

## Linking benthic fauna and seismic facies to improve stratigraphic reconstructions: the case of the Mid-Adriatic Deep since the late glacial period (Central Adriatic Sea)

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**KEY WORDS** - Benthic invertebrates, Stratigraphic Palaeobiology, Po Delta, Clinothem, late Quaternary.

**ABSTRACT** - Direct observations from the geologic record are commonly used in conjunction with indirect seismic inferences to detail environmental settings and stratal architecture of sedimentary successions. However, examples of integration between seismic and macrobenthic insights are scarce and limited to the use of such a group as an auxiliary to other proxies. We investigated mollusc and ostracod assemblages along an onshore-offshore transect that intersects the C<sub>2</sub> clinothem (15.6 - 14.4 ka BP) and the overlying transgressive deposits that recorded the last phase of progradation and abandonment of the Po River Lowstand Wedge (PRLW). We applied multivariate analyses to benthic data to assess the extent to which mollusc and ostracod assemblages can improve both the resolution of seismic-derived depositional environments and the sequence stratigraphic architecture of targeted sedimentary succession. Along the onshore-offshore transect, seismic reflection geometries correspond with three broad sedimentary environments: High Amplitude Continuous reflections (HAC) are interpreted as delta plain/subaqueous shelves, High Amplitude Continuous Wavy Dipping reflections (HACWDip) as prodeltas and Low Amplitude Continuous reflections (LAC) are associated to distal basin settings. The integration of quantitative palaeoecologic trends with seismic-derived depositional environments allowed us to subdivide the HAC facies into a proximal (core LSD-26) and distal (cores LSD-27 and -28) area. The proximal HAC facies, in particular, encompasses lower delta plain semi-barred settings with vegetated substrates that upcore pass to nearshore settings. The distal HAC facies is distinguished by clusters that suggest ecological mixing due to strong bioturbation and wave-aided hyperpycnal flows in offshore transition/inner shelf settings. The paucity of benthic fauna for the geophysical units HACWDip (core LSD-05) and LAC (core LSD-04) hampered a complete reconstruction of the palaeoenvironmental dynamics. However, both benthic groups support a seismically derived interpretation of shelf and basinal settings, respectively, and both were subjected to high sedimentation rates. Moreover, integration of mollusc and ostracod multivariate-derived trends with grain-size data across the onshore-offshore transect reveals distinctive stratal stacking patterns that are useful in constraining the position of the Maximum Regressive Surface that marks the abandonment of the PRLW in the Central Adriatic Sea.

### INTRODUCTION

Quaternary marine palaeoecology has experienced a major renovation thanks to its integration with high-resolution seismic facies analysis. The indirect inferences on sedimentary successions derived from seismic data can be validated by direct observations obtained from a wealth of biologic and sedimentary proxies (e.g., foraminifers, sedimentary structures). This has led to a more detailed interpretation of environmental settings and processes. This approach ultimately leads to an increase in the reliability of the reconstructed stratigraphic architecture of continental margins, which plays a pivotal role in modern society as shelf-related deposits host a large share of energy resources (e.g., Vear, 2005; Khain & Polyakova, 2008; Spencer et al., 2011; Pellegrini et al., 2017a).

Within this research field, foraminifers represent key traditional tools to develop synergies with seismic-

based investigations (Langone et al., 1997; Asioli et al., 2001; Scott et al., 2004; Piva et al., 2008; Ridente et al., 2009; Fanget et al., 2013; Pellegrini et al., 2015; Ronchi et al., 2018; Patruno et al., 2019). Examples of integration between seismic and mollusc or ostracod-derived insights are less abundant in the literature and are essentially limited to the use of such groups as auxiliary and qualitative data (e.g., Maselli et al., 2014; Gamberi et al., 2019). However, Quaternary macro- and meiofaunas are primarily represented by extant taxa with wide environmental distribution and sensitivity to shifts in environmental conditions. These groups have already proved successful in integrated stratigraphic investigations focused on stratal stacking patterns and palaeoenvironmental dynamics of recent paralic and marine successions now found onshore the Italian Peninsula (Amorosi et al., 2014, 2016; Scarponi et al., 2014, 2017; Crippa & Raineri, 2015; Azzarone et

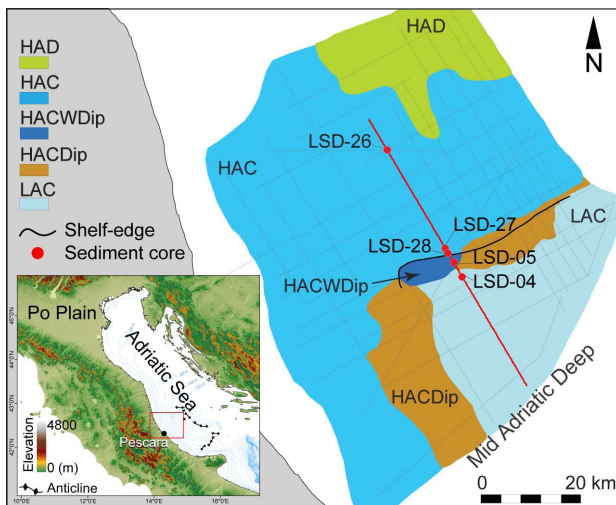


Fig. 1 - Seismic-derived facies map of the Po River Lowstand Wedge during the deposition of the clinothem  $C_2$  (modified after Pellegrini et al., 2018). The map reports also the position of the investigated cores (red dots) along the studied transect (red line). The inset shows the location of the study area and the main tectonic structures: Gallignani-Pelagosa and Tremiti (longitudinal and latitudinal oriented crosses) delimiting the Mid-Adriatic Deep. For a description of all the seismic facies retrieved in the study area and the inferred depositional environments, see Tab. S2 of the Supplementary Online Material - SOM 1).

al., 2018; Crippa et al., 2018, 2019; Rossi et al., 2018; Dominici et al., 2019).

We present here a multidisciplinary and quantitative study that integrates insights from the distribution of benthic organisms (molluscs and auxiliary ostracods) and seismic-derived environmental reconstruction of the last glacial period. In this context, the Mid-Adriatic Deep and its adjacent shelf located roughly offshore Pescara (Fig. 1), represent a natural laboratory where direct bio-sedimentary findings from cores can be integrated with seismic facies reconstructions from high-resolution profiles; all this in a high-resolution chronostratigraphic framework (Pellegrini et al., 2017a). Thus, our study area represents a modern analogue for a better understanding of hydrocarbon systems found in shelf-edge deltaic successions. Recent investigations on the Late Pleistocene succession of the Mid-Adriatic Deep enabled recognition of the composite stacking pattern of the Po River Lowstand Wedge (PRLW). This complex stratal architecture reflects eustatic, climatic, and environmental oscillations that characterised the last glacial phase (Pellegrini et al., 2017a, b, 2018; Gamberi et al., 2019).

Furthermore, we examined the uppermost sedimentary succession of the Mid-Adriatic Deep to tune the turnaround between normal progradational and retrogradational stacking patterns that define the Maximum Regressive Surface (MRS; Helland-Hansen & Martinsen, 1996; Neal et al., 2016). The MRS that coincides, at first approximation, with the transgressive surface is a surface of notable sequence stratigraphic importance, elevated to the rank of sequence boundary in downstream-controlled settings (Catuneanu, 2019; and references therein).

In conclusion, the abundance of direct (sediment cores) and indirect (seismic) data provides the opportunity to assess, by means of multivariate analyses, to what extent

the integration of mollusc and ostracod data can refine our understanding of the seismic-derived depositional environments and stratal architecture in the Central Adriatic Sea during the late glacial phase and the onset of the current interglacial phase.

## STUDY AREA

### *The Mid-Adriatic Deep and the Po River Lowstand Wedge (PRLW)*

The interval between the former interglacial (Eemian) and the Last Glacial Maximum led to a substantial reconfiguration of the depositional setting of the northern Adriatic basin with a sea level drop of ca. 135 m (Lambeck et al., 2014) associated with a seaward shift of the shoreline of ~300 km (Pellegrini et al., 2017a). The concomitant progressive exposure of the northern Adriatic shelf caused the enlargement of the fluvial catchment area which was up to three times larger than the modern one (196 000 km<sup>2</sup> vs 74 000 km<sup>2</sup>; Kettner & Syvitski, 2008; Amorosi et al., 2016). During that time, extensive glaciers capped the Alpine Chain (Monegato et al., 2017) and fed the ancestral Po River system that discharged directly into the structurally confined Mid-Adriatic Basin (Gallignani-Pelagosa and Tremiti structures; Fig. 1), where it built the Po River Lowstand Wedge (PRLW). During the sea level lowstand the Mid-Adriatic Deep remained connected to the Mediterranean Sea, thereby maintaining a link to global sea level, so that variations in its shoreline position as well as in depositional environments were recorded (Trincardi et al., 1996). In recent years, detailed studies shed light on the complex stacking pattern of the 13 elemental clinothems that constitute the PRLW (from  $A_1$  to  $C_2$  in Pellegrini et al., 2017a, b, 2018) and attained a thickness of up to 350 m in only 17 ky (Pellegrini et al., 2017a).

### *The $C_2$ clinothem, drowning and abandonment of the PRLW*

The  $C_2$  clinothem that is bounded at the base by the s7 surface (~15.7 ka BP), and at the top by the MRS (~14.4 ka BP), recorded the last phase of deposition of the PRLW that resulted in > 20 m of shelf aggradation and in > 1 km of shelf-edge progradation (Fig. 2; Pellegrini et al., 2017a). During the  $C_2$  clinothem deposition, the decrease in sediment supply to the Mid-Adriatic Deep and the presence of an efficient oceanographic regime on the outer shelf (Gamberi et al., 2019) did not allow coastal systems to reach the Adriatic shelf-break. In this scenario, the aggradation of alluvial and delta plains hampered sand transport to deeper water. Therefore, with sand almost entirely trapped on the shelf, fine-grained deposits accumulated in the slope and basinal sectors of the Mid-Adriatic Deep (Pellegrini et al., 2018; Gamberi et al., 2019).

The post-Last Glacial Maximum (LGM) eustatic rise, with rates of up to 12 m/ky (Lambeck et al., 2014), led to the abandonment of the  $C_2$  clinothem close to the onset of Termination I after ~14.4 ka BP. Due to the drastic reduction of the sediment supply compared to the LGM acme, the basinal area recorded the sub-millennial scale palaeoceanographic oscillations that characterised the Bølling/Allerød, Younger Dryas and Holocene (Asioli,

1996; Asioli et al., 2001). Along the Adriatic shelf, elongated sedimentary bodies recorded short-lived intervals of rapid sedimentation (Trincardi et al., 1996) linked to sea-level stillstand phases in the overall post-glacial transgression (e.g., Storms et al., 2008; Pellegrini et al., 2015; Rovere et al., 2019).

## MATERIALS AND METHODS

### *Seismic profile and targeted seismic facies*

The multichannel seismic reflection profile used in this work was acquired with a mini water-gun source (Sercel S15-02 of 15 in<sup>3</sup>) and a multichannel streamer (Teledyne mini-streamer with 24 channels; 80-500 Hz frequency bandwidth) during the oceanographic cruise Low Stand Delta (LSD) 2014. Our sampling rate was 0.25 ms, with a record length of 832 ms TWT (Two Ways Time). Traces were processed using the software Disco/Focus by Paradigm<sup>®</sup> up to time migration. Normal Move Out correction was performed using a simplified velocity model with an increase in sound velocity from 1500 m s<sup>-1</sup> at the seabed to 1850 m s<sup>-1</sup> at 0.832 s. In general, the multichannel seismic profiles allow us to trace stratigraphic surfaces with a vertical resolution of ~0.8 m. However, at the shelf-edge, the uncertainty in tracing key stratigraphic surfaces is higher because of the presence of coarse-grained deposits characterised by reflections with lower lateral continuity.

Seismic amplitude, continuity and dip (where dipping reflections are > 0.8°), internal reflection characters, the nature of their boundaries, and their position in the depositional system were the attributes used to distinguish the different seismic facies. Grouping these seismic parameters into mappable seismic facies allowed a preliminary interpretation in terms of lithofacies and depositional environments (Pellegrini et al., 2018). Here this seismic interpretation is linked with quantitative

macro- and meiofaunal inferences. Along the investigated onshore-offshore transect of the C<sub>2</sub> clinothem, we analysed three out of four seismic facies based on core availability (Fig. 1 and Tab. 1; see Pellegrini et al., 2018 and the SOM 1 for description of all the seismic facies recognised within the study area).

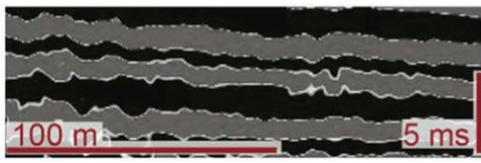

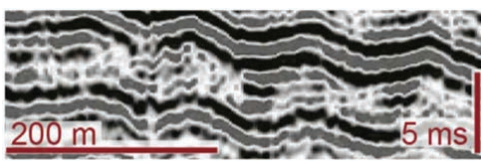

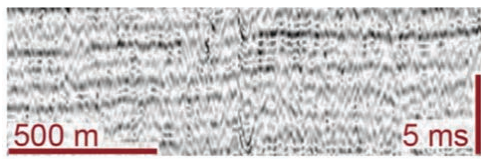
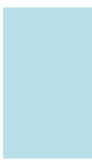
**HIGH AMPLITUDE CONTINUOUS (HAC) REFLECTIONS** - These are associated with clinothem topsets and bottomset of the PRLW. However, in the C<sub>2</sub> this seismic facies is found only in the topset portion of the clinothem. Inferred depositional environment: HAC seismic facies in the topset have been interpreted to represent delta plain to subaqueous shelf deposits, whereas in the bottomset the HAC has been interpreted to represent fine-grained basinal deposits (Trincardi et al., 1996).

**HIGH AMPLITUDE CONTINUOUS WAVY DIPPING (HACWDIP) REFLECTIONS** - These characterise the foreset of the C<sub>2</sub> clinothem. Inferred depositional environment: HACWDip seismic facies represent the complex foreset stratigraphy of the upper prodelta-slope due to the presence of 10-m-scale wavy irregularities associated with heterolithic bedsets (e.g., Urgeles et al., 2011).

**LOW AMPLITUDE CONTINUOUS (LAC) REFLECTIONS** - These are associated with clinothem developed in the late phase of the PRLW progradation. Inferred depositional environment: LAC seismic facies have been interpreted to represent fine-grained deposits in basinal settings under continuous background sediment accumulation.

### *Sampling methods*

The five cores used in the present investigation, which were collected during the LSD-2015 cruise using the Research Vessel Minerva I, are distributed along a NW-SE transect (Figs 1 and 2). We performed mollusc analyses on a total of 41 samples (~150 cm<sup>3</sup> each) collected from

SEISMIC FACIES	ACRONYMS AND COLOURS	INTERNAL REFLECTIONS	DEPOSITIONAL ENVIRONMENT
	 HAC	High Amplitude Continuous	Delta plain/ subaqueous shelf
	 HACWDip	High Amplitude Continuous Wavy Dipping	Prodelta
	 LAC	Low Amplitude Continuous	Distal basin

Tab. 1 - Summary of the investigated seismic facies retrieved along the seismic profile. For each facies is also reported the acronym and the colour used in the text and in the figures (modified after Pellegrini et al., 2018).

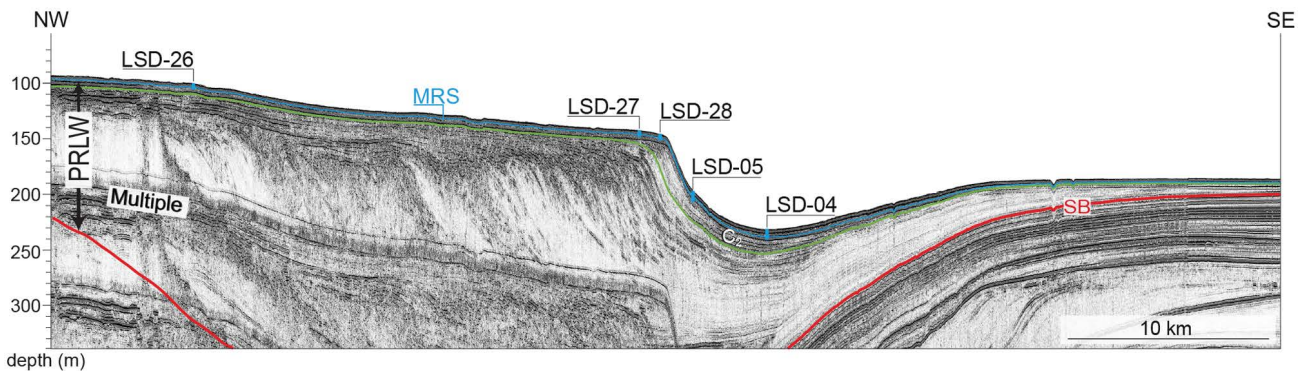


Fig. 2 - Downdip multichannel seismic profile LSD-22 showing the internal geometry of the ca. 350 m thick succession of the Po River Lowstand Wedge (PRLW) along the main direction of progradation and the stratigraphic position of the clinothem  $C_2$  and investigated cores (after Pellegrini et al., 2018). Clinothem  $C_2$  is delimited at the bottom by the green line and at the top by the maximum regressive surface (MRS, blue line). The thick red line represents the sequence boundary (SB).

regressive deposits and lower portions of the overlying transgressive unit in each core with a maximum vertical spacing of  $\sim 0.90$  m. A suite of ostracod samples was analysed from selected stratigraphic intervals (e.g., from the basal core and at lithofacies changes) to improve the palaeontological record and to constrain the position of the MRS. Samples were soaked in 10%  $H_2O_2$  overnight, water-screened with two stacked 125  $\mu m$  and 63  $\mu m$  mesh sieves to retrieve macro- and meiofauna, and then dried in an oven at 40° C for 24 h. For both groups, we performed fossil picking under a stereomicroscope. Mollusc fossils were picked according to the procedures described in Scarponi & Angeletti (2008) and identified at the species level when possible. Mollusc identification relied on the malacology collection of the Dipartimento di Scienze Biologiche, Geologiche e Ambientali, Università di Bologna.

For ostracods, a minimum of 100 valves (carapaces were considered two valves) were counted for each selected sample in the size fraction  $> 125 \mu m$ ; otherwise, counting was performed for all residue. Following the procedures outlined in Boomer et al. (2003), valves with evident signs of transport or reworking, such as marked abrasions or a greyish/dark appearance, and those that were highly fractured (less than 50% of the valve preserved) were considered allochthonous and not included in the counting. All adult and juvenile specimens that bore morphological features sufficiently developed to allow a species-level classification were picked, transferred into micro-palaeontological slides, and counted. The identification of ostracod taxa relied on the original descriptions (see Ellis & Messina, 1952) and several reference works (e.g., Athersuch et al., 1989; Frenzel et al., 2010; Cabral & Loureiro, 2013) with specific attention paid to the Adriatic area (Bonaduce, 1975; Breman, 1975).

#### Data matrix

The mollusc and serpulid dataset includes 3555 specimens that belong to 69 genera and 82 species, while the ostracod dataset counts 2032 specimens (SOM 2), represented by one group (undetermined freshwater/brackish species) and 39 genera including 76 species. As for ostracods, species sharing the same ecological

requirements were gathered up to genus level (SOM 3). Regarding the macroinvertebrate dataset, analyses were conducted at species level, that is, all open nomenclature taxa above species were considered only if no identified co-generic species was present. Lastly, a few small-sized samples were merged together when sampled from homogenous deposits and spaced less than 0.7 m apart. This allowed a quantitative insight also from deposits otherwise characterised by dispersed macrofossil content.

Prior to multivariate analysis, both the mollusc and ostracod matrices were culled by removing rare species (i.e., those that occurred in only one sample) and small samples ( $n < 20$  specimens). The final macroinvertebrate matrix includes 32 samples, 3342 specimens, 41 genera and 49 species of molluscs while the ostracod matrix consists of 21 samples, 2001 specimens, 4 groups, 26 genera, and 26 species. Herein the word specimen refers to a complete fossil or a unique fragment (i.e., a fragment that contains the apex for gastropods or umbo for bivalves).

#### Multivariate analysis

We investigated the mollusc dataset separately and employed Detrended Correspondence Analysis (DCA) to identify key environmental drivers of molluscan assemblages. DCA is an indirect gradient analysis that simultaneously determines scores for samples and taxa within the ordination space and environmental gradients can be inferred from the taxonomic information of the investigated taxa. This method has been used effectively in several studies comparing stratigraphic and palaeoecological data (e.g., Patzkowsky & Holland, 2012; Scarponi et al., 2014; Rivero-Cuesta et al., 2019). Prior to the application of the DCA analysis, the matrix was log transformed. In addition, we performed cluster analysis (R-mode) on both the mollusc and ostracod datasets using an unweighted pair-group method with arithmetic averaging (UPGMA) and correlation as similarity coefficient. Prior to the application of the cluster analysis, both matrices were transformed to relative abundance. The use of ordination and cluster analysis proved to be powerful for investigating benthic data. Indeed, ordination allows us to visualise samples and

taxa distribution along gradients, whereas cluster analysis sketches out groups of recurring species (Patzkowsky & Holland, 2012).

All statistical analyses were performed using R software (R 3.6.1; R Core team, 2019; SOM 4).

## RESULTS

### Ordination: molluscs

The 2-dimensional output based on DCA of macrobenthic variables returned a substantial representation of the multivariate mollusc dataset (Fig. 3). The position of 26 selected extant key-taxa with well-known ecological needs suggests that water depth (and covariant salinity) is associated with DCA axis1 (DCA1) scores. Indeed, samples rich in *Ecrobia* gr. *ventrosa* (Montagu, 1803) and *Rissoa monodonta* Philippi, 1836 that are characteristic of shallow water and brackish settings attain the lowest DCA1 scores (left side of Fig. 3). For positive values of DCA1 (right side of Fig. 3), a variety of species that are now distributed from shelf (e.g., *Timoclea ovata* [Pennant, 1777], *Saccella commutata* [Philippi, 1844]) to deeper settings (e.g., *Kelliella miliaris* [Philippi, 1844], *Bathyarca pectunculoides* [Scacchi, 1835] and *Alvania testae* [Aradas & Maggiore, 1844]; Fig. 3) are found across the samples.

The DCA1-inferred palaeobathymetric gradient is also supported by the position of the samples when grouped by core. Samples are distributed along DCA1 in accordance with the position of the cores along the depositional profile and morphological gradient (Fig. 2). Specifically, samples that belong to the core from the basinal sector (LSD-04) are located on the extreme right of the plot. Moving toward the left side of DCA1, we begin to see samples collected

from cores located along the shelf (LSD-27, LSD-28) followed by those belonging to the most proximal sector (LSD-26).

### R cluster: molluscs

The R cluster analysis of the mollusc dataset detected eight clusters plus the *Anomia* gr. *ephippium* Linnaeus, 1758 singleton (Fig. 4).

**CLUSTER M1** - This cluster is dominated by the bivalves *Bathyarca pectunculoides* and *Kelliella miliaris*. Both species are byssate and filter feeders, and characterise soft bottoms from outer shelf to deeper settings (water depth > 100 m) of modern (Morton, 1982; Krylova et al., 2018) or past continental margins (Bernasconi & Stanley, 1997; Scarponi et al., 2014). These taxa are accompanied by the outer-shelf gastropod *Alvania testae*. The negligible presence of the bivalve *Corbula gibba* (Olivi, 1792) in this cluster can be explained with reworking from shallower settings or deposits.

**CLUSTER M2** - This cluster groups ten taxa, of which two are left in open nomenclature (*Venerupis* spp. and *Euspira* spp.), and is dominated by the lucinids *Lucinella divaricata* (Linnaeus, 1758) and *Loripes orbiculatus* Poli, 1795. These are chemosymbiotic bivalves thriving in nearshore shallow sandy-muddy substrates and protected areas with vegetated cover (Pères & Picard, 1964; Van der Geest et al., 2014). Other abundant species are *Bittium reticulatum* (da Costa, 1778), a small gastropod distributed in the photic zone on sea grasses (a habitat shared with *Tricolia tenuis* [Michaud, 1829] and *Rissoa* gr. *membranacea* [Rueda et al., 2003, 2009]), and *Parvicardium exiguum* (Gmelin, 1791), a small bivalve that thrives in shoreface to offshore transition

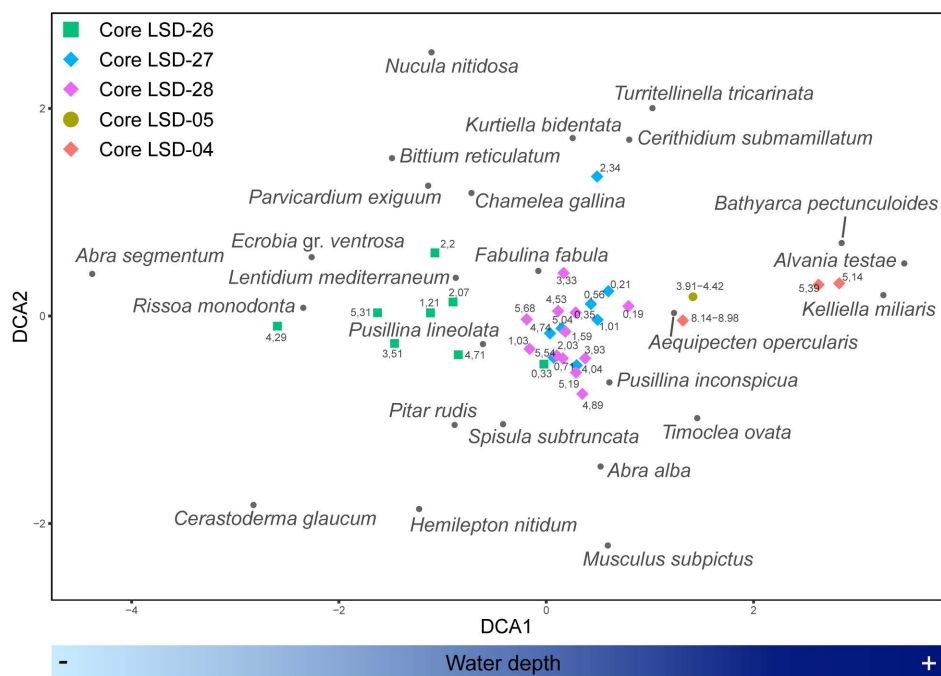


Fig. 3 - Detrended Correspondence Analysis (DCA) was applied to investigate the main gradient that underlines the distribution of samples. Small numbers next to sample points indicate the sample core-depth (in meters). DCA output reports only a subset of 26 selected species, for the complete version the reader can refer to Fig. S1 of the SOM 1.

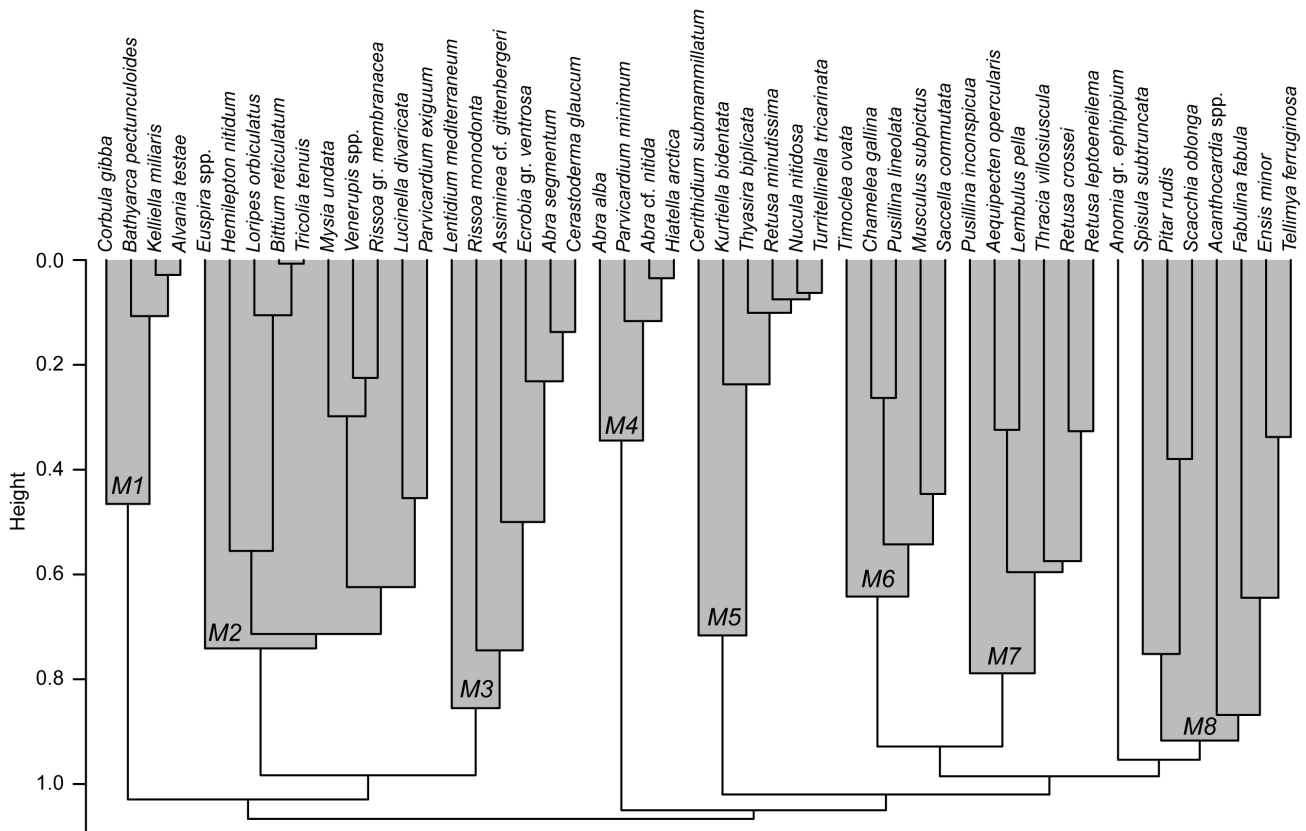


Fig. 4 - R-cluster output (UPGMA, Correlation index) for the mollusc data. Investigated dataset allowed the definition of eight major groups of species (clusters M1 to M8), and one singleton (*Anomia gr. ephippium*).

sandy-muddy substrates but can also survive a reduced level of salinity (Tebble, 1966). This cluster also records, albeit with negligible abundances, the shelf-related bivalves *Hemilepton nitidum* (W. Turton, 1822) and *Mysia undata* (Pennant, 1777), both common in coarse-grained substrates (Tebble, 1966). Hence, cluster M2 points toward a suite of nearshore to offshore transition environments characterised by a vegetated substrate.

**CLUSTER M3** - This cluster consists of six species dominated by *Lentidium mediterraneum* (Costa, 1830) and *Rissoa monodonta*, both common in very shallow coastal settings influenced by riverine input. The latter species suggests the presence of vegetated substrates; this is also supported by the abundance of *Ecrobia gr. ventrosa*, a small grazer and detritus feeder gastropod (Zettler et al., 2017). The presence of *Cerastoderma glaucum* (Bruguière, 1789), and *Assimineia gittenbergeri* Van Aartsen, 2008, and the occurrence of *Abra segmentum* (Récluz, 1843), are indicative of brackish conditions (Ivell, 1979; Van Aartsen, 2008). This evidence points toward protected environments and nearshore strongly fluviially-influenced settings with vegetated substrates (e.g., embayment, lower delta plain).

**CLUSTER M4** - This cluster groups four species and is dominated by *Abra alba* (W. Wood, 1802), a deposit/filter feeder distributed in substrates with variable grain size, from lower shoreface to shelf settings. When found in association with *Fabulina fabula* (Gmelin, 1791) it is

diagnostic of lower shoreface environments. Here, it is clustered with *Parvicardium minimum* (Philippi, 1836), which shows a comparable bathymetric distribution with a tendency to become more abundant toward outer shelf settings (Van Aartsen & Goud, 2000). The low abundance of *Abra nitida* (O.F. Müller, 1776), a shelf-related species, indicates a generic offshore transition to shelf environment. *Hiatella arctica* (Linnaeus, 1758), a byssate or boring bivalve distributed along the shelf, does not allow for further constraint of the depositional environment.

**CLUSTER M5** - This group is composed of six species and dominated by the gastropods *Cerithidium submamillatum* (de Rayneval & Ponzi, 1854) and *Turritellinella tricarinata* (Brocchi, 1814). Both species are found on modern shelf settings with sandy-muddy substrates (Bakir et al., 2012). When *T. tricarinata* forms oligotypic horizons, it suggests an increased influence by riverine waters. The bivalves *Nucula nitidosa* Winckworth, 1930 and *Thyasira biplicata* (Philippi, 1836) are commonly distributed in Mediterranean to northern European muddy to silty deposits along the shelf (Tebble, 1966; Oliver & Killeen, 2002). *Kurtiella bidentata* (Montagu, 1803) shares the same environmental settings and points toward ophiuroid dominated communities with which it is commonly found to be associated (Ockelmann & Muus, 1978). Cluster M5 is interpreted to reflect shelf-related sandy-muddy bottoms variably influenced by riverine waters.

CLUSTER M6 - This cluster includes five species. The dominant gastropod, *Pusillina lineolata* (Michaud, 1830), is a small Mediterranean grazer and detritus feeder in nearshore to offshore-transition settings (Maidanou et al., 2017). The other species, *Chamelea gallina* (Linnaeus, 1758), is nearshore-related but represented only by juveniles; *Musculus subpictus* (Cantraine, 1835), an epibyssate on kelp holdfast or hard substrates, also supports the presence of vegetated nearshore settings (Antit et al., 2016). With regard to *Timoclea ovata* and *Saccella commutata*, they are primarily shelf-related bivalves, even if typical of sandy-substrates (Morton, 2009; Martins et al., 2014); they are found here in reduced percentages. The contrasting ecological characteristics of these species allow only a generic attribution to sandy substrates and are interpreted as the result of mixing due to phases of increased fluvial discharge in nearshore to shelf related environments.

CLUSTER M7 - This cluster counts six species and is dominated by the bivalves *Lembulus pella* (Philippi, 1844), which implies shallow marine sandy-muddy substrates, and *Thracia villosiuscula* (MacGillivray, 1827). The latter, along with *Aequipecten opercularis* (Linnaeus, 1758), favour coarser sediments from the intertidal zone to the shelf (Tunberg, 1981). The contemporaneous presence of gastropods associated with vegetation on sandy bottoms (i.e., *Pusillina incospicua* [Alder, 1844], *Retusa crossei* [Bucquoy, Dautzenberg & Dollfus, 1886], and *Retusa leptoneilema* [Brusina, 1866]; Graham, 1988; Rueda et al., 2009) signals a suite of offshore transition environments characterised by vegetated substrates.

CLUSTER M8 - This cluster groups seven bivalves and is dominated by *Spisula subtruncata* (da Costa, 1778) and *Fabulina fabula*, both infaunal filter/deposit feeders that thrive in shoreface settings, a trophic habit also shared by the burrowers *Ensis minor* (Chenu, 1843) and *Tellimya ferruginosa* (Montagu, 1808) (Pérès & Picard, 1964). The latter species is a commensal with the sand-burrowing echinoderm *Echinocardium cordatum* (Pennant, 1777) (Morton, 1962). All other species (i.e., *Pitar rudis* [Poli, 1795], *Acanthocardia* sp., *Scacchia oblonga* [Philippi, 1836]) are represented by low abundances or occurrences. This species group represents a known ecological unit commonly cited in nearshore settings from the Mediterranean to the northern European seas (Petersen, 1914; Pérès & Picard, 1964; Petersen, 2004).

Lastly, the singleton *Anomia* gr. *ephippium* resulted from our cluster analysis. *A. ephippium* is a eurybathic, sessile bivalve that thrives on hard substrates and suggests, when abundant, hydraulic sorting or current-swept settings (Broekman, 1974). *A. ephippium* oligotypic assemblages are commonly found in Quaternary deposits in Italy and associated with environmental instability (Cau et al., 2019).

#### R cluster: ostracods

From the cluster analysis of the ostracod dataset, we identified four clusters and a singleton (Fig. 5).

CLUSTER O1 - This gathers typical nearshore ostracods that prefer very sandy bottoms (e.g., *Semicytherura*

*sulcata* [Müller, 1894], *Cytheretta adriatica* Ruggieri, 1952, and *Neocytherideis subulata* [Brady, 1868]). The latter species are recorded at a water depth between 5-85 m in the Adriatic Sea but have an optimum water depth of < 20 m (Breman, 1975). We consider cluster O1 indicative of a shallow marine setting subject to the action of bottom currents, such as a nearshore-offshore transition zone.

CLUSTER O2 - *Pontocythere turbida* (Müller, 1894) is the most abundant species among the variety of taxa that make up this cluster, followed by *Falunia sphaerulolineata* (Jones, 1857), *Loxoconcha* ex gr. *rhomboidea* (Fischer, 1855) and *Cistacythereis turbida* (Müller, 1894). *Pontocythere turbida* is common in the Adriatic Sea, and typically shows high concentrations on sandy or mixed sandy-muddy bottoms at water depths of < 120 m with an optimum between ~40-80 m (Bonaduce, 1975; Breman, 1975). Similar ecological features characterise the other taxa within this cluster. Variety and composition of cluster O2 are consistent with an inner-mid shelf environment.

CLUSTER O3 - This cluster is characterised by taxa that prefer muddy substrates at water depths > 70 m, with an optimum depth between ~120-200 m in the Adriatic Sea, such as *Pontocypris acuminata* (Müller, 1894), *Krithe* and *Argilloecia* species (Bonaduce, 1975). The presence of *Cytheropteron* spp., with optimum water depth generally recorded in the circalittoral zone, is consistent with the composition of the cluster (Bonaduce, 1975; Breman, 1975). This cluster also includes *Leptocythere ramosa* (Rome, 1942) and *Semicytherura incongruens* (Müller, 1894), opportunistic circalittoral species, widely distributed in the Adriatic Sea (Bonaduce, 1975). The composition of cluster O3 suggests a generic mid-outer shelf environment.

CLUSTER O4 - This group mostly includes *Cyprideis torosa* (Jones, 1850), *Pseudocandona* spp., and *Leptocythere* ex. gr. *psammophila* Guillaume, 1976, which are associated with lower frequencies of *Cytheromorpha fuscata* (Brady, 1869), *Leptocythere bacescoi* (Rome, 1942), *Xestoleberis* spp. and other oligohaline to mesohaline taxa. In this cluster, taxa commonly restricted to back-barrier settings, such as *C. torosa*, *C. fuscata* and *Pseudocandona* spp., are found with species living in outer estuarine/lagoonal and shallow marine settings (e.g., *L. bacescoi* and *Xestoleberis* spp.; Breman, 1975; Pint & Frenzel, 2016; Mazzini et al., 2017). The composition of cluster O4 suggests a semi-barred coastal setting subject to variable salinity conditions.

Singleton *Palmoconcha turbida* (Müller, 1894) is reported as a separate species in the cluster analysis (Fig. 5). It is relatively abundant down to a water depth of 40 m but reaches maximum concentrations on fine-grained substrates at < 20 m water depth in proximity to the modern Po Delta and it is positively correlated with organic matter (Barbieri et al., 2019). It is considered an opportunistic species that is tolerant to lowered oxygen conditions and forms monospecific assemblages in highly stressed environments (Bodergat et al., 1998; Ruiz et al., 2005). Ostracod fauna strongly dominated by *Palmoconcha turbida* is considered to reflect a prodelta subject to

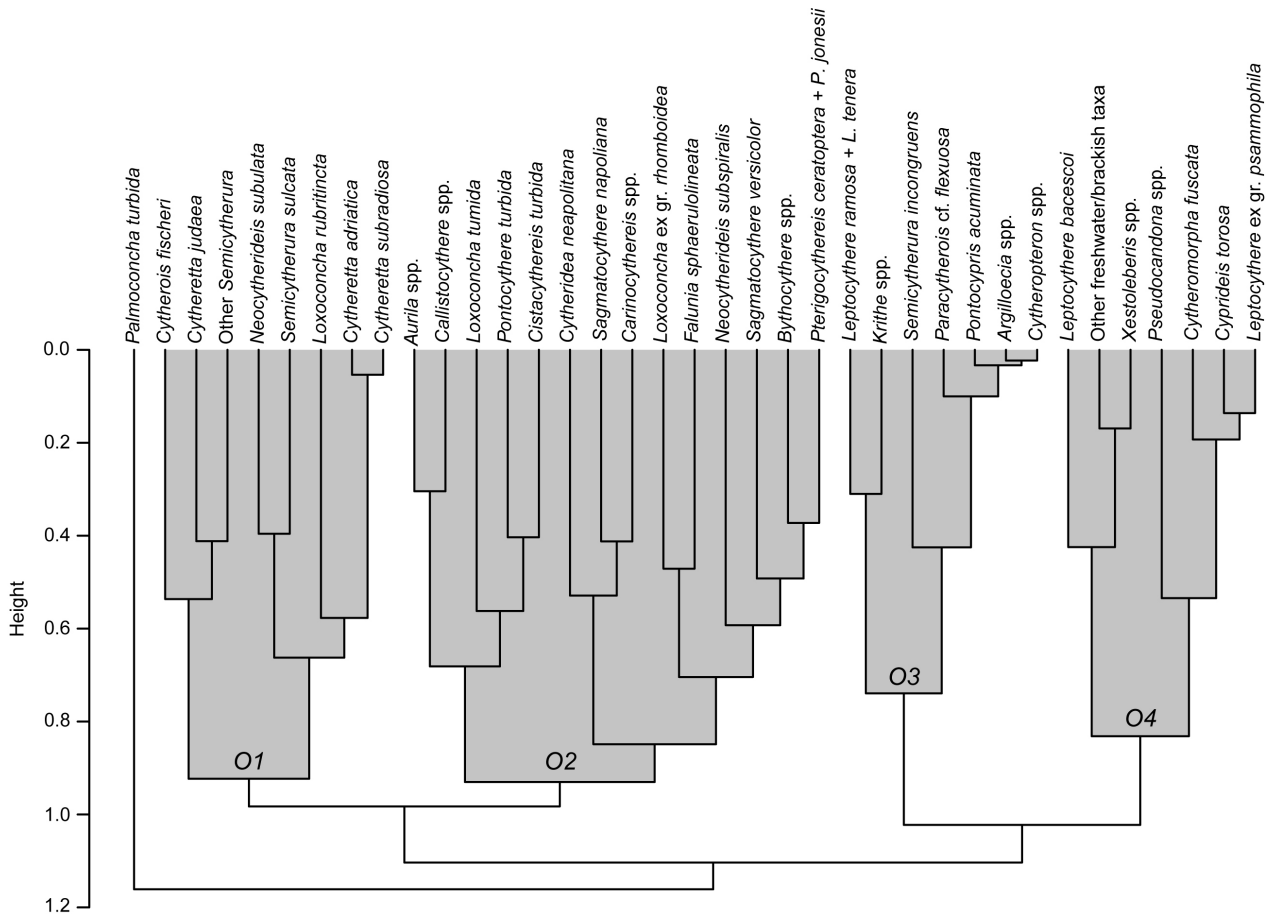


Fig. 5 - R-cluster output (UPGMA, Correlation index) for the ostracod data. Investigated dataset defined four major groups of taxa (clusters O1 to O4), and one singleton (*Palmoconcha turbida*).

abundant riverine inputs of sediment and organic matter (Rossi, 2009). However, in the Mediterranean area this species has also been recorded with variable percentages within Holocene estuarine/lagoon successions (Fanget et al., 2013; Amorosi et al., 2014; Vittori et al., 2015).

## DISCUSSION

### *Faunal dynamics and sequence stratigraphic implications*

DCA derived trends suggest that bathymetry and covariant physical factors (e.g., salinity) are the main drivers that control mollusc turnover along the investigated onshore-offshore transect (Fig. 2). Meanwhile, R-clusters identify recurring groups of benthic species (molluscs and ostracods), and allow the reconstruction of palaeoenvironment turnover through the cored succession.

CORE LSD-26 (ANALYSED STRATIGRAPHIC INTERVAL: 0-5.4 m; FIG. 6a) - The stratigraphic correlation based on multichannel seismic profile suggests that the Maximum Regressive Surface (MRS) crosses the LSD-26 core at depth of ~4.0 m +/- 0.5 m (uncertainty due to the post-processing vertical resolution of the seismic profiles). From the core base to ~4.0 m (core depth), both mollusc and ostracod samples are dominated by clusters of species

characteristic of strongly fluviially influenced shallow coastal environments (i.e., M3 and O4; Figs 4-6). In addition, DCA1 sample scores highlight a shallowing-upward trend resulting at core depth of ~4.30 m, in a more proximal lower delta plain setting. Within the lowermost part of the LSD-26 core (~4.7 m; Fig. 6a), the abundance of cluster M8, indicative of nearshore deposits (Fig. 4), is here interpreted as reworked material from relatively distal shoreface settings or the result of short-lived, more open conditions controlled by autogenic processes in such dynamic deltaic brackish environments.

From a core depth of ~3.5 m upward, the DCA1 sample scores suggest a progressively stronger increase in water depth and marine influence. Concurrently, R-clusters record a turnover in overall sample composition. R-clusters indicative of brackish and more confined settings (i.e., M3 and O4) are partly replaced by clusters indicative of nearshore to shelf settings with vegetated substrates (clusters M8, M2 and clusters O2, O1; Figs 4 and 5). Hence, the integration between R-cluster units and the DCA1 trend suggests a position for the MRS at core depth around 4 m (Fig. 6a). Along the core, the onset of the transgression is typified by the passage from semi-protected, brackish environments to more open coastal settings. The top-most sample, represented by the M8-nearshore cluster, is indicative of erosion or sediment starvation in the time since the post-glacial sea level rise.



CORE LSD-28 (ANALYSED STRATIGRAPHIC INTERVAL: 0-5.70 m; FIG. 6b) - Moving ~25 km basinward, toward the shelf edge (Fig. 2), cores LSD-27 and LSD-28 record the environmental evolution of clinothem C<sub>2</sub> and post-glacial sea level rise in fully marine settings. Based on seismic inferences, the MRS thus could either be located in core depth intervals between 3.6-2.7 m or 1.5-0.5 m (Figs 6b and S2). Due to the proximity to the LSD-28 location (ca. 2 km), core LSD-27 has similar seismic facies, sediment texture (overall sandy deposits) and faunal turnover. Hence, we have highlighted here only the benthic dynamics recorded in core LSD-28 (see SOM 1 for explanation on core LSD-27).

Along the LSD-28 core, all mollusc samples examined are well represented or dominated by the M8-nearshore cluster (20% to 65% total sample abundance) or the *A. gr. ephippium* singleton (18% to 70%), a sessile bivalve distributed along the shelf and indicative of current-swept settings when it shows an oligotypic distribution (Figs 4 and 6b). However, a striking feature in LSD-28 (and LSD-27) is the high (and increasing upcore) number of clusters within each sample with contrasting environmental significance (Figs 4-6b; Fig. S2 of the SOM 1). The mixing of ecologically non-overlapping taxa that results from this is interpreted here as the combined result of increased bioturbation activity and/or offshore discharge linked to storm events. The latter process was also hypothesised in Gamberi et al. (2019) based on qualitatively derived macrobenthic inferences.

Similarly, the ostracod clusters suggest a mixed fauna along the core with nearshore and inner/mid-shelf related species of cluster O1 (ca. 10-30%; primarily *N. subulata*) and O2 (ca. 50-64%; mainly *Pontocythere turbida*) respectively, that co-occur with a noticeable presence (ca. 5-20%) of brackish ostracods such as *C. torosa* and *Pseudocandona* spp. (cluster O4, Fig. 5).

Finally, the DCA1 sample scores show an overall aggradational trend along most of the cored succession, with no signs of important bathymetric changes except within the topmost 0.9 m cored interval, where DCA1 trend turns toward deeper settings (Fig. 6b). This deepening upward trend is proved by the presence in the top-most sample of outer shelf/slope species (cluster M1). The appearance of such taxa is hypothesised to reflect the ensuing transgression on the exposed North Adriatic shelf, when the entire PRLW was drowned and sea-level rise allowed the establishment of such deeper water taxa. Hence, coupled DCA and environmental derived inferences suggest a position for the MRS in the topmost part of the cored succession, likely between core depths of 0.30-0.90 m (Fig. 6b).

CORE LSD-05 (ANALYSED STRATIGRAPHIC INTERVAL: 3.0-9.0 m; FIG. S2 OF SOM 1) - Within core LSD-05, seismic data correlation indicates that the position of the MRS is between 3.5 m and 4.5 m cored depth (Fig. S2 of SOM 1). However, only one out of the nine samples that we investigated (a mollusc sample that resulted from the merging of two low abundance samples at ca. ~4 m core depth) reached the threshold of 20 specimens. Thus, neither the mollusc turnover nor the position of the MRS could be evaluated. The two ostracod samples taken within the transition from LST to TST demonstrate a similar faunal

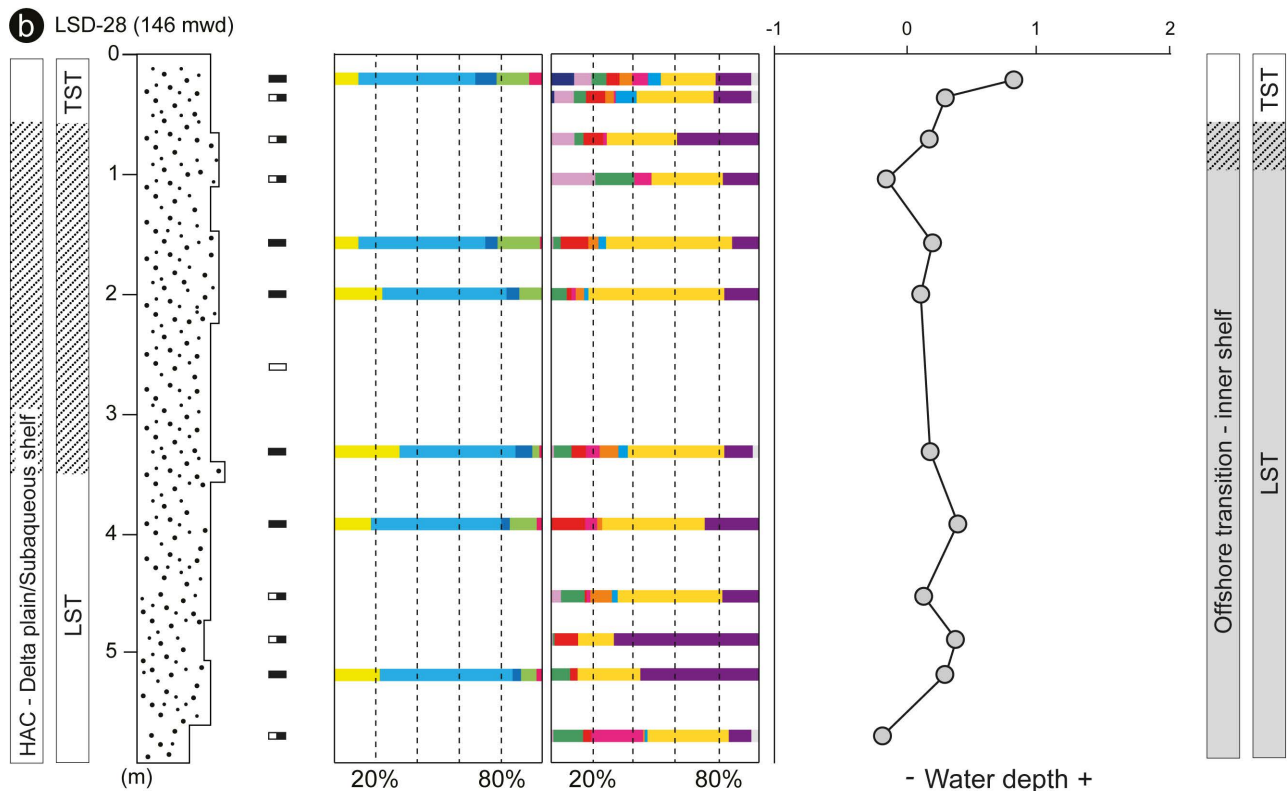
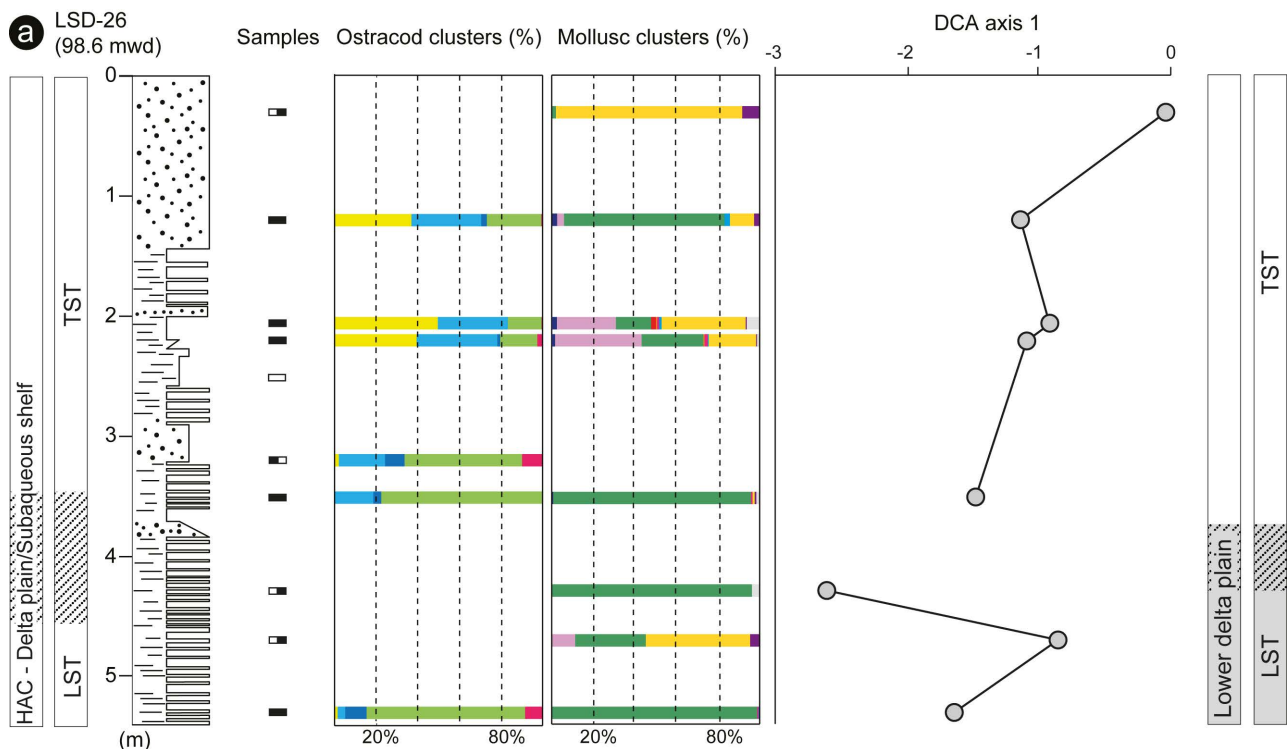
content dominated by mid-outer shelf (cluster O3; > 40%) and inner-mid shelf (cluster O2; ca. 20-30%) species. This feature, along with the remarkable occurrence of brackish and nearshore ostracods (clusters O4: ca. 12% and O1: ca. 10-20%, respectively), is considered indicative of a shelf environment likely developed under lowstand conditions and subject to remarkable sedimentary inputs from the coastal area. Thus, the ostracod fauna suggests a position for the MRS above 3.9 m core depth.

CORE LSD-04 (ANALYSED STRATIGRAPHIC INTERVAL: 9.0-5.0 m; FIG. S2 OF SOM 1) - Seismic data correlation indicates that the position of the MRS within LSD-04 is between 5.4 m and 6.4 m cored depth (Fig. S2 of SOM 1). Like LSD-05, core LSD-04 shows sparse macrofaunal content. The three mollusc samples investigated (out of six collected) are positioned at core depths of ~8.6 m (resulting from the merging of two low abundance samples), 5.4 m and 5.14 m core depth. The lowermost sample is dominated by the *A. gr. ephippium* singleton and suggests open marine current-swept settings (Fig. 4), whereas at 5.4 m and 5.14 m core depth, 80 to 95% of the total abundance is represented by cluster M1 which is indicative of deeper settings. This cluster testifies to a strong depositional shift, probably related to the post-glacial sea-level rise. The ecological requirements of the dominant M1 species (all epifaunal and filter feeders) also point towards a reduction of the sedimentary input. The only ostracod sample retrieved close to the lower boundary of the TST (at ca. 5.15 m core depth; Fig. S2 of SOM 1) shows an oligotypic assemblage that is almost exclusively composed of *Palmoconcha turbida*. This peculiar ostracod composition suggests that there is still a strong fluvial influence in the basin, especially in terms of high organic matter and low oxygen concentrations at the bottom (Bodergat et al., 1998; Barbieri et al., 2019). The DCA supports the turnaround between normal regressive lowstand deposits and transgressive deposits in the middle lower portion of the core, although the scanty number of samples does not allow us to constrain the position of the MRS derived by seismic profiles and currently located at 5.9 m core depth ( $\pm 0.5$  m).

#### *Palaeobiological characterisation of seismic-inferred facies*

Integrated meio- and macrobenthic analysis provides a primary source to constrain the seismic-derived facies (Tab. 1) encountered in the study area (i.e., topmost clinothem C<sub>2</sub> of the PRLW; Tab. S2 of SOM 1).

HIGH AMPLITUDE CONTINUOUS REFLECTIONS (HAC) - NORTHERN-CENTRAL SECTOR OF THE PRLW (TOPSETS) - This seismic unit features high amplitude continuous reflections of deposits emplaced during the entire progradational/aggradational phase of the PRLW (i.e., clinothems A<sub>6</sub> to C<sub>2</sub>). Within the studied succession, Pellegrini et al. (2018) have interpreted the HAC seismic facies as delta plain and subaqueous shelf deposits emplaced during the first phase of sea-level rise. This seismic-derived environmental subdivision along the C<sub>2</sub> clinothem is not associated with any change in the geophysical attributes of HAC but, rather, is sustained by changes in the geometry of the reflections and, in



Ostracod clusters

- O1: nearshore - offshore transition
- O2: inner-middle shelf
- O3: mid-outer shelf
- O4: lower delta plain
- P. turbida* (riverine-influenced, organic-rich environments)

Mollusc clusters

- M1: outer shelf-basinal
- M2: nearshore - offshore transition
- M3: lower delta plain - nearshore
- M4: offshore transition - shelf
- M5: shelf
- M6: nearshore - shelf
- M7: offshore transition
- M8: nearshore

- A. gr. ephippium* (nearshore - shelf)

Samples

- ostracods and molluscs
- only molluscs investigated
- only ostracods investigated
- barren
- Mollusc sample

- Biosedimentary-inferred MRS position
- Seismic-inferred MRS position

Lithology

- Medium - fine sand
- Muddy-silt and sand
- Mud and muddy-silt

particular, by the presence of compound rollover points (i.e., coastal and subaqueous) within the C<sub>2</sub> clinothem (Gamberi et al., 2019). Notably, mollusc and ostracod multivariate insights support fluviially influenced coastal settings (core LSD-26) and fully marine environments (core LSD-27 and -28) in the northern and southern portion of the HAC, respectively. The lack of sediment cores in the middle portion of the HAC seismic facies does not allow for a better constraint of the transition from fluviially influenced coastal to more open marine settings. Specifically, HAC proximal deposits (e.g., core LSD-26) record deltaic progradation into shallow (i.e., a few meters deep) brackish and protected settings with vegetated substrates and subject to frequent high energy events as inferred by the centimeter thick sandy and muddy alternations (Fig. 6a and S3 of SOM 1), and by euryhaline benthic assemblages (clusters M3 and O4). Strong storms commonly recorded by washover events on these semi-barred and brackish environments could explain the presence of molluscs typical of nearshore settings. In the distal HAC, the marine bioclastic sandy silt is homogeneous along both cores. Groups of species with contrasting ecological characteristics (e.g., M8-nearshore vs M3-lower delta plain; O1-nearshore-offshore transition vs O3-mid-outer shelf), provide information on the energy of the depositional environment and the intensity of bioturbation from burrowers. Specifically, multivariate outputs reinforce qualitatively based bio-sedimentary insights, pointing toward settings that are characterised by high-energy conditions due to river activity and storms. Indeed, storm-aided hyperpycnal flows were responsible for the accretion of a wide and thick sandy lobe (extending to the outer shelf) in the area facing the main distributaries of the late PRLW (Gamberi et al., 2019).

**HIGH AMPLITUDE CONTINUOUS WAVY DIPPING REFLECTIONS (HACWDIP) - SOUTHERN SECTOR OF THE PRLW (UPPER FORESETS) -** This seismic facies develops in the foreset of the clinothems of the PRLW (i.e., A to C<sub>2</sub>). The HACWDIP has been interpreted to represent heterolithic foreset deposits related to prodelta on upper slope settings (Pellegrini et al., 2018).

The investigated deposits (nine samples) are invariably characterised by barren or sparse mollusc content, with most taxa identified only at genus or family level. In the case of core LSD-05, the single point derived by merging low abundance samples (from core depths of 3.91 m and 4.42 m) suggests a shelf setting possibly subject to environmental instability. The paucity of macrofossil content might indicate that the high sedimentation rate is a source of the latter. These conditions are confirmed by ostracod fauna that also suggest mid-shelf settings (Fig. S2 of SOM 1).

**LOW AMPLITUDE CONTINUOUS REFLECTIONS (LAC) SOUTHERN SECTOR OF THE PRLW (BOTTOMSETS) -** This

seismic facies characterises the deposits formed during the late phase of PRLW growth (i.e., clinothems C<sub>1,2</sub>). Pellegrini et al. (2018) argue that the LAC represents deep-marine muddy basinal environments. All samples from the C<sub>2</sub> succession were barren or below the minimum sample size required. The only datum available, which resulted from the merging of LSD-04 samples 8.14 and 8.98 (Fig. S2 of SOM 1), supports the previous seismic-inferred depositional setting. In addition, mollusc insights (*A. gr. ephippium*, indicator of current-swept setting) suggest that these fine-grained deposits possibly result from recurrent remobilizations and transport of shelf deposits to the basinal sector. The presence of shallow coastal species in such basinal settings (represented here by M3-cluster; Fig. S2 of SOM 1) is possibly linked to high fluvial inputs and proximity to the shelf edge of river mouths during the late lowstand phase of the PRLW.

## CONCLUSIONS

Our paper demonstrates that palaeontological inferences (DCA1-bathymetric trends and benthic faunal turnover) complement seismic-derived stratigraphic interpretations and allow to constrain the position of the Maximum Regressive Surface within the Mid-Adriatic Deep, Late Pleistocene sedimentary succession. In addition, the quantitative analysis of bio-sedimentary insights provides information on several environmental variables (e.g., energy levels, salinity, vegetation cover, oxygen content, proximity to sediment source and river entry points, and organic matter availability) and is thus a powerful tool to detail the variation of depositional settings and improve palaeogeographic reconstructions of cored successions.

Our results provide a reference for future seismically based interpretations of sedimentary environments in similar geological settings while also testing the power of benthic fauna in seismically based stratigraphic reconstructions.

More generally, this work shows that the integrated use of benthic fauna (molluscs and ostracods) and seismic data is successful in the delineation of the surfaces of sequence stratigraphic significance, and in tracing palaeoenvironmental evolution in connection with sea-level variations.

## SUPPLEMENTARY ONLINE MATERIAL

All the Supplementary data of this work are available on the BSPI website at:

<http://paleoitalia.org/archives/bollettino-spi/>

SOM 1: Figs S1-3; Tabs S1-2; description of the seismic facies recovered in the study area and of core LSD-27.

←  
Fig. 6 - Temporal stratal stacking patterns and faunal trends across two selected cores LSD-26 (a) and LSD-28 (b). From left to right, the columns represent seismic-derived facies interpretations and investigated systems tracts following Pellegrini et al. (2018); core lithology; stratigraphic changes in faunal composition (ostracods and molluscs) estimated by R-cluster analyses and DCA axis 1 sample scores; palaeoenvironmental interpretation and sequence stratigraphic architecture derived by integrated quantitative bio-sedimentary inferences. For stratal stacking patterns and faunal trends across all investigated cores refer to Fig. S2 of the SOM 1.

SOM 2: Mollusca and Polychaeta Dataset.  
 SOM 3: Ostracoda Dataset.  
 SOM 4: R-code for multivariate analyses.

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#### REFERENCES

- Alder J. (1844). Descriptions of some new British species of *Rissoa* and *Odostomia*. *Annals and Magazine of Natural History*, 13: 323-328.
- Amorosi A., Maselli V. & Trincardi F. (2016). Onshore to offshore anatomy of a late Quaternary source-to-sink system (Po Plain-Adriatic Sea, Italy). *Earth-Science Reviews*, 153: 212-237.
- Amorosi A., Rossi V., Scarponi D., Vaiani S.C. & Ghosh A. (2014). Biosedimentary record of postglacial coastal dynamics: high-resolution sequence stratigraphy from the northern Tuscan coast (Italy). *Boreas*, 43: 939-954.
- Antit M., Daoulati A., Urra J., Rueda J.L., Gofas S. & Salas C. (2016). Seasonality and trophic diversity in molluscan assemblages from the Bay of Tunis (southern Mediterranean Sea). *Mediterranean Marine Science*, 17: 692-707.
- Aradas A. & Maggiore G. (1844). Catalogo ragionato delle conchiglie viventi e fossili di Sicilia. *Atti dell'Accademia Gioenia di Scienze Naturali*, 15: 187-366.
- Asioli A. (1996). High resolution foraminifera biostratigraphy in the Central Adriatic basin during the last deglaciation: a contribution to the PALICLAS Project. *Memorie-Istituto Italiano di Idrobiologia*, 55: 197-218.
- Asioli A., Trincardi F., Lowe J.J., Ariztegui D., Langone L. & Oldfield F. (2001). Sub-millennial scale climatic oscillations in the central Adriatic during the Late glacial: palaeoceanographic implications. *Quaternary Science Reviews*, 20: 1201-1221.
- Athersuch J., Horne D.J. & Whittaker J.E. (1989). Marine and brackish water ostracods. In Kermack D.M. & Barnes R.S.K. (eds), *Synopses of the British Fauna (New Series)*, 43. 345 pp. Brill E.J., Leiden.
- Azzarone M., Ferretti P., Rossi V., Scarponi D., Capraro L., Macri P., Huntley J.W. & Faranda C. (2018). Early-Middle Pleistocene benthic turnover and oxygen isotope stratigraphy from the Central Mediterranean (Valle di Manche, Crotone Basin, Italy): Data and trends. *Data in brief*, 17: 1099-1107.
- Bakir B.B., Öztürk B., Doğan A. & Önen M. (2012). Mollusc fauna of Iskenderun Bay with a checklist of the region. *Turkish Journal of Fisheries and Aquatic Sciences*, 12: 171-184.
- Barbieri G., Rossi V., Vaiani S.C. & Horton B.P. (2019). Benthic ostracoda and foraminifera from the North Adriatic Sea (Italy, Mediterranean Sea): A proxy for the depositional characterisation of river-influenced shelves. *Marine Micropaleontology*, 153: 101772.
- Bernasconi M.P. & Stanley D.J. (1997). Molluscan biofacies, their distributions and current erosion on the Nile delta shelf. *Journal of Coastal Research*, 14: 1201-1212.
- Bodergat A.M., Ikeya N. & Irzi Z. (1998). Domestic and industrial pollution: use of ostracods (Crustacea) as sentinels in the marine coastal environment. *Journal de Recherche Oceanographique*, 23: 139-144.
- Bonaduce G. (1975). Distribution of ostracoda in the Adriatic Sea. *Pubblazioni della Stazione zoologica di Napoli*, 40. 154 pp. Olschki L.S., Napoli.
- Boomer I., Horne D.J. & Slipper I.J. (2003). The use of ostracods in palaeoenvironmental studies, or what can you do with an ostracod shell? In Park L.E. & Smith A.J. (eds), *Bridging the Gap: Trends in the Ostracod Biological and Geological Sciences. The Paleontological Society Papers*, 9: 153-179.
- Brady G.S. (1868). A monograph of the recent British Ostracoda. *Transactions of the Linnean Society of London*, 26: 353-495.
- Brady G.S. (1869). Contributions to the study of the Entomostraca IV. Ostracoda from the river Scheldt and the Grecian Archipelago. *Annals and Magazine of Natural History*, Series 4: 45-50.
- Breman E. (1975). The distribution of Ostracodes in the bottom sediments of the Adriatic Sea. 165 pp. PhD thesis, Free University of Amsterdam, the Netherlands.
- Brocchi G.B. (1814). Conchiologia fossile subapennina con osservazioni geologiche sugli Apennini e sul suolo adiacente. Volume 1. 240 pp. Stamperia Reale, Milano.
- Broekman J.A. (1974). Sedimentation and paleoecology of Pliocene lagoonal-shallow marine deposits on the Island of Rhodes (Greece). *Utrecht Micropaleontological Bulletins*, 8. 146 pp. UBM 1974, Odijk.
- Bruguière J.G. (1789). Encyclopédie méthodique ou par ordre de matières. *Histoires Naturelle des Vers, des Mollusques*, 1: 292-293.
- Brusina S. (1866). Contribuzione pella fauna dei molluschi dalmati. *Verhandlungen der Kaiserlich-königlichen Zoologisch-botanisch Gesellschaft in Wien*, 16: 1-134.
- Bucquoy E., Dautzenberg P. & Dollfus G.F. (1886). *Les mollusques marins du Roussillon*. Tome 1. 66 pp. Bailliere & Fils, Paris.
- Cabral M.C. & Loureiro I.M. (2013). Overview of Recent and Holocene ostracods (Crustacea) from brackish and marine environments of Portugal. *Journal of Micropaleontology*, 32: 135-159.
- Cantraine F.J. (1835). Diagnoses ou descriptions succinctes de quelques espèces nouvelles de mollusques. *Bulletin de l'Académie Royale des Sciences et Belles-lettres de Bruxelles*, 2: 380-401.
- Catuneanu O. (2019). Model-independent sequence stratigraphy. *Earth-Science Reviews*, 188: 312-388.
- Cau S., Laini A., Monegatti P., Roveri M., Scarponi D. & Taviani M. (2019). Palaeoecological anatomy of shallow-water Plio-Pleistocene biocalcarenes (northern Apennines, Italy). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 514: 838-851.
- Chenu J.C. (1843). Illustrations conchyliologiques, ou description et figures de toutes les coquilles connues, vivantes et fossiles. Tome 2. 53 pp. A Franck, Paris.
- Costa O.G. (1830). Catalogo sistematico e ragionato de' testacei delle Due Sicilie. 8 pp. Tipografia della Minerva, Napoli.
- Crippa G., Azzarone M., Bottini C., Crespi S., Felletti F., Marini M., Petrizzo M.R., Scarponi D., Raffi S. & Raineri G. (2019). Bio- and lithostratigraphy of lower Pleistocene marine successions in western Emilia (Italy) and their implications for the first occurrence of *Arctica islandica* in the Mediterranean Sea. *Quaternary Research*, 92: 549-569.
- Crippa G., Baucon A., Felletti F., Raineri G. & Scarponi D. (2018). A multidisciplinary study of ecosystem evolution through early Pleistocene climate change from the marine Arda River section, Italy. *Quaternary Research*, 89: 533-562.
- Crippa G. & Raineri G. (2015). The genera *Glycymeris*, *Aequipecten* and *Arctica*, and associated mollusk fauna of the lower Pleistocene Arda River section (Northern Italy). *Rivista Italiana di Paleontologia e Stratigrafia*, 121: 61-101.
- da Costa M.E. (1778). *Historia naturalis testaceorum Britanniae*, or, the British conchology; containing the descriptions and other particulars of natural history of the shells of Great Britain

- and Ireland: illustrated with figures. In English and French. - *Historia naturalis testaceorum Britanniae*, ou, la conchologie Britannique; contenant les descriptions & autres particularités d'histoire naturelle des coquilles de la Grande Bretagne & de l'Irlande: 1-254, 117-118.
- de Rayneval A.G. & Ponzi G. (1854). Catalogue des fossiles du Monte Mario (près Rome), recueillis par M. le Cte de Rayneval, Mgr Vanden Hecke et M. le professeur Ponzi. 26 pp. Beau jeune, Versailles.
- Dominici S., Benvenuti M., Forli M., Bogi C. & Guerrini A. (2019). Upper Miocene molluscs of Monti Livornesi (Tuscany, Italy): Biotic changes across environmental gradients. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 527: 103-117.
- Ellis B.F. & Messina A.R. (1952). Catalogue of Ostracoda (text unpaginated). The American Museum of Natural History Special Publications, New York.
- Fanget A.S., Bassetti M.A., Arnaud M., Chiffolleau J.F., Cossa D., Goineau A., Fontanier C., Buscaill R., Jouet G., Maillet G.M., Negri A., Dennielou B. & Berné S. (2013). Historical evolution and extreme climate events during the last 400 years on the Rhone prodelta (NW Mediterranean). *Marine Geology*, 346: 375-391.
- Fischer S. (1855). Beitrag zur Kenntnis der Ostracoden. *Abhandlungen der Mathematisch-Physikalischen Classe der koeniglich-Beyerischen Akademie der Wissenschaften*, 7: 635-666.
- Frenzel P., Keyser D. & Viehberg F.A. (2010). An illustrated key and (palaeo)ecological primer for Postglacial to Recent Ostracoda (Crustacea) of the Baltic Sea. *Boreas*, 39: 567-575.
- Gamberi F., Pellegrini C., Dalla Valle G., Scarponi D., Bohacs K.M. & Trincardi F. (2019). Compound and hybrid clinothems of the last lowstand Mid-Adriatic Deep: Processes, depositional environments, controls and implications for stratigraphic analysis of prograding systems. *Basin Research* (in press). doi: [org/10.1111/br.12417](https://doi.org/10.1111/br.12417).
- Gmelin J.F. (1791). Vermes. In Gmelin J.F. (ed.), *Caroli a Linnaei Systema Naturae per Regna Tria Naturae*, G.E. Beer, Lipsiae [Leipzig], Ed. 13. Tome 1: 3021-3910.
- Graham A. (1988). Molluscs: Prosobranch and Pyramidellid gastropods. Synopses of British Fauna (new series), 2. The Linnean Society of London and The Estuarine and Brackish-water Sciences Association. 665 pp. E.J. Brill, Leiden.
- Guillaume M.C. (1976). A taxonomic revision of two species of the family Leptocytheridae, *Leptocythere pellucida* (Baird) and *Leptocythere castanea* (Sars) with a description of a new species, *Leptocythere psammophila*. *Verhandlungen des Naturwissenschaftlichen Vereins in Hamburg*, 18-19 (Suppl.): 325-330.
- Helland-Hansen W. & Martinsen O.J. (1996). Shoreline trajectories and sequences; description of variable depositional-dip scenarios. *Journal of Sedimentary Research*, 66: 670-688.
- Ivell R. (1979). The biology and ecology of a brackish lagoon bivalve, *Cerastoderma glaucum* Bruguiere, in Lago Lungo, Italy. *Journal of Molluscan Studies*, 45: 364-382.
- Jones T.R. (1850). Description of the Entomostraca of the Pleistocene Beds of Newbury Copford, Clacton and Grays. *The Annals and magazine of natural history*, 6: 25-28.
- Jones T.R. (1857). A monograph of the Tertiary Entomostraca of England. *Palaeontographical Society Monograph*, 9. 68 pp. Adlard J.E., London.
- Kettner A.J. & Syvitski J.P.M. (2008). Predicting discharge and sediment flux of the Po River, Italy since the Last Glacial Maximum. *Special Publication International Association of Sedimentologists*, 40: 171-189.
- Khain V.E. & Polyakova I.D. (2008). Oil and gas potential of continental margins of the Pacific Ocean. *Lithology and Mineral Resources*, 43: 81-92.
- Krylova E.M., Sahling H. & Borowski C. (2018). Resolving the status of the families Vesicomysidae and Kelliellidae (Bivalvia: Venerida), with notes on their ecology. *Journal of Molluscan Studies*, 84: 69-91.
- Lambeck K., Rouby H., Purcell A., Sun Y. & Sambridge M. (2014). Sea level and global ice volumes from the Last Glacial Maximum to the Holocene. *Proceedings of the National Academy of Sciences*, 111: 15296-15303.
- Langone M.B., Davies T.A., Austin J.A. Jr & Olson H.C. (1997). Foraminiferal constraints on very high-resolution seismic stratigraphy and late Quaternary glacial history, New Jersey continental shelf. *Palaios*, 12: 249-266.
- Linnaeus C. (1758). *Systema Naturae per regna tria naturae, secundum classes, ordines, genera, species, cum characteribus, differentiis, synonymis, locis*. Editio decima, reformata [10<sup>th</sup> revised edition], 1. 824 pp. Salvius, Holmiae.
- MacGillivray W. (1827). Description of *Anatina villosiuscula*, a new species, and of *Venerupis nucleus*, a species new to the British fauna. *Edinburgh New Philosophical Journal*, 2: 370-372.
- Maidanou M., Koulouri P., Arvanitidis C., Koutsoubas D. & Dounas C. (2017). Macrobenthic assemblage structure associated with a *Caulerpa prolifera* meadow in the eastern Mediterranean Sea (Elounda Bay, Crete Island). *Regional Studies in Marine Science*, 14: 1-14.
- Martins R., Sampaio L., Quintino V. & Rodrigues A.M. (2014). Diversity, distribution and ecology of benthic molluscan communities on the Portuguese continental shelf. *Journal of Sea Research*, 93: 75-89.
- Maselli V., Trincardi F., Asioli A., Ceregato A., Rizzetto F. & Taviani M. (2014). Delta growth and river valleys: the influence of climate and sea level changes on the South Adriatic shelf (Mediterranean Sea). *Quaternary Science Reviews*, 99: 146-163.
- Mazzini I., Rossi V., Da Prato S. & Ruscito V. (2017). Ostracods in archaeological sites along the Mediterranean coastlines: three case studies from the Italian peninsula. In Williams M., Hill T., Boomer I. & Wilkinson I.P. (eds), *The Archaeological and Forensic Applications of Microfossils: A Deeper Understanding of Human History*. Geological Society, London. *The Micropalaeontological Society Special Publications*: 121-142.
- Michaud A.L.G. (1829). Description de plusieurs espèces nouvelles de coquilles vivantes. *Bulletin d'Histoire Naturelle de la Société Linnéenne de Bordeaux*, 3: 260-276.
- Michaud A.L.G. (1830). Description de plusieurs espèces de coquilles du genre *Rissoa*. 19 pp. Perrin, Lyon.
- Monegato G., Scardia G., Hajdas I., Rizzini F. & Piccin A. (2017). The Alpine LGM in the boreal ice-sheets game. *Scientific Reports*, 7: 2078.
- Montagu G. (1803). *Testacea Britannica or Natural History of British Shells, Marine, Land, and Fresh-Water, Including the Most Minute: Systematically Arranged and Embellished with Figures*. Vol. 2: 293-606, 44-45.
- Montagu G. (1808). Supplement to *Testacea Britannica* with Additional Plates. v + 183 pp. Woolmer, Exeter.
- Morton B. (1982). Functional morphology of *Bathyarca pectunculoides* (Bivalvia: Arcacea) from a deep Norwegian fjord with a discussion of the mantle margin in the Arcoidea. *Sarsia*, 67: 269-282.
- Morton B. (2009). Aspects of the biology and functional morphology of *Timoclea ovata* (Bivalvia: Veneroidea: Venerinae) in the Açores, Portugal, and a comparison with *Chione elevata* (Chioninae). *Açoreana* (Suppl. 6): 105-119.
- Morton J.E. (1962). Habit and orientation in the small commensal bivalve mollusc, *Montacuta ferruginosa*. *Animal Behaviour*, 10: 126-133.
- Müller G.W. (1894). Die Ostracoden des Golfes von Neapel und der angrenzenden Meeres-abschnitte. In Zoologischen station zu Neapel, Fauna und Flora des Golf von Neapel und der angrenzenden Meeres-Abschnitte. 404 pp. Friedländer & Sohn, Berlin.
- Müller O.F. (1776). *Zoologiae Danicae Prodrromus, seu Animalium Daniae et Norvegiae indigenarum characteres, nomina, et synonyma imprimis popularium*. 274 pp. Hallageri, Copenhaen.

- Neal J.E., Abreu V., Bohacs K.M., Feldman H.R. & Pederson K.H. (2016). Accommodation succession ( $\delta A/\delta S$ ) sequence stratigraphy: observational method, utility and insights into sequence boundary formation. *Journal of the Geological Society*, 173: 803-816.
- Ockelmann K.W. & Muus K. (1978). The biology, ecology and behaviour of the bivalve *Mysella bidentata* (Montagu). *Ophelia*, 17: 1-93.
- Oliver P.G. & Killeen I.J. (2002). The Thyasiridae (Mollusca: bivalvia) of the British continental shelf and North Sea Oilfields. *Studies in Marine Biodiversity and Systematics from the National Museum of Wales. BIOMOR Reports*, 3: 1-73.
- Olivì G. (1792). Zoologia Adriatica, ossia catalogo ragionato degli animali del golfo e delle lagune di Venezia. [ix] + 334 + xxxii pp. G. Remondini e fl., Bassano.
- Patrino S., Scisciani V., Helland-Hansen W., D'Intino N., Reid W. & Pellegrini C. (2019). Upslope-climbing shelf-edge clinofolds and the stepwise evolution of the northern European glaciation (lower Pleistocene Eridanos Delta system, UK North Sea): When sediment supply overwhelms accommodation. *Basin Research* (in press). doi: [org/10.1111/bre.12379](https://doi.org/10.1111/bre.12379).
- Patzkowsky M.E. & Holland S.M. (2012). Stratigraphic paleobiology: understanding the distribution of fossil taxa in time and space. 257 pp. University of Chicago Press, Chicago.
- Pellegrini C., Asioli A., Bohacs K.M., Drexler T.M., Feldman H.R., Sweet M.L., Maselli V., Rovere M., Gamberi F., Della Valle G. & Trincardi F. (2018). The late Pleistocene Po River lowstand wedge in the Adriatic Sea: Controls on architecture variability and sediment partitioning. *Marine and Petroleum Geology*, 96: 16-50.
- Pellegrini C., Bohacs K.M., Drexler T.M., Gamberi F., Rovere M. & Trincardi F. (2017b). Identifying the sequence boundary in over- and under-supplied contexts: the case of the late Pleistocene Adriatic continental margin. In *Sequence Stratigraphy: the Future Defined. Proceedings of the 36<sup>th</sup> Annual Perkins-Rosen Research Conference*: 160-182.
- Pellegrini C., Maselli V., Cattaneo A., Piva A., Ceregato A. & Trincardi F. (2015). Anatomy of a compound delta from the post-glacial transgressive record in the Adriatic Sea. *Marine Geology*, 362: 43-59.
- Pellegrini C., Maselli V., Gamberi F., Asioli A., Bohacs K.M., Drexler T.M. & Trincardi F. (2017a). How to make a 350-m-thick lowstand systems tract in 17,000 years: The Late Pleistocene Po River (Italy) lowstand wedge. *Geology*, 45: 327-330.
- Pennant T. (1777). British Zoology, vol. IV. Crustacea. Mollusca. Testacea. 154 pp. B. White, London.
- Pèrès J.M. & Picard J. (1964). Nouveau manuel de bionomie benthique de la mer Méditerranée. 138 pp. Station Marine d'Endoume, Marseille.
- Petersen C.G. (1914). The animal communities of the sea bottom and their importance for marine zoogeography. *Report of the Danish Biological Station*, 21: 1-44.
- Petersen K.S. (2004). Late Quaternary environmental changes recorded in the Danish marine molluscan faunas. *Geological Survey of Denmark and Greenland Ministry of the Environment*. 268 pp. GEUS, Copenhagen.
- Philippi R.A. (1836). Enumeratio molluscorum Siciliae cum viventium tum in tellure tertiaria fossilium, quae in itinere suo observavit. Vol. 1. 267 pp. Berolini, Schropp, Berlin.
- Philippi R.A. (1844). Enumeratio molluscorum Siciliae cum viventium tum in tellure tertiaria fossilium, quae in itinere suo observavit. Vol. 2. 303 pp. Eduard Anton, Halle.
- Pint A. & Frenzel P. (2016). Ostracod fauna associated with *Cyprideis torosa* - an overview. *Journal of Micropalaeontology*, 36: 113-119.
- Piva A., Asioli A., Andersen N., Grimalt J.O., Schneider R.R. & Trincardi F. (2008). Climatic cycles as expressed in sediments of the PROMESS1 borehole PRAD1-2, central Adriatic, for the last 370 ka: 2. Paleoenvironmental evolution. *Geochemistry, Geophysics, Geosystems*, 9: Q03R02.
- Poli J.X. (1795). Testacea utriusque Siciliae eorumque historia et anatomicae tabulis aeneis illustrata. Tomus Secundus. 264 pp. Ex Regio Typographeio, Parma.
- R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Récluz C.A. (1843). Monographie du genre *Syndosmya*. *Revue Zoologique, par la Société Cuvierienne*, 6: 359-369.
- Ridente D., Trincardi F., Piva A. & Asioli A. (2009). The combined effect of sea level and supply during Milankovitch cyclicality: Evidence from shallow-marine  $\delta^{18}O$  records and sequence architecture (Adriatic margin). *Geology*, 37: 1003-1006.
- Rivero-Cuesta L., Westerhold T., Agnini C., Dallanave E., Wilkens R.H. & Alegret L. (2019). Paleoenvironmental Changes at ODP Site 702 (South Atlantic): Anatomy of the Middle Eocene Climatic Optimum. *Paleoceanography and Paleoclimatology*, 34: 2047-2066.
- Rome D.R. (1942). Ostracodes marins des environs de Monaco, 2<sup>me</sup> note. *Bulletin de l'Institut Océanographique de Monaco*, 38: 1-28.
- Ronchi L., Fontana A., Correggiari A. & Asioli A. (2018). Late Quaternary incised and infilled landforms in the shelf of the northern Adriatic Sea (Italy). *Marine Geology*, 405: 47-67.
- Rossi V. (2009). Ostracod assemblages from Holocene subsurface deposits of modern Po Delta: a palaeoenvironmental proxy record. *Bollettino della Società Paleontologica Italiana*, 48: 95-103.
- Rossi V., Azzarone M., Capraro L., Faranda C., Ferretti P., Macri P. & Scarponi D. (2018). Dynamics of benthic marine communities across the Early-Middle Pleistocene boundary in the Mediterranean region (Valle di Manche, Southern Italy): Biotic and stratigraphic implications. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 495: 127-138.
- Rovere M., Pellegrini C., Chiggiato J., Campiani E. & Trincardi F. (2019). Impact of dense bottom water on a continental shelf: An example from the SW Adriatic margin. *Marine Geology*, 408: 123-143.
- Rueda J.L., Gofas S., Urra J. & Salas C. (2009). A highly diverse molluscan assemblage associated with eelgrass beds (*Zostera marina* L.) in the Alboran Sea: Micro-habitat preference, feeding guilds and biogeographical distribution. *Scientia Marina*, 73: 679-700.
- Rueda J.L. & Salas C. (2003). Seasonal variation of a molluscan assemblage living in a *Caulerpa prolifera* meadow within the inner Bay of Cádiz (SW Spain). *Estuarine, Coastal and Shelf Science*, 57: 909-918.
- Ruggieri G. (1952). Gli ostracodi delle sabbie grigie quaternario (Milazziano) di Imola Part 2. *Giornale di Geologia, Annali del Museo Geologico di Bologna, Serie 2<sup>a</sup>*, 22: 59-115.
- Ruiz F., Abad M., Bodergat A.M., Carbonel P., Rodríguez-Lázaro J. & Yasuhara M. (2005). Marine and brackish-water ostracods as sentinels of anthropogenic impacts. *Earth-Science Reviews*, 72: 89-111.
- Scacchi A. (1835). Notizie intorno alle conchiglie ed a zoofiti fossili che si trovano nelle vicinanze di Gravina in Puglia. *Annali Civili del Regno delle Due Sicilie*, 6: 75-84.
- Scarponi D. & Angeletti L. (2008). Integration of palaeontological patterns in the sequence stratigraphy paradigm: a case study from Holocene deposits of the Po Plain (Italy). *GeoActa*, 7: 1-13.
- Scarponi D., Azzarone M., Kusnerik K., Amorosi A., Bohacs K.M., Drexler T.M. & Kowalewski M. (2017). Systematic vertical and lateral changes in quality and time resolution of the macrofossil record: insights from Holocene transgressive deposits, Po coastal plain, Italy. *Marine and Petroleum Geology*, 87: 128-136.
- Scarponi D., Huntley J.W., Capraro L. & Raffi S. (2014). Stratigraphic paleoecology of the Valle di Manche section (Crotone Basin, Italy): a candidate GSSP of the Middle Pleistocene. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 402: 30-43.

- Scott G.H., King P.R. & Crundwell M.P. (2004). Recognition and interpretation of depositional units in a late Neogene progradational shelf margin complex, Taranaki Basin, New Zealand: foraminiferal data compared with seismic facies and wireline logs. *Sedimentary Geology*, 164: 55-74.
- Spencer A.M., Embry A.F., Gautier D.L., Stoupakova A.V. & Sørensen K. (2011). An overview of the petroleum geology of the Arctic. *Geological Society, London, Memoirs*, 35: 1-15.
- Storms J.E., Weltje G.J., Terra G.J., Cattaneo A. & Trincardi F. (2008). Coastal dynamics under conditions of rapid sea-level rise: Late Pleistocene to Early Holocene evolution of barrier-lagoon systems on the northern Adriatic shelf (Italy). *Quaternary Science Reviews*, 27: 1107-1123.
- Tebble N. (1966). British bivalve seashells. A handbook for identification. 212 pp. Trustees of the British Museum (Natural History), London.
- Trincardi F., Cattaneo A., Asioli A., Correggiari A. & Langone L. (1996). Stratigraphy of the late-Quaternary deposits in the central Adriatic basin and the record of short-term climatic events. *Memorie-Istituto Italiano di Idrobiologia*, 55: 39-70.
- Tunberg B. (1981). Two bivalve communities in a shallow and sandy bottom in Raunefjorden, western Norway. *Sarsia*, 66: 257-266.
- Turton W. (1822). *Conchylia insularum Britannicarum: The shells of the British islands*. 289 pp. Ma Nattali, London.
- Urgeles R., Cattaneo A., Puig P., Liqueste C., De Mol B., Sultan N. & Trincardi F. (2011). A review of undulated sediment features on Mediterranean prodeltas: distinguishing sediment transport structures from sediment deformation. *Marine Geophysical Research*, 32: 49-69.
- Van Aartsen J.J. (2008). The Assimineidae of the Atlantic-Mediterranean seashores. *Basteria*, 72: 165-181.
- Van Aartsen J.J. & Goud J. (2000). European marine Mollusca: notes on less well-known species. XV. Notes on Lusitanian species of *Parvicardium* Monterosato, 1884, and *Afrocardium richardi* (Audouin, 1826) (Bivalvia, Heterodonta, Cardiidae). *Basteria*, 64: 171-186.
- Van der Geest M., Sall A.A., Ely S.O., Nauta R.W., van Gils J.A. & Piersma T. (2014). Nutritional and reproductive strategies in a chemosymbiotic bivalve living in a tropical intertidal seagrass bed. *Marine Ecology Progress Series*, 501: 113-126.
- Vear A. (2005). Deep-water plays of the Mauritanian continental margin. *Geological Society, London, Petroleum Geology Conference series*, 6: 1217-1232.
- Vittori C., Mazzini I., Salomon F., Goiran J.P., Pannuzi S., Rosa C. & Pellegrino A. (2015). Palaeoenvironmental evolution of the ancient lagoon of Ostia Antica (Tiber delta, Italy). *Journal of Archaeological Science*, 54: 374-384.
- Winckworth R. (1930). Notes on nomenclature. *Journal of Molluscan Studies*, 19: 14-16.
- Wood W. (1802). XIV. Observations on the Hinges of British Bivalve Shells. *Transactions of the Linnean Society of London*, 1: 154-176.
- Zettler M.L., Darr A., Labrenz M., Sagert S., Selig U., Siebert U. & Stybel N. (2017). Biological indicators. In Snoeijs-Leijonmalm P., Schubert H. & Radziejewska T. (eds), *Biological Oceanography of the Baltic Sea*. Springer, Dordrecht: 513-526.

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