Tortora P. (1999) - *Intrusion of seawater into the river part of the Tiber mouth*. Water Resources, **26** (6): 679-686

Pilkey O.H., Young R.S., Riggs S.R. & Smith A.W. (1993) - *The concept of shoreface profile of equilibrium: acritical review.* Journal of Coastal Research, **9**: 255–278.

Recommendation of the European Parliament and of the Council of 30 May 2002 concerning the implementation of integrated coastal zone management in Europe (2002)- 2002/413/EC. Official Journal, L148: 24.

Sabatier F., Stive M. & Pons F. (2004) - *Longshore variation of depth of closure on a micro-tidal wave-dominated coast.* International Conference of Coastal Engineering 2004. American Society of Civil Engineering, Lisboa: 2329-2339.

Short A.D. (1999) - *Handbook of beach and shoreface morphodynamics.* Wiley, Chichester

Tarragoni C., Bellotti P., Davoli L., Petronio B.M. & Pietroletti M. (2011) - *Historical and recent environmental changes of the Ombrone Delta (Southern Italy).* Journal of Coastal Research, Special Issue **61**: 344-352.

Tarragoni C., Bellotti P., Davoli L., Raffi R. & Lupia Palmieri E. (2014) - *Assessment of coastal vulnerability to erosion: The case of Tiber River Delta (Tyrrhenian Sea, Central Italy).* Italian Journal of Engineering Geology and Environment, **14** (2): 5-16.

Received September 2019 - Accepted December 2019

