EQA – *Environmental quality / Qualité de l'Environnement / Qualità ambientale,* **19 (2015) 31-43**

FIRST OBSERVATIONS ON MARINE SUBAQUEOUS SOILS IN "TORRE DEL CERRANO" MARINE PROTECTED AREA, ADRIATIC SEA (ITALY)

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Abstract

Subaqueous soils have to be studied with proper methodologies, according to a pedological approach and considering the key role of animal bioturbation. Morphological and chemical characteristics of submerged soils found in the MPA of "Torre del Cerrano", Adriatic sea (Italy), have been studied in this way, and we conclude that submarine soils of the MPA are important examples of pedogenesis promoted by animals. Soils from the highly protected marine area hosted a major biodiversity than those from the sub- and non-protected areas, while no striking differences in terms of soil physical and chemical characteristics among protected, sub-protected and non-protected zones occurred.

Keywords: *Subaqueous soils, animal bioturbation, Chamelea gallina*.

Introduction

In the last two decades, intertidal habitats have captured the attention of soil scientists and offered an interesting challenge for pedologists who moved into subtidal territories (Demas et al., 1996; Demas and Rabenhorst, 1998; 1999a,b; 2001). Since the first studies, the concept of sediment as "unconsolidated geologic material" was substituted by that of "subaqueous soil", which should be studied with proper methodologies (Kristensen and Rabenhorst, 2015). Demas and Rabenhorst (1999), describing subaqueous soils of Sinepuxent Bay (Maryland), outlined that the addition of biogenic calcium carbonate (shells, organic fragments and organic matter), the loss of organic matter from the surface, the transfer of oxygen through diffusion and bioturbation processes and the transformation of humic substances confirmed that the general theory of soil genesis is valid even in

DOI: 10.6092/issn.2281-4485/5802

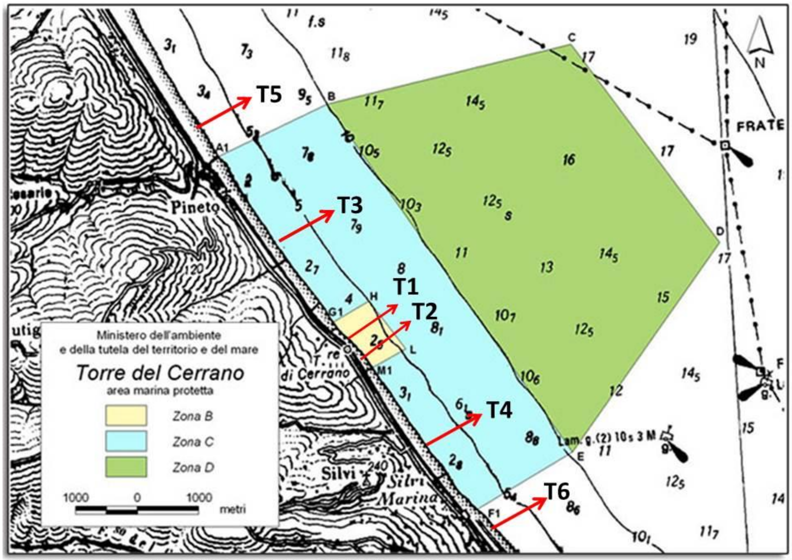
subaqueous environment. After the first works of Demas and Rabenhorst, the Soil Survey Staff (1999) changed the soil definition in “the upper limit of soil is the boundary between soil and air, or so shallow water to permit rooting of plants (generally less than 2.5 m)”. As a consequence, a revision of the equation for soil formation was proposed to include genesis and distribution of subaqueous soil (Demas and Rabenhorst, 2001). In this way, it is important considering the key role of animal bioturbation on the mixing of parent material, with the resulting particle movement due to the activity of infauna, epifauna, fish and mammals (Darwin, 1881; Cadée, 2001). Kristensen et al. (2012) defined *bioturbation* in intertidal habitats as “all transport processes carried out by animals that directly or indirectly affect sediment matrices as the displacement of particles (sediment reworking) and solutes (burrow ventilation) due to the infauna activity”. Many marine organisms typically pump water into and out of sediments during burrowing, feeding and defecation, and these activities modify the local pressure field within the porewater, causing flow of porewater away from and towards the animal (Wethey et al., 2008; Volkenborn et al., 2010). Because of this, we could consider all these animals strictly connected to subaqueous soil formation.

All these observations inspired us to approach a preliminary study on subaqueous soils within a Marine Protected Area of the Adriatic sea (Italy) following a pedological protocol that included description of soil mini-profiles and basic physicochemical analyses of the horizons collected from marine areas with different protection regime. Particular attention was spent to the numerous marine animals that are involved in the bioturbation processes and, consequently, on pedogenesis.

Matherials and methods

The Marine Protected Area (MPA) of "Torre del Cerrano" was founded by the Italian Department of Environment and Protection of Natural Territories on October 21, 2009. It extends for 3 nautical miles into the sea from the coast and spreads out along 7 km of coastline. The MPA has a surface of about 37 km^2 and includes *i*) a highly restricted B Zone having a square-shaped zone with a length of about 1 km, *ii*) a sub-restricted C Zone of 14 km^2 which extends 2 km into the sea from the coast, and *iii*) a scarcely restricted D Zone having a trapezium-shaped area of about 22 km^2 spreading out as far as the limit of 3 nautical miles. As indicated in Figure 1, subaqueous soils were sampled respectively out of the MPA surface (transects T5 and T6), in the C area (transects T3 and T4) and in the B area (transects T1 and T2). For each transect, mini-pits were collected at the bathymetries 2, 4, 6, 8 m. Marine mini-pits were retrieved by a mechanical grab bucket mounted on a boat, and removed by using a plastic blade that allowed us to obtain a stable and relatively undisturbed soil profile showing the first 2 or 3 horizons (Fig. 2). Profile descriptions was made according to Schoeneberger et al.

(2012), providing additional characteristics like identification and number of bivalves, gastropods, worms, etc. that are involved in bioturbation.



Nautical chart I.I.M. n. 34, 1:100.000. Coastline: 7.103 meters

Figure1 *MPA Torre del Cerrano (soil and water map).*

Figure2 *Soil structure promoted by bioturbators and soil profiles with different coloured horizons.*

The soil horizons were sampled and collected into plastic bags before drying. Soil texture was assessed by the pipette method (Day, 1965) after the samples were maintained one night submerged in deionized water. Coarse, medium and fine sand

(2–0.5, 0.5–0.25 and 0.25–0.053 mm, respectively) were recovered by wet sieving while silt was separated from clay by sedimentation maintaining the columns at 19–20°C. Soil pH was measured in a 1:2.5 solid:liquid ratio suspension by a combined glass-calomel electrode. Soil conductivity was measured in a 1:5 solid:liquid suspension by a conductimeter. The organic matter content was determined by thermogravimetric analysis (loss of ignition). Bioturbators were identified during soil sampling, diving recognitions, and sediments/soils sampling made by a Van Veen grab.

Results and discussions

The maximum depth of the collected profile was 8 cm (Table 1). All profiles showed at least two horizons, C1 and C2, which were characterized by variable thickness and colors, this latter being frequently darker in C2 than in C1 (see Figure 2).

All the horizons showed sandy textures; because of the sandy texture, scarcity of humic substances and abundance of Na^+, soil aggregation is often at single grain or, in few cases, at weak crumbs. Each horizon showed a variable content of plant remnants and other organic material, but they also included shells, worms, bivalves, gastropods and other animals (Fig. 3).

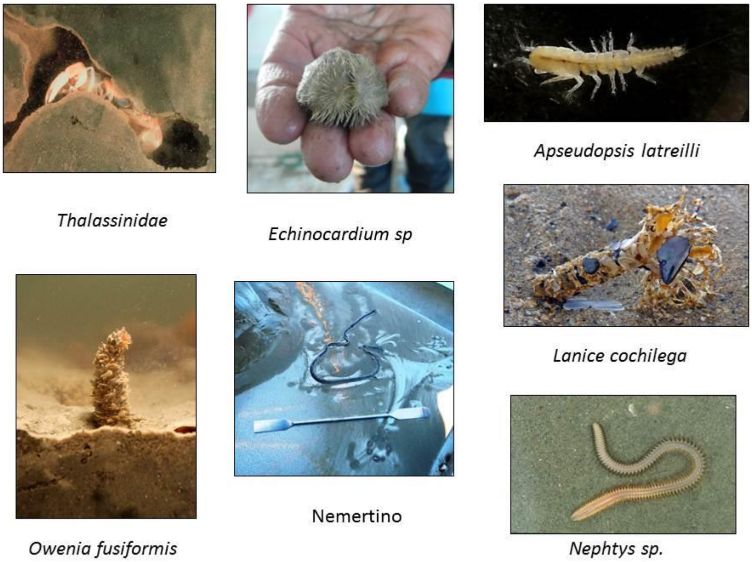


Figure 3 *Some of the bioturbators found in the soil of the MPA Torre del Cerrano.*

As shown in Figure 2, the structure was influenced by animals activities, as all these organisms differently contributed to soil aggregation. In fact, according to Gardner et al. (1987), François et al. (1997), and Gérino et al. (2003), on the basis of the animal activity, five groups of bioturbators can be obtained: biodiffusors, upward conveyors, downward conveyors, regenerators, and gallery-diffusors. Biodiffusors randomly mix sediment by free burrowing, while bio-advectors form more permanently occupied burrows that can penetrate deeper into the sediments and convey sediment upwards or downwards (Aller and Aller, 1998; Rosenberg, 2001; François et al., 2002). Bivalves like *Chamelea gallina* is the most diffused bioturbator of this MPA, and are among the major players in the modification of sediments. Among abundant and mobile macrofauna species, heart urchins of the genus *Echinocardium* (Figure 3) are regarded as key sediment bioturbators in marine systems throughout the world (Lohrer, 2005).

While moving horizontally through the sediment, these echinoids both pump oxygenated seawater from the sediment surface toward and around their outer surfaces (irrigation), and displace particles and pore-water of the surrounding sediment (Buchanan, 1966; De Ridder et al., 1987; Kanazawa, 1995). Crustaceans, which were described in high protected soils of the MPA, are among the most common burrowing animals in intertidal and sub-tidal soft sediments. One group of bioturbators of particular interest is that of the Thalassinidean decapods (Figure 3), which occur globally in all Mediterranean sea due to their burrowing life habit. Thalassinideans form one of the most active groups of burrowing macrofauna in coastal sediments as they create large, complex burrows that can increase the sediment surface area by up to 9 m² for every m² of the sediment surface (Griffis and Suchanek, 1991). Thalassinidean burrows not only provide protection from predators, but also buffer external environmental perturbations and provide a locus for feeding, moulting and breeding (Atkinson & Taylor, 1988; Bromley, 1990). Burrow irrigation behaviour influences the degree of oxygenation within the burrow, and the complexity of burrow architecture affects the spatial distribution of oxygen through the burrow. Such irrigation allows the introduction of oxygen deep into otherwise anoxic sediment (Aller, 1988). Worms like *Arenicola marina*, which was found in our site, is a typical head-down 'conveyor belt' feeder, which stays more or less permanently in its burrow while eating subsurface sediment and defecating at the surface. We could compared this activity with that of *Lumbricus terrestris*, which frequently improved terrestrial soil structure producing similar soil-casts (Figure 2).

The large tubiculous *Owenia fusiformis* (Figure 3) occurred in high number especially in the soils from protected and sub-protected areas, and is an active bioturbator as it builds discrete vertical burrows, ingests parts of sediments at depth and egests it at the sediments surface, so producing faecal mounds (Weffer et al., 2000). During the sampling it has been registered the presence of the tube-dwelling polychaete *Lanice conchilega*, which acts as a piston when moving in its tube, exchanging burrow water with the overlying water.

This mechanism, termed 'piston-pumping', is also potentially important in other smaller tube dwelling organisms (Forster and Graf, 1995).

Table 1. *Morphological description of subaqueous soils along six transects in the MPA of Torre del Cerrano, Teramo (Italy). Transects are listed from North to South (5, 3, 1, 2, 4, 6), while for each transect soils are listed by increasing bathymetry (2, 4, 6, 8 m).*

Transect/ profiles	**Horizons**	**Depth cm**	**Wet Color[a] Dry Color[a]**	**Texture[b]**	**Structure[c]**	**Fauna[d]**	**Other observations[e]**
5/1 (2 m)	**C1**	**0-2.5**	**2.5Y 4/2 2.5Y 7/2**	**S**	**sg**		**shells, plant remnants**
	C2	**2.5-5**	**2.5Y 2.5/1 2.5Y 6/2**	**S**	**sg**	***Chamelea gallina* +**	**shells, pebbles**
5/2 (4 m)	**C1**	**0-3**	**2.5Y 4/3 2.5Y 6/2**	**S**	**sg**	***Echinocardium cordatum* + *Chamelea gallina* +**	**odor +**
	C2	**3-5**	**2.5Y 3/2 2.5Y 6/2**	**S**	**g**	***Chamelea gallina* +**	**shells, odor ++**
5/3 (6 m)	**C1**	**0-1**	**2Y 4/3 10Y 6/2**	**S**	**sg & 1f cr**	**Worms + *Chamelea gallina* +**	**shells, plant remnants, odor ++**
	C2	**1-4**	**2Y 4/2 2.5Y 6/2**	**S**	**sg**	**worms, mussels +**	**charcoal, odor +**
5/4 (8 m)	**C1**	**0-4**	**2.5Y 4/2 2.5Y 6/3**	**S**	**sg**	***Chamelea gallina* + razor shells +**	**shells**
	C2	**4-6**	**2.5Y 3/2 5Y 6/3**	**S**	**sg**		
3/1 (2 m)	**C1**	**0-3.5**	**2.5Y 4/4 5Y 6/3**	**S**	**sg**	***Chamelea gallina* + mussels, worms +**	**shells, odor +++**
	C2	**3.5-5**	**2.5Y 3/3 2.5 Y 5/3**	**S**	**sg**	***Chamelea gallina* + mussels, worms +**	**odor +++**
3/2 (4 m)	**C1**	**0-2**	**2.5Y 4/3 2.5Y 6/4**	**S**	**sg**	**Copepods + *Chamelea gallina* + mussels, worms +**	**shells, plant remnants**
	C2	**2-4**	**2.5Y 3/1 2.5Y 7/3**	**S**	**sg**	***Chamelea gallina* + mussels, worms +**	**shells, plant remnants**
3/3 (6 m)	**C1**	**0-5**	**2.5Y 4/4 2.5Y 6/3**	**S**	**sg**	***Chamelea gallina* + mussels, worms +**	**shells, plant remnants**
	C2	**5-7**	**2.5Y 3/4 2.5Y 6/2**	**S**	**sg**	***Chamelea gallina* + mussels, worms +**	**shells, plant remnants**
3/4 (8 m)	**C1**	**0-3**	**2.5Y 4/3 2.5Y 6/2**	**S**	**sg & 1f cr**	***Chamelea gallina* + mussels, worms +**	**shells, plant remnants, odor +**
	C2	**3-7**	**2.5Y 4/2 2.5Y 6/3**	**S**	**sg**	***Chamelea gallina* + mussels, worms +**	**shells, plant remnants**
1/1 (2 m)	**C1**	**0-3**	**2.5Y 4/3 2.5Y6/3**	**S**	**sg & 1f cr**	***Chamelea gallina* + mussels, worms, Nemertini+, *Neverita josephinia*+ Gastropoda ++**	**casts, many shells**
	C2	**3-5**	**2.5Y 3/2 10YR 6/2**	**S**	**sg**	***Chamelea gallina* + mussels, worms**	**shells, plant remnants**
1/2 (4 m)	**C1**	**0-4**	**2.5Y 3/2 2.5Y6/3**	**S**	**sg**	***Chamelea gallina* ++ mussels, worms +**	**shells, plant remnants**
	C2	**4-5**	**2.5Y 4/2 2.5Y 6/3**	**S**	**sg**	***Chamelea gallina* +++ mussels, worms ++**	**shells, plant remnants**
1/3 (6 m)	**C1**	**0-6**	**2.5Y 4/2 5Y 6/3**	**S**	**sg**	***Owenia fusiformis* ++ *Chamelea gallina* ++ mussels, worms +**	**shells, plant remnants**
	C2	**6-7**	**2.5Y 4/3 5Y 6/3**	**S**	**sg**	***Chamelea gallina* +++ mussels, worms +**	**shells, plant remnants**
1/4 (8 m)	**C1**	**0-3**	**2.5Y 4/2 5Y 6/3**	**S**	**sg & 1f,m cr**	***Chamelea gallina* ++ mussels, worms +++**	**shells, plant remnants**
	C2	**3-6**	**2.5Y 3/2 5Y 6/3**	**S**	**sg**	***Chamelea gallina* ++ mussels, worms +**	**shells, plant remnants**

2/1 (2 m)	**C1**	**0-2**	**2.5Y 4/2 2.5Y 6/2**	**S**	**sg & 1f,m cr**	**worms +++ *Owenia fusiformis* +++ *Chamelea gallina* +, mussels**	**abundant shells, plant remnants**
	C2	**2-4**	**2.5Y 3/2 2.5Y 6/2**	**S**	**sg**	***Chamelea gallina* ++ worms, mussels +**	**abundant shells, plant remnants**
2/2 (4 m)	**C1**	**1-2.5**	**2.5Y 4/3 2.5Y 6/2**	**S**	**sg**	**shrimps ++ *Owenia fusiformis* +++ *Chamelea gallina* +++ worms, mussels +**	**abundant shells, plant remnants**
	C2	**2.5-6**	**2.5Y 4/2 5Y 6/3**	**S**	**sg**	***Chamelea gallina* +++ worms mussels ++**	**abundant shells, plant remnants**
2/3 (6 m)	**C1**	**0-4**	**2.5Y 4/2 2.5Y 6/2**	**S**	**sg**	***Echinocardium cordatum* + *Chamelea gallina* ++ worms, mussels +**	**abundant shells, plant remnants**
	C2	**4-8**	**2.5Y 3/2 5Y 6/3**	**S**	**sg**	***Chamelea gallina* ++ worms, mussels ++**	**abundant shells, plant remnants**
2/4 (8 m)	**C1**	**1-5.5**	**2.5Y 4/2 5Y 6/2**	**S**	**sg & 1f,m cr**	***Chamelea gallina* +++ worms, mussels +++**	**abundant shells, plant remnants**
	C2	**5.5-7**	**2.5Y 5/3 2.5Y 6/2**	**S**	**sg**	***Chamelea gallina* + worms, mussels +**	**abundant shells, plant remnants**
4/1 (2 m)	**C1**	**1-3.5**	**2.5Y 5/3 2.5Y 6/3**	**S**	**sg**	***Owenia fusiformis* ++ *Chamelea gallina* ++ worms, mussels ++**	**abundant shells, plant remnants**
	C2	**3.5-7**	**2.5Y 4/2 2.5Y 6/2**	**S**	**sg**	***Owenia fusiformis* ++ *Chamelea gallina* ++ worms, mussels ++**	**abundant shells, plant remnants**
4/2 (4 m)	**C1**	**0-2**	**2.5Y 4/2 5Y 6/3**	**S**	**sg & 1f-m cr**	***Chamelea gallina* ++ *Owenia fusiformis* ++ worms, mussels ++**	**abundant shells, plant remnants**
	C2	**2-5**	**2.5Y 2.5/1 5Y 6/2**	**S**	**sg**	***Chamelea gallina* ++ worms, mussels ++**	**abundant shells, plant remnants**
4/3 (6 m)	**C1**	**0-2.5**	**2.5Y 4/3 2.5Y 6/3**	**S**	**sg**	***Owenia fusiformis* ++ *Pagurus bernhardus* + *Chamelea gallina* + worm, mussels ++**	**abundant shells, plant remnants**
	C2	**2.5-5**	**2.5Y 3/3 2.5Y 6/3**	**S**	**sg**	***Chamelea gallina* ++ worms, mussels +**	**abundant shells, plant remnants**
4/4 (8 m)	**C1**	**0-2**	**2.5Y 4/3 2.5Y 6/2**	**S**	**sg**	***Owenia fusiformis* + *Pagurus bernhardus* + *Chamelea gallina* + worm, mussels ++**	**abundant shells, plant remnants**
	C2	**2-5**	**2.5Y 3/3 5Y 6/2**	**S**	**sg & 1f-m cr**	***Pagurus bernhardus* + *Chamelea gallina* + worms, razor shells ++**	**abundant shells, plant remnants**
6/1 (2 m)	**C1**	**0-3**	**2.5Y 4/3 2.5Y 6/2**	**S**	**sg & 1f cr**	***Pagurus bernhardus* + Worms +, *Chamelea gallina* +**	**Shells, pebbles, darker color at sites**
	C2	**3-5**	**2.5Y 4/3 2.5Y 6/2**	**S**	**Sg**	***Chamelea gallina* +**	**shells, pebbles**
6/2 (4 m)	**C1**	**0-4**	**2.5Y 4/3 2.5Y 6/2**	**S**	**sg & 1f cr**	***Chamelea gallina* + mussels +**	**casts, shells, pebbles, plant remnants**
	C2	**4-5**	**2.5Y 3/1 5Y 6/2**	**S**	**sg**	***Chamelea gallina* + mussels +**	**casts, shells, pebbles, plant remnants**
6/3 (6 m)	**C1**	**0-4**	**2.5Y 4/2 2.5Y 6/3**	**S**	**sg**	***Chamelea gallina* +**	**shells, pebbles, plant remnants**
	C2	**4-6**	**2.5Y 3/2 2.5y 6/3**	**S**	**sg**	***Chamelea gallina* + mussels, worms +**	**shells, pebbles, plant remnants**
6/4 (8 m)	**C1**	**0-3**	**2.5Y 4/2 2.5Y 6/2**	**S**	**sg**	***Chamelea gallina* + mussels, worms +**	**shells, pebbles, plant remnants**
	C2	**3-5**	**2.5Y 4/3 2.5Y 6/3**	**S**	**sg**	***Chamelea gallina* + mussel, worms +**	**shells, pebbles, plant remnants, charcoal**

[a] moist and crushed, according to the Munsell Soil Color Charts --- [b] S=sandy --- [c] sg = single grain; 1 = weak; f = fine, m = medium; cr = crumb --- [d] + = 1-2 individuals per 3 dm^2, ++ = 3-5 individuals per 3 dm^2, +++ = more than 6 individuals per 3 dm^2 --- [e] referred to odor: + = feeble, ++ = evident, +++ = intense.

DOI: 10.6092/issn.2281-4485/5802

Further, it is well known that crab-bioturbators like *Pagurus bernhardus*, which was widespread especially in the protected area, affect carbon burial (Gutierrez et al., 2006), and enhance sediment oxygenation (Daleo et al., 2007), benthic metabolism (Fanjul et al., 2011), and nutrient benthic flux (Fanjul et al., 2011).

The mixing and displacement of sediments by benthic macrofauna has major biogeochemical implications, and can control rates of organic matter degradation and carbon burial. It has been shown that bioturbation may increase microbial abundance and viable microbial biomass (Steward et al., 1996), and lead to establishing specific microbial communities in the burrows of macrorganisms (Marinelli et al., 2002; Matsui et al., 2004; Papaspyrou et al., 2005). For this reason, bioturbators have long been considered 'ecosystem engineers' (Jones, 1994; Lawton, 1994), and their presence can create unique micro-niches for sediment microrganisms to inhabit (Fenchel, 1996; Kristensen, 2005; Bertics, 2010). The physical mixing and irrigation of the sediments by benthic macrofauna has an important influence on the structure and diversity of benthic microbial communities. For example, infaunal burrow walls can have 10-fold higher numbers of bacteria compared with surrounding sediment (Papaspyrou et al., 2005). Finally, the presence of all these bioturbators that are able to modify porosity and consistency of the sediments, was considered responsible for the formation of aggregates and casts, and of the modification of sediments into soil.

Texture analysis (Table 2) confirmed field tests (Table 1), showing the prevalence of the medium and fine sand fractions and the virtually absence of clay. In all the samples, pH values ranged from 7.82 to 8.33, but they mostly were around 8.2-8.3: also electrical conductivity varied slightly, from 2.2 to 4.3 dS m^{-1} (Table 2).

The content of organic matter was relatively narrow (from 0.9 to 3.7%), but Figure 4 shows that it decreased from the Northen to the Southern transect. Interestingly, in all the investigated areas, even at 8 m of bathymetry, we observed morphological and analytical differences between the superficial C1 horizon (recently deposited sediments) and the underlying C2 horizon (pedogenized sediments).

As a matter of fact, bioturbation and excretion of organics produced by the marine fauna has changed the physical, chemical and biological properties of the sediments so to transform them into soil. Analogous to the "rhizosphere effect", which is often responsible of considerable pedogenic changes into sub-aerial soils, we would consider the genesis of submerged soils at bathymetry or conditions that prevent plant settlement as the product of a "zoosphere effect", whose action is mainly detectable in Wassents. By providing a theoretical reinforcement to the submarine pedogenesis debate, we suggest to expand soil studies till maritime territories with 8 m (or more) of bathymetry, provided that sea bottom is prone to pedogenesis.

Table 2. *Physical and chemical results of subaqueous soils samples along six transects in the MPA of Torre del Cerrano, Teramo (Italy).*

Transect profiles	Horizons	Depth (cm)	Texture (%)					pH	Electrical conductivity	Organic matter
			Coarse sand	Medium sand	Fine sand	Silt	Clay		(dS m^{-1})	(%)
5/1	C1	0-2.5	1.1	78.8	17.3	2.8	<d.l.	8.21	3.67	1.13
	C2	2.5-4	6.0	73.2	19.6	1.2	<d.l.	8.22	2.71	1.49
5/2	C1	0-3	0.3	76.6	19.9	3.2	<d.l.	8.25	3.85	1.70
	C2	3-4	0.4	75.0	20.6	4.0	<d.l.	8.23	4.08	2.15
5/3	C1	0-1	0.4	61.2	37.9	0.5	<d.l.	8.19	3.44	2.12
	C2	1-4	0.2	77.3	20.0	2.5	<d.l.	8.24	3.70	0.93
5/4	C1	0-4	<d.l.	61.7	37.9	0.4	<d.l.	8.21	3.28	1.37
	C2	4-6	<d.l.	36.0	56.7	7.3	<d.l.	8.21	3.67	2.24
3/1	C1	0-3.2	0.3	67.4	30.6	1.7	<d.l.	8.29	3.99	1.28
	C2	3.2-4.5	0.3	74.2	24.2	1.3	<d.l.	8.24	3.86	1.28
3/2	C1	0-2	0.2	65.2	32.6	2.0	<d.l.	8.31	3.78	1.89
	C2	2-3	0.2	65.7	31.1	3.0	<d.l.	8.31	3.56	1.07
3/3	C1	0-5	0.2	45.0	53.7	1.1	<d.l.	8.33	3.56	1.39
	C2	5-6.5	0.2	58.9	40.3	0.6	<d.l.	8.33	3.93	0.96
3/4	C1	0-3	0.2	45.0	53.9	0.9	<d.l.	8.26	4.08	3.74
	C2	3-6.5	0.3	34.7	63.4	1.6	<d.l.	8.32	4.01	2.94
1/1	C1	0-3	0.4	79.0	18.4	2.2	<d.l.	8.26	2.76	0.88
	C2	3-4.2	0.4	79.0	18.4	2.2	<d.l.	8.21	3.20	1.12
1/2	C1	0-4	0.3	87.1	10.7	1.9	<d.l.	8.21	3.37	1.35
	C2	4-4.5	0.5	67.1	28.8	3.6	<d.l.	8.23	3.68	1.26
1/3	C1	0-6	0.3	85.3	13.6	0.8	<d.l.	8.24	3.64	1.13
	C2	6-6.7	0.2	84.2	15.1	0.5	<d.l.	8.23	3.56	1.16
1/4	C1	0-3	0.2	47.5	50.4	1.9	<d.l.	8.25	4.18	1.80
	C2	3-5.5	1.7	68.6	29.0	0.7	<d.l.	8.21	4.02	1.08
2/1	C1	0-2	0.4	81.1	17.2	1.3	<d.l.	8.25	4.32	1.02
	C2	2-4	0.3	82.6	16.1	1.0	<d.l.	8.27	3.94	1.10
2/2	C1	1-2.5	3.4	74.9	17.9	3.8	<d.l.	7.97	2.57	1.07
	C2	2.5-6	3.8	76.0	20.1	0.1	<d.l.	8.22	2.98	1.11
2/3	C1	0-4	0.1	38.8	60.4	0.7	<d.l.	7.82	3.24	1.03
	C2	4-8	0.1	69.9	29.3	0.7	<d.l.	8.25	3.55	1.13
2/4	C1	1-5.5	0.2	62.0	37.0	0.8	<d.l.	8.22	3.20	1.16
	C2	5.5-6.5	0.3	80.6	18.4	0.7	<d.l.	8.31	4.10	2.17
4/1	C1	1-3.5	0.3	65.5	33.1	1.1	<d.l.	8.26	2.25	0.99
	C2	3.5-6.5	2.4	61.7	35.5	0.4	<d.l.	8.24	2.27	0.92
4/2	C1	0-2	0.3	81.5	13.4	4.8	<d.l.	8.12	3.32	0.99
	C2	2-4	0.3	72.9	21.4	5.4	<d.l.	8.23	3.72	1.10
4/3	C1	0-2.5	2.0	80.1	16.5	1.4	<d.l.	8.21	2.92	1.12
	C2	2.5-4	0.4	73.1	25.7	0.8	<d.l.	8.22	3.90	0.92
4/4	C1	0-2	1.9	84.5	12.6	1.0	<d.l.	8.30	3.77	1.11
	C2	2-4	6.5	89.0	3.2	1.3	<d.l.	8.27	3.61	0.91
6/1	C1	0-3	0.5	76.8	19.8	2.9	<d.l.	8.24	4.05	0.93
	C2	3-4	0.6	78.5	17.6	3.3	<d.l.	8.23	3.70	0.92
6/2	C1	0-4	0.2	72.5	24.5	2.8	<d.l.	8.25	3.56	1.07
	C2	4-5	0.6	71.4	26.3	1.7	<d.l.	8.13	4.30	0.92
6/3	C1	0-4	<d.l.	81.7	16.8	1.5	<d.l.	8.16	3.71	1.09
	C2	4-5	0.1	69.7	29.2	1.0	<d.l.	8.25	3.55	0.90
6/4	C1	0-3	0.3	63.4	34.4	1.9	<d.l.	8.28	3.70	1.04
	C2	3-5	0.3	55.3	43.2	1.2	<d.l.	8.22	3.93	0.86

Coarse sand = 2-0.5 mm; Medium sand = 0.5-0.25 mm; fine sand = 0.25-0.05 mm.
<d.l.= below detection limit. which amounts to 0.025%.

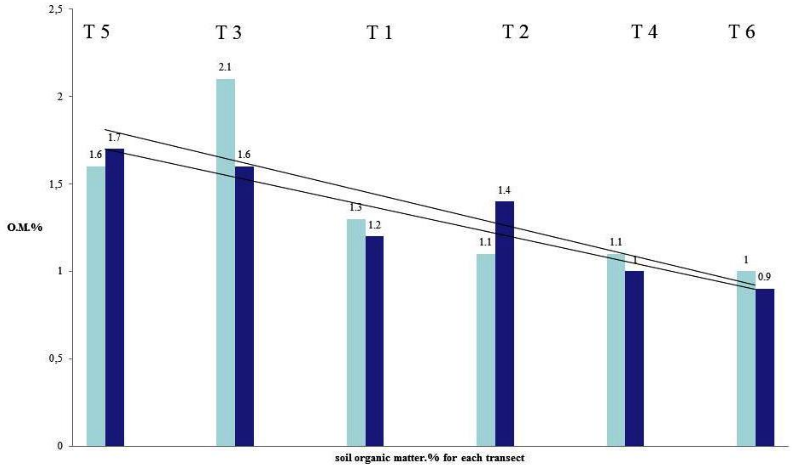


Figure 4 *Soil organic matter for each transect*

Conclusions

According to morphological and chemical characteristics of submerged soils found in the MPA of "Torre del Cerrano", we concluded that:
-submarine soils are important examples of pedogenesis led by animals that, with their bioturbation and the excretion of organics, foster the activity of a microbial population able to change sediments into soil;
-soils from the highly protected marine zone hosted a major biodiversity than those from the sub- and non-protected zones;
-there were no striking differences in terms of physical and chemical characteristics among protected, sub-protected and non-protected zones;
-we are confident that expanding soil studies till maritime territories with higher than 2.5 m bathymetry will provide important knowledge to the understanding of this ecosystems.

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