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VALVULINERIA BRADYANA (FORNASINI) IN ORGANIC MATTER-ENRICHED ENVIRONMENT (OMBRONE RIVER MOUTH, CENTRAL ITALY).

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RIASSUNTO – Lo scopo di questo lavoro è quello di comprendere il significato ecologico di elevate frequenze di *Valvulineria bradyana*, presenti in associazioni recenti a foraminiferi bentonici di ambiente circalitorale in corrispondenza della foce del fiume Ombrone (Toscana meridionale). Nonostante stagionalmente occorrano lunghi periodi di scarsa ossigenazione al fondo, questa specie può raggiungere elevate frequenze fino a costituire più del 50% dell'associazione totale. *Valvulineria bradyana* è una forma opportunista che, più di ogni altra specie presente nelle associazioni studiate, rivela una buona tolleranza ad ambienti scarsamente ossigenati e ricchi di sostanza organica. Per tale comportamento *Valvulineria bradyana* manifesta spiccate caratteristiche *r*-selettive.
Inoltre, la struttura della comunità bentonica, individuata in questo studio potrebbe costituire un modello teorico utile nelle ricostruzioni paleoambientali.

ABSTRACT - This paper discusses the significance of the high frequency of *Valvulineria bradyana* in recent benthic foraminiferal assemblages, from a circalittoral environment, near to the Ombrone River mouth (Southern Tuscany). In spite of long seasonal periods of low oxygen levels, this species may reach high densities in typical assemblages, where it sometime constitutes more than 50%. *Valvulineria bradyana* is characterised by good tolerance to scarcely oxygenated environments and by opportunistic behaviour, which allow it to take advantage of the high trophic levels due to the river contributions, more than any other species in the studied assemblages. For this behaviour, marked *r*-selective features may be attributed to *Valvulineria bradyana*. Moreover, the structure of the assemblages constitutes a conceptual model that might be useful for paleoecological reconstruction.

Key words: *Valvulineria bradyana*, opportunism, organic matter, oxygen.
Parole chiave: *Valvulineria bradyana*, opportunismo, materia organica, ossigeno.

1. INTRODUCTION

Aim of this paper is to describe the typical benthic foraminiferal assemblages strongly dominated by *Valvulineria bradyana*, which are contained in fine sediments (silty clay) of Recent age near the Ombrone River mouth, to understand their ecological significance and to infer a behavioural model related to particular environmental conditions.

Valvulineria bradyana is widespread in the Mediterranean Basin but, usually, it does not reach high frequencies in the assemblages. Blanc-Vernet (1969) considers this species typical of VTC biocenoses, where is not more abundant than a few percent, with its optimum between -40 and –110 m. These findings agree with those reported by Violanti *et al.* (1990) for the Gulf of Noto (East Sicily). In this area *Valvulineria bradyana* is present (max 9%) in assemblages that may be attributed to the VTC, ranging in depth from 50 to150 m.

Sgarrella & Moncharmont-Zei (1993) found it in the Gulf of Naples with maximum abundance in the 90-120 m depth range.

Coppa *et al.* (1994) recorded assemblages dominated by *Valvulineria bradyana* (13-17%) in silty-sandy sediments and pelites (between -48 and -51 m) of the South Tyrrhenian Sea (between Agropoli and Capo Palinuro) which are influenced by river discharge.

Jorissen (1987) studied the benthic foraminiferal assemblages of the Adriatic Sea and identified some species (*Nonionella turgida*, *Bulimina marginata* and *Valvulineria bradyana*) which are correlated with high percentages of organic matter and low oxygen concentration in the sediment. These species may have extremely high frequencies in the pelitic belt, which runs parallel to the Italian coast. This area shows maximum percentages of organic matter, due to the sedimentation of the Po runoff products. The above three taxa seem to be excellent markers of high benthic productivity, which is often related to moderate environmental stress (Verhallen, 1991). In this case, it is probably caused by low oxygen levels at the bottom.

The Ombrone River delta environment seems comparable with that of the Po River mouth in the Adriatic Sea, because a limited enclosure of the basin, surrounded by islands and promontories, originates scarce water circulation. After Astraldi *et al.* (1993), as in summer, as in winter, the structures of circulation within the Tuscany Archipelago are local, and there are prevalent rotating movements, characterised by weak values of current. This fact, combined with the high input of organic matter from the river, results in poor oxygenation of the sea floor (Carboni *et al.*, 1998), specially during summer, when a thermic stratification of waters occurs.

2. MATERIALS AND METHODS

Several hundreds of samples (gravity cores, box-cores, grab-samples) were collected during two cruises (Urania '94 and Maremma '96) which were part of a multidisciplinary research project on the Ombrone River basin (Southern Tuscany), sponsored by CNR (Centro di Studio per il Quaternario e l'Evoluzione Ambientale).

	Latitude	Longitude	Water depth
NK6	42°38'36"	10°58'04"	42.4 m
NK5	42°38'32"	10°57'55"	49.7 m
NK4	42°38'04"	10°56'59"	76.4 m
B6I	42°39'15"	10°57'09"	58 m
B6L	42°38'50"	10°56'25"	75.5 m
NK2	42°34'31"	10°59'24"	87.2 m

Tab. 1 - Geographic co-ordinates and water depth of samples.

Coordinate geografiche e profondità d'acqua dei campioni studiati.

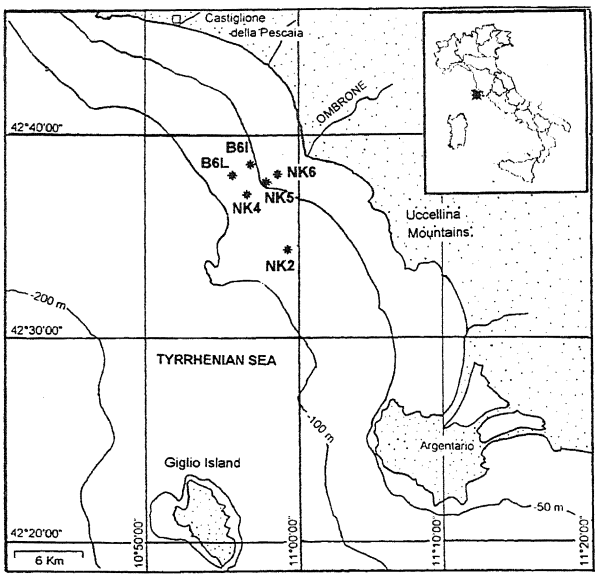

Fig. 1 - Location of studied samples.

Ubicazione dei campioni studiati.

	NK6	NK5	NK4	B6I	B6L	NK2
Ammonia beccarii (Linnè)	1,9%	0,0%	0,0%	0,0%	0,0%	0,0%
Ammonia inflata (Seguenza)	5,0%	12,7%	4,4%	10,7%	8,7%	14,7%
Ammonia parkinsoniana (d'Orbigny)	8,3%	1,3%	0,0%	2,0%	0,0%	<1%
Ammonia tepida (Cushman)	12,1%	<1%	<1%	7,7%	<1%	0,0%
Amphicoryna scalaris (Batsch)	0,0%	0,0%	2,2%	<1%	<1%	1,0%
Bulimina marginata d'Orbigny	1,9%	8,0%	7,5%	10,3%	6,7%	3,6%
Bulimina sublimbata Panizza	0,0%	0,0%	2,2%	<1%	2,0%	4,2%
Cassidulina neocarinata Thalman	0,0%	<1%	4,4%	1,3%	4,0%	7,8%
Elphidium advenum (Cushman)	0,0%	2,3%	1,2%	2,3%	1,3%	0,0%
Elphidium granosum (d'Orbigny)	1,2%	1,7%	1,6%	2,0%	1,7%	<1%
Elphidium translucens Natland	0,0%	1,0%	0,0%	1,3%	<1%	1,7%
Globocassidulina subglobosa (Brady)	0,0%	0,0%	4,4%	<1%	1,7%	1,0%
Hyalinea balthica (Schroeter)	0,0%	<1%	8,1%	1,0%	2,0%	5,2%
Lobatula lobatula (Walker & Jacob)	0,0%	0,0%	1,0%	0,0%	1,7%	<1%
Melonis barleeanus (Williamson)	0,0%	0,0%	0,0%	0,0%	1,3%	0,0%
Melonis pompilioides (Fichtel & Moll)	<1%	6,3%	4,4%	1,7%	9,0%	11,7%
Nonionella turgida (Williamson)	4,1%	2,7%	<1%	3,0%	<1%	<1%
Pyrgo inornata (d'Orbigny)	0,0%	<1%	1,0%	0,0%	<1%	2,6%
Pyrgoella sphaera (d'Orbigny)	0,0%	0,0%	2,6%	0,0%	0,0%	<1%
Quinqueloculina padana Perconig	0,0%	0,0%	1,6%	<1%	4,0%	2,9%
Quinqueloculina seminulum (Linnè)	1,6%	3,0%	1,0%	0,0%	0,0%	0,0%
Quinqueloculina viennensis (Le Calvez J. & Y.)	0,0%	1,0%	0,0%	0,0%	2,7%	2,6%
Rectuvigerina phlegeri Le Calvez	<1%	4,0%	0,0%	5,0%	<1%	0,0%
Sigmoilopsis schlumbergeri (Silvestri)	0,0%	0,0%	<1%	0,0%	1,3%	<1%
Spiroloculina excavata (d'Orbigny)	0,0%	0,0%	0,0%	0,0%	0,0%	2,5%
Textularia bocki Hoeglund	3,8%	6,3%	3,9%	<1%	12,3%	3,2%
Textularia sagittula Defrance	1,2%	0,0%	0,0%	0,0%	0,0%	<1%
*Triloculina plicata*Terquem	0,0%	<1%	0,0%	0,0%	2,0%	0,0%
Uvigerina mediterranea Hofker	0,0%	0,0%	0,0%	0,0%	0,0%	1,7%
Uvigerina peregrina Cushman	0,0%	0,0%	<1%	0,0%	<1%	2,2%
Valvulineria bradyana (Fornasini)	53,0%	44,3%	32,1%	43,3%	27,0%	13,7%

Tab. 2 – Results of quantitative analyses. Only species more frequent than 1% at least in one sample are reported.

Risultati dell'analisi quantitativa. Sono riportate solamente le specie la cui frequenza supera l'1% in almeno un campione.

Box-cores and grab samples were treated with Rose Bengal in order to identify living specimens at the moment of sampling. From this large set, six samples, collected from Recent sediments, characterised by typical assemblages very rich (13,7%-53%) in *Valvulineria bradyana* were selected for this study.

All the sample sites are located a few kilometres away from the coast (Fig. 1). Three samples (NK6, NK5, NK4) derived from the top centimetres of three gravity cores, collected along a transect, starting from the river mouth and extending from the coast to the open sea. Two samples (B6I and B6L) were obtained from a shipek-grab, came from another transect, parallel to the former, and located about two kilometres north of it. The last sample consisted of the top part of a gravity core (NK2), collected no more than five kilometres south of the delta axis. Geographic co-ordinates and water depth are given in Table 1. The sediments of all samples consist of silty clay. Like the grab-samples, the top of gravity cores had a volume of about 400cc. The quantitative analyses was carried out on the total assemblage (>125 mm fraction) and about 300 individuals were counted from subsamples obtained by a microsplitter. In Table 2 frequencies of species more abundant than 1% at least in one sample are reported.

In order to estimate benthic productivity, the benthic number (BN) was calculated as the total number of specimens in the fraction >125 μm per gram of dry sediment. Richness of the species was measured by applying the α index of Fisher *et al.* (1943). The α index values were obtained by plotting the number of species against the number of individuals, counted in each sample, on the graph proposed by Murray (1976). To get a more detailed picture of the structure of the assemblages, the unequal distribution of individuals among the species had to be determined. As the richness of species did not give this indication, the index of heterogeneity H (S) is calculated using the Shannon-Weaver formulation . The results are reported in Table 3, where the maximum values of H (S) are between parentheses. These values are attained in a hypothetical assemblage where all the species have equal abundance. Table 3 lists the frequencies of *V. bradyana* in the total assemblage.

In order to evaluate the preferred microhabitat, species of total assemblages were divided in two groups: shallow and deep infauna (Jorissen *et al.*, 1995), considering only the species with frequencies greater than 1% (Tab. 4). In the diagram of Fig. 2, a bar shows the number of individuals belonging to both groups for all samples. The species that generally live in the top two centimetres were attributed to the former group; those living deeper were assigned to the latter group (Buzas *et al.*, 1993). The species were considered to belong to shallow or deep infauna either based on experimental data either on morphogroups subdivision (Corliss, 1985; Corliss & Chen 1988; Corliss, 1991; Jorissen *et al.* 1992; Murray, 1991; Barmawidjaja *et al.*; 1992). Anyway, Linke & Lutze (1993) point out that foraminiferal microhabitats should not be classified according to a static concept, but should be regarded as a dynamic adaptation to optimise food acquisition.

3. DISCUSSION OF DATA

The analyses of the assemblages show high frequencies of *Valvulineria bradyana* (Tab. 3). The highest abundance of the species is observed in samples NK6, NK5 and NK4 located along the transect from the coast to offshore. The three other samples (B6I, B6L, NK2) show lower values. Nevertheless, all the samples have similar assemblages. Generally, only Rotaliidae (*Ammonia inflata*, *A. parkinsoniana*, *A. tepida*) Buliminidae (*Bulimina margi-*

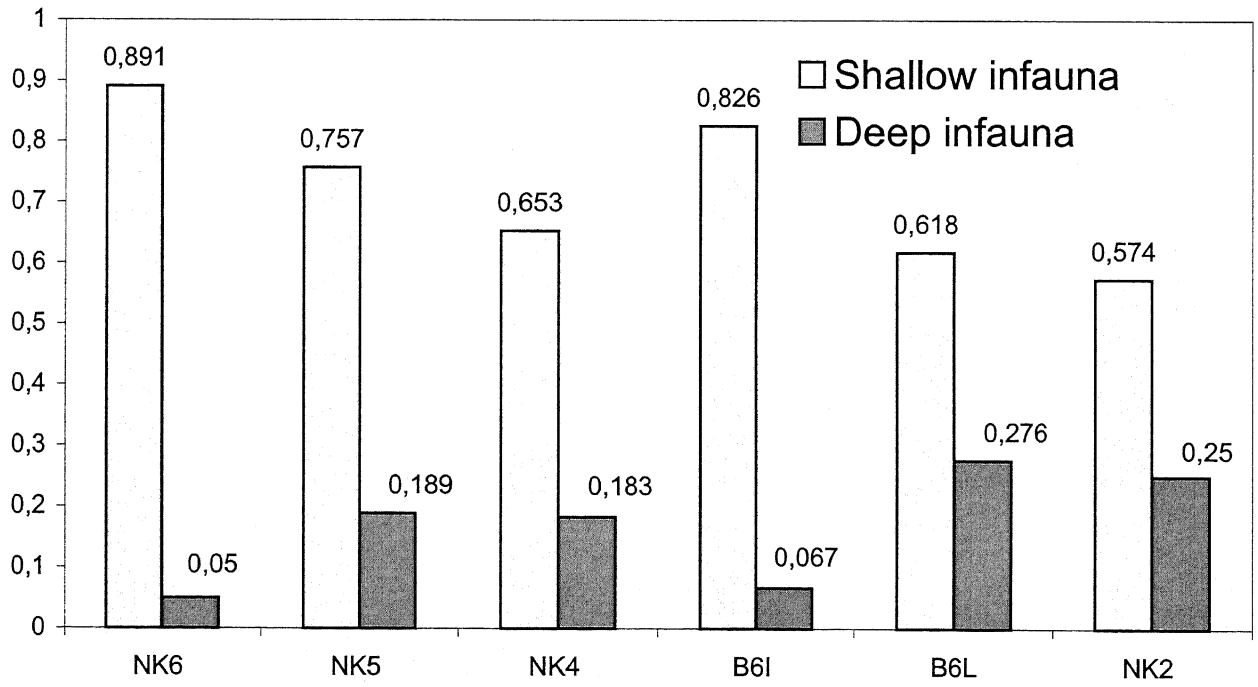

Fig. 2 - Abundance of shallow and deep infauna in the single samples.

Abbondanza di "infauna superficiale" e "infauna profonda" nei singoli campioni

	% *V. bradyana*	BN>125 μm	α index	H(S) ($H(S)_{max}$)
NK6	53.00	5000	4-5	1.818 (2.995)
NK5	44.33	3488	6-7	2.065 (3.295)
NK4	43.33	2239	8-9	2.186 (3.434)
B6I	27.00	1470	15-16	2.792 (3.828)
B6L	32.14	1370	14-15	2.778 (3.713)
NK2	13,70	1402	12-13	3.017 (3.689)

Tab. 3 - Percent abundance of *Valvulineria bradyana*, benthic number (>125 μm), species diversity and heterogeneity in each sample.

Per ogni campione sono riportate abbondanza percentuale di Valvulineria bradyana, *benthic number (>125 μm) ed eterogeneità.*

Shallow infauna (living shallower than 2 cm in the sediment. More abundant than 1% in the assemblage)
Ammonia beccarii (Linnè)
Ammonia inflata (Seguenza)
Ammonia parkinsoniana (d'Orbigny)
Ammonia tepida (Cushman)
*Bulimina marginata*d'Orbigny
Cassidulina neocarinata Thalman
Elphidium translucens Natland
Hyalinea balthica (Schroeter)
Lobatula lobatula (Walker & Jacob)
Nonionella turgida (Williamson)
Pyrgo inornata (d'Orbigny)
Pyrgoella sphaera (d'Orbigny)
Quinqueloculina padana Perconig
Quinqueloculina seminulum (Linnè)
Quinqueloculina viennensis (Le Calvez J. & Y.)
Sigmoilopsis schlumbergeri (Silvestri)
Spiroloculina excavata (d'Orbigny)
*Triloculina plicata*Terquem
Valvulineria bradyana (Fornasini)
Deep infauna (living deeper than 2 cm in the sediment. More abundant than 1% in the assemblage)
Amphicoryna scalaris (Batsch)
Bulimina sublimbata Panizza
Elphidium advenum (Cushman)
Globocassidulina subglobosa (Brady)
Melonis barleeanus (Williamson)
Melonis pompilioides (Fichtel & Moll)
Rectuvigerina phlegeri Le Calvez
Textularia bocki Hoeglund
Textularia sagittula Defrance
Uvigerina mediterranea Hofker
Uvigerina peregrina Cushman

Tab. 4 - List of species more abundant than 1%. Subdivision in "shallow infauna" and "deep infauna" was made following literature data (see text).

Lista delle specie più abbondanti dell'1%.. La suddivisione in "infauna superficiale" e "infauna profonda" è stata effettuata in base a dati di letteratura (vedi testo).

nata) and Nonionidae (*Melonis pompilioides*, *Nonionella turgida*) reach significant frequencies. Among agglutinants, *Textularia bocki* is common whereas, among Cassidulinidae, *Cassidulina neocarinata* and *Globocassidulina subglobosa* are frequent, below about 70 m of water depth.

As regards species diversity (Tab. 3), the samples collected in front of the river mouth (NK5, NK6, NK4) with maximum frequencies of *Valvulineria bradyana* are indicative of a peculiar environment. In effect, their α index values may be considered low for a normal inner shelf environment (Murray, 1991). Generally, poor species diversity reflects ecologically stressed environments (Jorissen, 1987; Van der Zawaan & Jorissen, 1991). This condition is confirmed by the relatively low heterogeneity of the assemblages (H (S)). This datum may be inferred from the comparison between H (S) and H $(S)_{max}$. The gradual increase of species diversity and heterogeneity with increasing distance from the river mouth suggests that fluvial input is the limiting factor for benthic diversity and assemblage heterogeneity. The samples collected north of the delta axis (B6I, B6L) displayed much higher values of α and H (S), in spite of the abundance of *Valvulineria bradyana*, which dominates the assemblages. Similar α values characterise the single sample collected from the southern area (NK2). This sample stands out from the other ones because it shows lower frequencies of *Valvulineria bradyana*, which is associated with *Ammonia inflata* and *Melonis pompilioides*. The abundance of more than one species explain the high heterogeneity of this sample, the farthest from the river mouth.

According to Jorissen (1988), *Ammonia inflata* is an epi-benthic feeder that "prefers increased availability of some particular type of food". In the samples collected along the Latium coast, few living specimens, probably due to low oxygen levels at the bottoms, were found. Among these, *Ammonia inflata*, *Valvulineria bradyana* and *Bulimina marginata* were the most frequent (Bergamin, 1998). Therefore, a certain degree of opportunism may be attributed to this species.

Melonis pompilioides may be regarded as a deep infaunal species, *sensu* Buzas *et al.* (1993) (Murray, 1991), well adapted to nutrient-rich environments. However, it does not seem to tolerate strong ecological stress due to long periods of very low oxygen levels (Sjoerdsma & Van der Zwaan, 1992).

The diagram of Fig. 2 shows that the shallow infauna dominates in all samples, but the minimum segregation of microhabitats is present in the shallow sites. Along both transects, from coast to offshore, the shallow/deep infauna ratio decreases. Moreover, a similar microhabitat selection is present in the two samples (B6L and NK2) that were collected at the same water depth, from opposite sides of the delta axis.

4. CONCLUSIONS

All the parameters investigated in this study appear to be closely correlated and depict two different ecological situations. The three samples collected from the delta axis are characterised by low diversity, low heterogeneity, and very high frequency of *V. bradyana*. The samples collected laterally to the delta axis show higher α index values and heterogeneity, associated with lower abundance of *V. bradyana*. In the first case, ecological stress, which may be

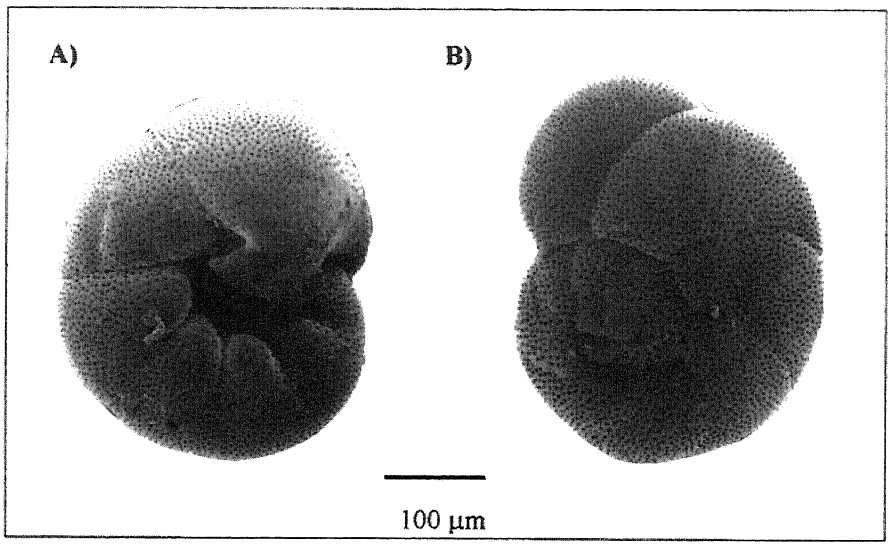

Fig. 3 - *Valvulineria bradyana*. A) Ventral view. A well developed umbilical flap is present. B) Dorsal view.

Valvulineria bradyana. *A) Vista ventrale. È presente un flap ombelicale ben sviluppato. B) Vista dorsale.*

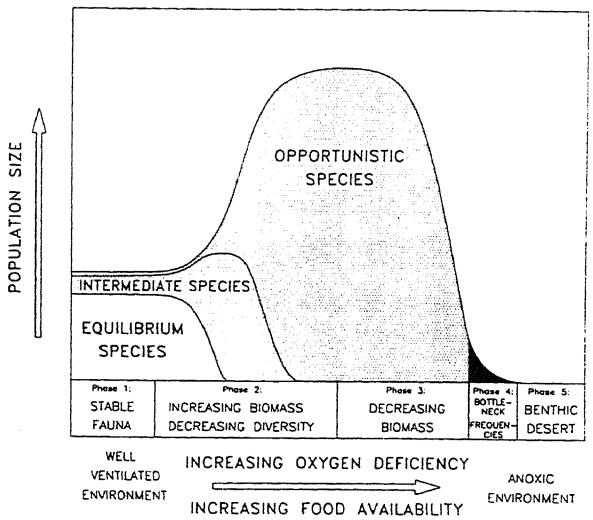

Fig. 4 - Population size and diversity as a function of oxygen and organic matter contents in the benthic environment (after Verhallen, 1991).

Dimensioni della popolazione e diversità in funzione dei contenuti di ossigeno e materia organica in ambiente bentonico (da Verhallen, 1991).

linked to fluvial discharge, is evident. In fact, Jorissen (1987; 1988) found, in the pelitic belt created in the Adriatic Sea by the sediment supply of Po River, benthic foraminiferal communities very similar to those discussed here, as for the structure, as for the species. In the second group of samples, the structure of the communities may be considered normal for areas characterised by high benthic productivity.

After Gooday (1993), opportunistic epifaunal taxa, which profit from the abundance of high quality food, dominate the assemblages in environments characterised by an irregular input of organic matter, like those due to river contribution. No data are available about organic matter in the Ombrone basin, but the extreme abundance of phytodetritus in the studied samples allows us to suppose an eutrophic environment at the bottom.

Environmental instability may be ascribed to the different seasonal position of the critical (for benthic life) oxygen level, inside the sediments. In fact, in periods of scarce circulation, due to the seasonal water stratification (late summer, early autumn), the decomposition of large amounts of organic matter supplied by the river on the sea bottom determines the consumption of oxygen. Consequently, the critical level is pushed upward, towards the sediment/water interface. When it reaches the interface (usually in late summer/autumn), no living fauna is present, as described in the model of Van der Zwaan & Jorissen (1991). This is confirmed by the analyses of the living assemblage in samples collected in early autumn near the Ombrone river mouth, which presented extremely rare Rose Bengal stained specimens (Bergamin, 1998; Carboni *et al.*, 1998).

In such condition of ecological stress, an opportunist species as *V. bradyana* is favoured because it can withstand low oxygen contents thanks to its large umbilical flap (Van der Zwaan & Jorissen, 1991) (Fig. 3). Consequently, it can utilise the available large amount of trophic resources. Moreover, the shallow infaunal microhabitat, inhabited by this species, has the longest period of oxygenation in the year. In fact, following the model of Van der Zwaan & Jorissen (1991), when the critical oxygen level migrates upward (in late summer/autumn), it reaches the superficial sediments last. By contrast, the top centimetres are the first to benefit of good oxygenation when water circulation is re-established (in winter). In this context, probably the sites with the highest shallow/deep infauna ratio, are those in which the critical oxygen level remains near the sediment-water interface for the longest period. These condition are usually more evident near the river mouth, even if oxygen content may be affected by local factors (B6l). Furthermore, the scarce presence of deep infaunal species in the total assemblage might be attributed to the limited penetration in the sediments of this critical oxygen level also in the periods of strongest circulation. A control of microhabitat by the critical oxygen level in eutrophic environment is supposed by the *TROX*-model of Jorissen *et al.* (1995), in which the shallow oxygenated sediment-layer does not permit the existence of deep infauna. All these findings are supported by recent laboratory experiments (Moodley *et al.*, 1998). These experiments demonstrated that, although the migration of foraminifers into the sediments is not directly linked to oxygen gradient, their upward movement might occur as response to absence of oxygen.

Based on the scheme proposed by Verhallen (1991), initially, when trophic resources augment and oxygen content diminishes, population density increases, but diversity

decreases (Fig. 4). Data on the abundance of *V. bradyana* and on benthic productivity (Tab. 3) well identify this situation and consequently permit to attribute to this taxon a clear *r*-selective behaviour.

In conclusion, considerable fluvial supply of organic matter to basins, which are partially enclosed from a geographical viewpoint and characterised (at least seasonally) by limited circulation, may give rise to particular environmental conditions. The Ombrone River delta area is bounded northwards and southwards by the Piombino promotory - Isola d'Elba and Argentario promontory – Isola del Giglio systems, respectively. This may be the main reason why there are strong similarities between the benthic foraminiferal communities of the Ombrone river basin and those of the Adriatic Sea. A benthic foraminiferal community structure, comparable to the one discussed here, is likely to settle in basins with a similar fluvial influence, although it may display different species. This model based on the study of Recent sediments may be utilised for paleoecological reconstruction of fossil environments.

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