Macrozoobenthic Community of the Orbetello Lagoon (Tuscany, Italy): An Updated Checklist

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Abstract: Coastal lagoons are vulnerable transitional ecosystems, where biodiversity patterns reflect the interaction between natural environmental gradients and increasing anthropogenic pressures. In this context, updated taxonomic inventories are essential for biodiversity assessment, ecological monitoring, and conservation planning. The present study provides an updated checklist of the macrozoobenthic community of the Orbetello Lagoon (Italy), representing the first comprehensive revision of its taxonomic inventory in more than two decades. Monthly sampling was carried out between April 2025 and April 2026 at eight stations distributed across the western and eastern basins of the lagoon. A total of 113 macrozoobenthic taxa were recorded, establishing a robust baseline for future ecological assessments and long-term biodiversity monitoring. Community composition in both basins was consistently dominated by opportunistic and euryhaline species, confirming the influence of environmental confinement and organic enrichment on present-day assemblages. Beyond documenting taxon occurrence, the updated checklist provides an essential reference for evaluating future changes in biodiversity and supports conservation planning and management strategies for this ecologically important Mediterranean coastal lagoon.

Keywords: coastal lagoons; benthic macroinvertebrates; biodiversity; Western Mediterranean Sea.

1. Introduction

Coastal lagoons are typically shallow, brackish-water ecosystems. According to Kjerfve (1994), they are “shallow water bodies separated from the ocean by a barrier, connected at least intermittently to the ocean by one or more restricted inlets, and usually oriented shore parallel.” Nevertheless, the term has also been applied to some estuarine systems and coastal lakes. Regardless of their classification, these environments are among the most productive and dynamic aquatic ecosystems, with their intertidal zones ranking among the most productive marine habitats worldwide (Anthony et al., 2009).

Despite their high productivity, coastal lagoons are naturally stressful environments characterized by pronounced fluctuations in salinity, temperature, oxygen availability, and nutrient inputs. Consequently, their biological communities are adapted to highly variable environmental conditions. Traditional biodiversity metrics, such as species richness and evenness, have long been used to assess the ecological effects of environmental degradation. However, these indices are strongly influenced by sampling effort, habitat complexity, and sample size, and often fail to exhibit consistent or monotonic responses to anthropogenic disturbance (Leonard et al., 2006). Furthermore, lagoon ecosystems generally support lower native species richness than adjacent marine environments because only a limited number of species possess the physiological adaptations required to tolerate their naturally fluctuating environmental conditions (Kjerfve, 1994).

Within these ecosystems, the macrozoobenthic community is typically composed of three main ecological groups: marine species associated with sheltered, low-energy coastal habitats such as bays and harbors; opportunistic species capable of thriving in organically enriched environments; and characteristic euryhaline species adapted to brackish-water conditions (Rossi & Lardicci, 1995). Because the relative abundance of these groups closely reflects environmental quality, comprehensive taxonomic inventories and long-term monitoring programs represent a fundamental prerequisite for effective ecosystem assessment and management (Benedetti-Cecchi et al., 2001).

The macrozoobenthic community of the Orbetello Lagoon has been extensively investigated for more than three decades. Research began with the first taxonomic checklist published in 1978, which documented nearly 70 species (Cognetti et al., 1978), and subsequently expanded through a series of studies describing temporal changes in species composition, abundance, and ecological dynamics, including those associated with the establishment of non-indigenous species (Rossi & Lardicci, 1995; Lardicci et al., 1997; Benedetti-Cecchi et al., 2001; Lardicci et al., 2001; De Biasi et al., 2003). However, a

comprehensive update of the lagoon's macrozoobenthic fauna has not been available for over two decades.
The present study addresses this knowledge gap by providing an updated taxonomic checklist of the macrozoobenthic fauna inhabiting both the western and eastern basins of the Orbetello Lagoon. By documenting current biodiversity patterns and evaluating the occurrence of opportunistic and non-indigenous species, this study establishes an updated reference framework for future ecological investigations and supports the development of evidence-based conservation strategies and long-term environmental monitoring programs for this ecologically valuable coastal ecosystem.

2. Materials and Methods

The Orbetello Lagoon is a shallow coastal lagoon of high ecological and conservation value, covering approximately 2,700 ha and reaching a maximum depth of less than 2 m (Figure 1). The lagoon is separated from the Tyrrhenian Sea by two sand spits, the Giannella to the northwest and the Feniglia to the southeast, together with the Monte Argentario promontory. A central dam and bridge connect Monte Argentario to the town of Orbetello (approximately 14,000 inhabitants), dividing the lagoon into two distinct basins: the Western Basin (1,633.1 ha) and the Eastern Basin (1,045.5 ha). These basins differ markedly in their geomorphological and hydrodynamic characteristics (Grazioli et al., 2025).



Figure 1. Geographical location of the study area**.** Map processing QGIS 3.38 Source: EMODnet

Despite its protected status, the lagoon is subject to considerable environmental pressures. The coexistence of rooted macrophytes (*Ruppia maritima*) and opportunistic macroalgae (*Cladophora* spp.) poses significant management challenges. Opportunistic macroalgae rapidly assimilate available nutrients, often leading to extensive blooms whose subsequent decomposition can trigger severe dystrophic events and widespread hypoxia or anoxia throughout the lagoon (Giusti et al., 2005).

To characterize the full range of benthic habitats and update the taxonomic inventory of the lagoon's macrobenthic fauna, monthly sampling was conducted from April 2025 to April 2026. Samples were processed according to the standardized procedures described in UNI EN ISO 16665:2014 for the quantitative assessment of soft-bottom benthic macrofauna, ensuring methodological consistency and comparability with other coastal and transitional water monitoring programs.

Eight sampling stations were established, comprising six coastal stations and two central stations, with five stations located in the Western Basin and three in the Eastern Basin (Figure 1). At each survey area, sampling was conducted in duplicate (n = 2) along a shore-normal transect at progressively increasing distances from the coastline, specifically at 0 (shoreline), 50, 100, 200, and 500 meters from the coast. Samples were collected using an ultra-light Van Veen grab with a sampling area of 0.025 m² and a maximum capacity of approximately 3 L. The grab was deployed vertically at a constant speed to minimize pressure-wave disturbances and avoid disturbing surface-dwelling organisms. Only undisturbed samples with a penetration depth of greater than 5 cm were retained for analysis; otherwise, the sample was discarded and another grab deployment was performed.

To ensure a comprehensive and representative framework of the lagoon ecosystem, the selection of the eight sampling stations was systematically based on a combination of ecological, geographical, and management criteria. Spatial representativeness was

achieved by distributing the stations across both the Ponente and Levante basins, thereby facilitating a direct comparison between areas characterized by differing morphology and hydrodynamic regimes. Furthermore, the sampling design incorporated a distinct gradient of anthropogenic pressure; specific stations located near historically impacted areas were strategically selected to evaluate the ecological effects of wastewater discharge, fishing activities, and past industrial practices. Conversely, well-preserved and natural areas within both basins were chosen to serve as reference control sites, providing a baseline for evaluating benthic fauna and avifauna communities. Finally, logistical feasibility was factored into the selection process to ensure safe vessel accessibility across all tidal conditions, ultimately guaranteeing the precise and replicable deployment of sampling gear over time.

Prior to sorting, samples previously fixed in 80% ethanol were gently washed with freshwater through a 0.5 mm mesh sieve to remove fine sediments while preserving delicate specimens. Large shell fragments, coarse organic debris, and other structural materials were carefully inspected under a stereomicroscope for attached organisms before being discarded, thereby reducing sorting time while minimizing the risk of losing specimens.

The retained material was transferred to shallow, high-contrast gridded sorting trays filled with freshwater and examined under a stereomicroscope. Individual organisms were manually removed from the sediment using fine forceps and initially sorted into major taxonomic groups (Polychaeta, Mollusca, Crustacea, Echinodermata, and other taxa) to facilitate subsequent identification. Following sorting, specimens were preserved in 70% ethanol until taxonomic examination.

Taxa were identified to the lowest practicable taxonomic level, preferably to species, using standard taxonomic literature and identification keys relevant to the groups examined., together with stereomicroscopes (Euroteck – NB50B) and compound light microscopes (Nikon – ECLIPSE Ci-L). Specimens that were damaged or represented immature life stages were identified only to the highest reliable taxonomic rank (genus, family, or higher) when diagnostic characters were insufficient for species-level determination. Organism abundance was determined by direct counts. To avoid overestimating abundance due to fragmented specimens, only individuals with a recognizable head, anterior region, or complete body were included in the final counts.

3. Results

A total of 113 taxa were recorded across the eight sampling stations. Annelid Polychaetes represented the taxonomically richest group, with 51 taxa (45% of the total taxonomic richness), followed by molluscs (30 taxa, 27%), arthropods (27 taxa, 24%), bryozoans (1

taxon, 1%), hemichordates (1 taxon, 1%), nemerteans (1 taxon, 1%), phoronids (1 taxon, 1%), and platyhelminths (1 taxon, 1%) (Figure 2).

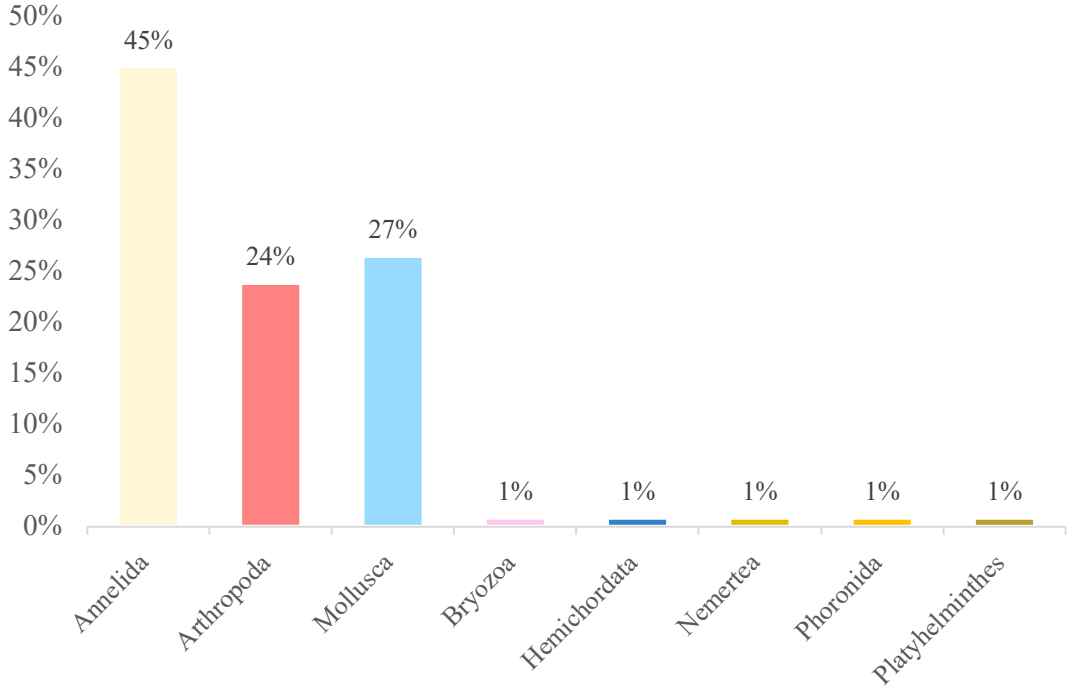


Figure 2. Percentage contribution of the major taxonomic groups to total taxonomic richness in the samples analyzed

Among the polychaetes, several opportunistic taxa characteristic of organically enriched environments, including *Capitella capitata* (Fabricius, 1780), *Neanthes acuminata* (Ehlers, 1868), and *Spio filicornis* (O.F. Müller, 1776), were recorded at all sampling stations. These opportunistic taxa were among the characteristic components of the assemblage, although their distribution differed between basins (Table 1).

The Western Basin (Ponente) supported the highest biodiversity, with a total of 97 recorded taxa. The assemblage was dominated by taxa typically associated with euryhaline and confined lagoon environments. Particularly high abundances were observed for the gastropod *Ecrobia ventrosa* (Montagu, 1803), the bivalve *Abra segmentum* (Récluz, 1843), and the amphipod *Monocorophium insidiosum* (Crawford, 1937). Among the polychaetes, *Capitella capitata and Neanthes acuminata were also abundant in the Western Basin*, although the annelid community also included a diverse assemblage of other taxa, such as *Armandia cirrhosa* Filippi, 1861, and *Hediste diversicolor* (O.F. Müller, 1776).

In contrast, the Eastern Basin (Levante) exhibited a distinctly different community structure (61 recorded taxa), characterized by shifts in species dominance and a reduced abundance of several taxonomic groups, particularly polychaetes. This decline was partially compensated by higher abundances of selected bivalves and crustaceans. Although *Ecrobia ventrosa* and *Abra segmentum* remained among the dominant species, the eastern basin was distinguished by high abundances of *Mytilaster minimus* (Poli, 1795) and the non-indigenous bivalve *Cerastoderma edule* (Linnaeus, 1758). Furthermore, the marked abundance of the amphipod *Gammarus insensibilis* Stock, 1966, together with the

reduced occurrence of *Monocorophium insidiosum*, may indicate greater coverage of submerged vegetation, including *Ruppia* spp. and filamentous macroalgae such as *Chaetomorpha* spp., both plant species widely documented in the lagoon, as also reported by Lenzi et al. (2009).

The monitoring programs confirm the permanent establishment of at least eight non-indigenous species (NIS) within the macrozoobenthic assemblages of the Orbetello Lagoon. The bryozoan *Amathia verticillata* represents a significant component, whose distribution dynamics as a vector for secondary introductions in Italian waters have been thoroughly documented (Marchini et al., 2015). Among the tube-building serpulid polychaetes, the reef-building *Ficopomatus enigmaticus* constitutes one of the earliest introductions in the basin, with mass occurrences and structural reef-building behaviors formally described by Bianchi and Morri (2001). The same authors documented the concurrent presence of the non-native congeners *Hydroides dianthus* and *Hydroides elegans*, which have heavily colonized low-energy sheltered sectors alongside *Hydroides niger*. Regarding peracarid crustaceans, the introduction of the North-East Pacific sphaeromatid isopod *Paracerceis sculpta* was tracked along the Italian coastlines following its initial Western Mediterranean expansion (Marchini et al., 2016), frequently taking advantage of *A. verticillata* meadows as a microhabitat (Marchini et al., 2015). Finally, the bivalve *Cerastoderma edule* and the gastropod *Littorina saxatilis* have been long integrated into the malacological records of the area, reflecting decades of altered hydrodynamic regimes and anthropogenic vectors.

Table 1. Mean density (ind. m^{-2}) of macrozoobenthic taxa recorded in the western and eastern basins of Orbetello Lagoon

TAXONOMIC GROUPS		Author	SAMPLING STATIONS			
			Western		Eastern	
			Mean	SD	Mean	SD
Bryozoa	*Amathia verticillata*	(delle Chiaje, 1822)	0.29	2.53	0.00	0.00
Hemichordata	Enteropneusta ind.	-	0.07	1.27	0.00	0.00
Nemertea	Nemertea ind.	-	0.36	2.82	0.38	2.88
Phoronida	*Phoronis* sp.	-	0.07	1.27	0.00	0.00
Platyhelminthes	*Platyhelminthes ind.*	-	0.07	1.27	0.00	0.00
Annelida	*Abarenicola claparedi*	(Levinsen, 1884)	0.00	0.00	0.63	4.40
	Abarenicola sp.	-	0.07	1.27	0.00	0.00
	Aphelochaeta marioni	(Saint-Joseph, 1894)	0.15	1.79	0.25	2.36
	Armandia cirrhosa	Filippi, 1861	0.87	5.33	1.01	6.20
	Capitella capitata	(Fabricius, 1780)	9.80	41.88	7.83	26.36
	Capitella minima	Langerhans, 1880	1.53	11.35	0.00	0.00
	Cirratulus cirratus	(O.F. Müller, 1776)	0.07	1.27	0.00	0.00
	Cirrophorus furcatus	(Hartman, 1957)	3.27	25.21	0.00	0.00
	Cirrophorus sp.	-	0.15	1.79	0.00	0.00
	Dasybranchus caducus	(Grube, 1846)	0.07	1.27	0.00	0.00

TAXONOMIC GROUPS		Author	SAMPLING STATIONS			
			Western		Eastern	
			Mean	SD	Mean	SD
Annelida	*Diopatra neapolitana*	Delle Chiaje, 1841	0.00	0.00	0.13	1.68
	Exogone naidina	Örsted, 1845	0.00	0.00	0.25	3.35
	Ficopomatus enigmaticus	(Fauvel, 1923)	0.00	0.00	0.63	5.00
	Glycera alba	(O.F. Müller, 1776)	0.94	4.49	5.68	14.00
	Glycera sp.	-	0.00	0.00	0.63	5.54
	Harmothoe reticulata	(Claparède, 1870)	1.89	8.80	2.02	8.65
	Harmothoe sp.	-	0.07	1.27	0.00	0.00
	Hediste diversicolor	(O.F. Müller, 1776)	4.36	27.83	0.00	0.00
	Hesionidae ind.	-	0.15	1.79	0.00	0.00
	Hydroides dianthus	(Verrill, 1873)	0.00	0.00	1.01	13.40
	Hydroides elegans	(Haswell, 1883)	0.73	8.01	0.38	2.88
	Hydroides sp.	-	0.15	1.79	0.00	0.00
	Lagis koreni	Malmgren, 1866	0.00	0.00	0.13	1.68
	Mysta barbata	Malmgren, 1865	0.29	3.59	0.13	1.68
	Neanthes acuminata	(Ehlers, 1868)	17.28	83.31	0.00	0.00
	Neanthes sp.	-	0.15	1.79	0.00	0.00
	Nephasoma sp.	-	1.67	7.34	1.52	13.97
	Nephtys hombergii	Savigny in Lamarck, 1818	0.07	1.25	0.00	0.00
	Nereimyra punctata	(O.F. Müller, 1776)	0.22	2.19	0.00	0.00
	Nereiphylla castanea	(Marenzeller, 1879)	0.07	1.27	0.00	0.00
	Nereiphylla rubiginosa	(Saint-Joseph, 1888)	3.27	12.75	4.17	17.68
	Notomastus latericeus	Sars, 1851	1.74	13.47	0.00	0.00
	Oxydromus pallidus	Claparède, 1864	0.07	1.27	0.13	1.68
	Paraprionospio coora	Wilson, 1990	0.44	5.38	0.00	0.00
	Perinereis sp.	-	0.07	1.27	0.00	0.00
	Phascolosoma (Phascolosoma) granulatum	Leuckart, 1828	0.15	1.79	0.00	0.00
	Phyllodoce sp.	-	0.15	1.79	0.00	0.00
	Phylo foetida	(Claparède, 1868)	3.70	44.01	0.00	0.00
	Platynereis dumerilii	(Audouin & Milne Edwards, 1833)	4.07	30.95	0.00	0.00
	Polydora ciliata	(Johnston, 1838)	5.01	86.39	1.01	7.81
	Prionospio cf. ehlersi	Fauvel, 1928	0.00	0.00	0.25	3.35
	Prionospio ehlersi	Fauvel, 1928	0.15	2.54	0.13	1.68
	Protoaricia oerstedii	(Claparède, 1864)	0.29	3.10	0.00	0.00
	Protodorvillea kefersteini	(McIntosh, 1869)	2.03	11.20	0.00	0.00
	Sabellaria spinulosa	Leuckart, 1849	0.00	0.00	0.13	1.68
	Scoloplos sp.	-	0.07	1.27	0.00	0.00

TAXONOMIC GROUPS		Author	SAMPLING STATIONS			
			Western		Eastern	
			Mean	SD	Mean	SD
Annelida	*Scoloplos typicus*	(Eisig, 1914)	0.29	3.59	0.00	0.00
	Spio decorata	Bobretzky, 1870	0.29	5.08	0.00	0.00
	Spio filicornis	(O.F. Müller, 1776)	12.64	57.77	7.45	23.83
	Spionidae ind.	-	0.00	0.00	0.13	1.68
	Syllis gracilis	Grube, 1840	0.00	0.00	0.13	1.68
Arthropoda	**Crustacea**	-	0.00	0.00	0.00	0.00
	Apohyale sp.	-	0.07	1.27	0.00	0.00
	Chondrochelia dubia	(Krøyer, 1842)	0.22	2.19	0.00	0.00
	Copepoda ind.	-	34.20	292.67	0.13	1.68
	Cumacea ind.	-	0.22	3.81	0.00	0.00
	Ericthonius sp.	-	0.00	0.00	0.76	10.05
	Ericthonius brasiliensis	(Dana, 1853)	3.20	29.51	0.25	3.35
	Ericthonius difformis	H. Milne Edwards, 1830	14.31	138.22	8.84	60.06
	Gammarus aequicauda	(Martynov, 1924)	5.08	60.44	4.42	28.61
	Gammarus crinicornis	Stock, 1966	5.23	58.55	0.13	1.68
	Gammarus insensibilis	Stock, 1966	63.11	240.75	85.98	179.15
	Gammarus sp.	-	0.00	0.00	0.13	1.68
	Idotea chelipes	(Pallas, 1772)	48.66	205.57	10.10	33.24
	Idotea emarginata	(Fabricius, 1793)	0.73	7.16	0.25	2.36
	Iphinoe serrata	Norman, 1867	15.03	67.85	8.08	28.25
	Iphinoe trispinosa	(Goodsir, 1843)	0.36	3.35	0.00	0.00
	Lekanesphaera hookeri	(Leach, 1814)	0.07	1.27	0.38	2.88
	Lekanesphaera rugicauda	(Leach, 1814)	6.17	43.33	0.00	0.00
	Microdeutopus gryllotalpa	Costa, 1853	67.68	582.19	26.39	63.41
	Microdeutopus sp.	-	3.34	31.14	0.13	1.68
	Monocorophium insidiosum	(Crawford, 1937)	483.08	1376.51	124.12	354.73
	Ostracoda ind.	-	0.15	1.79	0.00	0.00
	Palaemon adspersus	Rathke, 1836	0.00	0.00	0.13	1.68
	Paracerceis sculpta	(Holmes, 1904)	13.29	79.44	1.52	8.09
	Sphaeroma serratum	(Fabricius, 1787)	0.15	1.79	0.00	0.00
	Tanais dulongii	(Audouin, 1826)	0.15	1.79	0.25	3.35
	Insecta	-	0.00	0.00	0.00	0.00
	Chironomus salinarius	Kieffer, 1915	1087.98	2800.52	2560.78	6775.63
	Halocladius varians	(Staeger, 1839)	1.31	8.53	2.27	13.87
Mollusca	*Abra segmentum*	(Récluz, 1843)	488.24	648.45	447.47	523.23
	Acanthocardia tuberculata	(Linnaeus, 1758)	5.88	37.48	2.40	15.30
	Bittium latreillii	(Payraudeau, 1826)	0.29	3.10	0.00	0.00

TAXONOMIC GROUPS		Author	SAMPLING STATIONS			
			Western		Eastern	
			Mean	SD	Mean	SD
Mollusca	*Bulla striata*	Bruguière, 1792	0.07	1.27	0.00	0.00
	Cerastoderma edule	(Linnaeus, 1758)	58.90	157.18	254.55	506.78
	Cerastoderma glaucum	(Bruguière, 1789)	0.80	7.70	7.83	65.28
	Ecrobia ventrosa	(Montagu, 1803)	845.46	1653.59	1240.40	1669.14
	Elysia sp.	-	0.07	1.25	0.00	0.00
	Epitonium clathrus	(Linnaeus, 1758)	0.15	2.54	0.13	1.68
	Gastrana fragilis	(Linnaeus, 1758)	0.00	0.00	0.51	4.72
	Gastropoda ind.	-	0.15	1.79	0.00	0.00
	Gibbula sp.	-	0.07	1.27	0.00	0.00
	Haminoea navicula	(da Costa, 1778)	0.87	6.91	1.64	8.24
	Haminoea orbignyana	(Férussac, 1822)	0.22	3.81	0.00	0.00
	Littorina saxatilis	(Olivi, 1792)	0.22	2.19	0.00	0.00
	Littorina sp.	-	0.15	2.54	0.00	0.00
	Loripes orbiculatus juv.	(Poli, 1791)	5.01	61.89	0.00	0.00
	Lucinella divaricata	(Linnaeus, 1758)	1.09	10.04	0.00	0.00
	Musculus costulatus	(Risso, 1826)	0.15	2.54	0.38	3.74
	Mytilaster minimus	(Poli, 1795)	19.83	73.75	369.95	1406.61
	Mytilidae juv.	-	0.07	1.27	0.00	0.00
	Parthenina sp.	-	0.35	6.25	0.51	4.08
	Parvicardium exiguum	(Gmelin, 1791)	7.04	43.08	12.50	64.78
	Peronidia albicans	(Gmelin, 1791)	0.00	0.00	0.13	1.68
	Polititapes aureus	(Gmelin, 1791)	3.99	25.61	7.32	17.53
	Polititapes aureus juv.	(Gmelin, 1791)	0.73	12.70	0.00	0.00
	Rissoa sp.	-	0.80	6.31	1.01	6.20
	Ruditapes decussatus	(Linnaeus, 1758)	0.73	11.50	1.01	5.21
	Spisula subtruncata	(da Costa, 1778)	0.07	1.27	0.00	0.00
	Thericium vulgatum	(Bruguière, 1792)	0.07	1.27	0.00	0.00
MEAN DENSITY SAMPLED PER SITE			3375	9367	5219	12055
MEAN DENSITY			4297			
NUMBER OF TAXA			94		61	

4. Discussion and Conclusions

The present study provides the first comprehensive update of the macrozoobenthic fauna of the Orbetello Lagoon in more than two decades and represents an important baseline for assessing the ecological changes that have occurred in recent years, including the spread of non-indigenous species and the consequences of the severe anoxic events recorded during the summer of 2024 (Polonelli et al., 2025).

Comparison with surveys conducted during the 1990s reveals substantial changes in the composition of the macrozoobenthic assemblages, the increased occurrence of opportunistic species suggesting a progressive deterioration of environmental conditions within the lagoon. Although Rossi and Lardicci (1995) had already reported the presence of the chironomid *Chironomus salinarius* Kieffer, 1915, a well-known indicator of severe organic enrichment, its abundance at that time was considerably lower than that observed in the present study. During the same period, the authors also documented the establishment and subsequent expansion of *Halocladius varians* (Staeger, 1839), a macrophyte-associated chironomid whose proliferation was linked to recurrent macroalgal blooms. This observation aligns well with the findings of the present study; indeed, in addition to *C. salinarius*, larvae of *H. varians* were also recorded.

Consistent with the ecological patterns described following the dystrophic crises of the 1990s, *Abra segmentum* remained one of the dominant molluscan species in the Western Basin, whereas *Cerastoderma edule* continued to characterize the Eastern Basin. In contrast, environmentally sensitive taxa, including *Gibbula* sp., *Epitonium clathrus* (Linnaeus, 1758), and *Littorina saxatilis* (Olivi, 1792), were still present but occurred at substantially lower abundances. Following the 1995 dystrophic event, these species became largely restricted to areas immediately adjacent to the tidal inlets connecting the lagoon with the open sea.

In this context the work by Rossi and Lardicci (1995) represents a checklist available for a real comparison of lagoon's macrozoobenthic species. Indeed, all subsequent studies have not provided a full species inventory, focusing on variations in macrozoobenthic assemblages, their distribution along gradients, or their responses to anthropogenic activities and stressful events (Lardicci et al., 1997; Benedetti-Cecchi

The updated taxonomic checklist presented here provides a robust reference framework for future ecological investigations and long-term biodiversity monitoring. Beyond documenting the current composition of the macrozoobenthic community, it establishes a baseline for detecting future ecological changes, evaluating the effectiveness of management actions, and supporting evidence-based conservation and restoration strategies for the Orbetello Lagoon.

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REFERENCES

Anthony, A., Atwood, J., August, P., Byron, C., Cobb, S., Foster, C., Fry, C., Gold, A., Hagos, K., Heffner, L., Kellogg, D. Q., Lellis-Dibble, K., Opaluch, J. J., Oviatt, C., Pfeiffer-Herbert, A., Rohr, N., Smith, L., Smythe, T., Swift, J., & Vinhateiro, N. (2009). Coastal lagoons and climate change: Ecological and social ramifications in U.S. Atlantic and Gulf Coast ecosystems. *Ecology and Society*, *14*(1), Article 8. http://www.jstor.org/stable/26268055

Benedetti-Cecchi, L., Rindi, F., Bertocci, I., Bulleri, F., & Cinelli, F. (2001). Spatial variation in development of epibenthic assemblages in a coastal lagoon. *Estuarine, Coastal and Shelf Science 443*(52(5), 659–668. https://doi.org/10.1006/ecss.2001.0775

Bianchi, C. N., & Morri, C. (2001). The Battle is not to the Strong: Serpulid Reefs in the Lagoon of Orbetello (Tuscany, Italy). *Estuarine, Coastal and Shelf Science*, 53(2), 215–220. https://doi.org/10.1006/ecss.2001.0793

Cognetti, G., Angelis, C. M., Orlando, E., Bonvicini Pagliai, A. M., Cognetti Varriale, A. M., Crema, R., Mari, M., Mauri, M., Tongiorgi, P., & Zunarelli Vandini, R. (1978). Situazione ecologica e ittiocoltura. In *Risanamento e protezione dell'ambiente idrobiologico delle lagune di Orbetello* (pp. 35–98). Regione Toscana, Comune di Orbetello.

De Biasi, A. M., Benedetti-Cecchi, L., Pacciardi, L., Maggi, E., Vaselli, S., & Bertocci, I. (2003). Spatial heterogeneity in the distribution of plants and benthic invertebrates in the lagoon of Orbetello (Italy). *Oceanologica Acta*, *26*(1), 39–46. https://doi.org/10.1016/S0399-1784(02)01226-4

Giusti, E., & Marsili-Libelli, S. (2005). Modelling the interactions between nutrients and the submersed vegetation in the Orbetello Lagoon. *Ecological Modelling, 184*(1), 141–161. https://doi.org/10.1016/j.ecolmodel.2004.11.014

Grazioli, E., Anselmi, S., Biagiotti, I., Mancini, E., Leporatti Persiano, M., Di Dio, S., Gentiloni, P., Cerioni, S., & Renzi, M. (2025). Ecosystem Services in the Orbetello Lagoon: Estimate of Value and Possible Effects Due to Global Change. *Oceans, 6*(1), 12–31. https://doi.org/10.3390/oceans6010014

Kjerfve, B. (1994). Coastal lagoons. In B. Kjerfve (Ed.), *Coastal lagoon processes* (Elsevier Oceanography Series, Vol. 60, pp. 1–8). Elsevier Science Publishers B.V. https://doi.org/10.1016/S0422-9894(08)70006-0

Lardicci, C., Como, S., Corti, S., & Rossi, F. (2001). Recovery of the macrozoobenthic community after severe dystrophic crises in a Mediterranean coastal lagoon (Orbetello, Italy). *Marine Pollution Bulletin*, *42*(3), 202–214. https://doi.org/10.1016/S0025-326X(00)00144-2

Lardicci, C., Rossi, F., & Castelli, A. (1997). Analysis of macrozoobenthic community structure after severe dystrophic crises in a Mediterranean coastal lagoon. *Marine Pollution Bulletin*, *34*(7), 536–547. https://doi.org/10.1016/S0025-326X(96)00164-6

Lenzi, M., Birardi, F., Boddi, S., Roffilli, R., Solari, D., & Sartoni, G. (2009). The Orbetello lagoon. In *Flora and Vegetation of the Italian Transitional Water Systems*. CoRiLa, Stampa Multigraf Spinea, Venezia. pp. 111–123.

Leonard, D. R. P., Clarke, K. R., Somerfield, P. J., & Warwick, R. M. (2006). The application of an indicator based on taxonomic distinctness for UK marine biodiversity assessment. *Journal of Environmental Management*, *78*(1), 52-62. https://doi.org/10.1016/j.jenvman.2005.04.008

Marchini, A., Ferrario, J., & Nasi, E. (2016). Arrival of the invasive amphipod *Grandidierella japonica* to the Mediterranean Sea. *Marine Biodiversity Records, 9*, 38. https://doi.org/10.1186/s41200-016-0049-y

Marchini, A., Ferrario, J., Minchin, D., & Occhipinti-Ambrogi, A. (2015). Marinas may act as hubs for the spread of the pseudo-indigenous bryozoan *Amathia verticillata* and its associated peracarid fauna. *Scientia Marina*, 79(3), 355–365. https://doi.org/10.3989/scimar.04238.03A

Polonelli, F., Leporatti Persiano, M., Melillo, C., & Lenzi, M. (2025). Evolution of a Dystrophic Crisis in a Non-Tidal Lagoon Through Microphyte Blooms. *Phycology*, *5*(4), 78. https://doi.org/10.3390/phycology5040078

Rossi, F., & Lardicci, C. (1995). Evoluzione delle comunità zoobentoniche di fondo molle della laguna di Orbetello: variazioni nella composizione specifica. *Atti della Società Toscana di Scienze Naturali, Memorie, Serie B*, *102*, 31–36.

Rossi, F., Castelli, A., & Lardicci, C. (2006). Distribution of macrobenthic assemblages along a marine gradient in Mediterranean eutrophic coastal lagoons. *Marine Ecology*, *27*(1), 66–75. https://doi.org/10.1111/j.1439-0485.2006.00078.x

Tomassetti, P., Lenzi, M., Lattanzi, L., Persia, E., Mercatali, I., Gennaro, P., Vani, D., & Porrello, S. (2014). Modifications of macrobenthos assemblages on land-based fish farm phytotreatment basins in the Orbetello lagoon. *International Journal of Environment and Health*, *7*(2), 114–127. https://doi.org/10.1504/IJENVH.2014.067357