geosciences

MDPI

Article

Spatial Distribution of Benthic Foraminifera in the Neretva Channel (Croatia Coast): Faunal Response to Environmental Parameters

Lucilla Capotondi [1,*], Sergio Bonomo [2], Andrea Graiani [1], Michele Innangi [3], Sara Innangi [4], Federico Giglio [5], Mariangela Ravaioli [1] and Luciana Ferraro [4]

1 Istituto di Scienze Marine-Consiglio Nazionale delle Ricerche ISMAR-CNR, Via P. Gobetti 101, 40129 Bologna, Italy
2 Istituto di Geologia Ambientale e Geoingegneria-Consiglio Nazionale delle Ricerche IGAG-CNR, Area della Ricerca di Roma 1, Via Salaria km29,3, 00015 MontelibrettiItaly, Italy
3 Dipartimento di Bioscienze e Territorio, Università degli Studi del Molise, 86090 Pesche, Italy
4 Istituto di Scienze Marine-Consiglio Nazionale delle Ricerche ISMAR-CNR, Calata Porta di Massa, 80133 Naples, Italy
5 Istituto di Scienze Polari-Consiglio Nazionale delle Ricerche ISP-CNR, Via P. Gobetti 101, 40129 Bologna, Italy;
* Correspondence: lucilla.capotondi@bo.ismar.cnr.it; Tel.: +39-051-6398876

Abstract: Benthic foraminiferal assemblages have been studied at 11 sediment surface samples located in the Neretva Channel covering the delta habitat and the adjacent open sea areas. The major objective of the investigation was to explore the main environmental parameters affecting the benthic foraminifera compositional changes. To this end, a statistical approach was applied that integrates micropaleontological data with physical, geochemical and sedimentological parameters (total organic carbon and grain size). Statistical analyses identified four distinct groups (cluster A1, A2, B1, B2) corresponding to different environmental settings. Cluster A1 groups samples under Neretva river influence and is characterized by *Aubignyna perlucida*, *Nonionella turgida*, *Eggerelloides scaber* and *Rectuvigerina* sp.; species able to live in organic-matter-rich sediments and in a wide range of oxygen content. Cluster A2 includes samples distant from the fluvial outlet and samples along the NW coast partially influenced by the Neretva river plume. In these environmental conditions, *Ammonia beccarii*, *Bulimina marginata*, *Nonionella turgida* and *Textularia* sp. resulted as the most characteristic taxa. Cluster B1 distinguishes the deepest stations which are in connection with the open Adriatic Sea. Here *Asterigerinata mamilla*, *Buccella granulata*, *Cibicides* group, *Reussella spinulosa* and *Textularia* sp. reach their maximum abundance associated with coarse-grained sediments. Cluster B2 groups samples collected in the inner bay of the southernmost sector of the studied area characterized by silt and clay and a negligible influence by river inputs. The benthic microfauna is principally composed of Miliolids, *Porosononion granosum* and *Textularia* sp.

Keywords: benthic foraminifera; Neretva Channel; organic matter; water depth; riverine influx

Citation: Capotondi, L.; Bonomo, S.; Graiani, A.; Innangi, M.; Innangi, S.; Giglio, F.; Ravaioli, M.; Ferraro, L. Spatial Distribution of Benthic Foraminifera in the Neretva Channel (Croatia Coast): Faunal Response to Environmental Parameters. *Geosciences* **2022**, *12*, 456. https://doi.org/10.3390/geosciences12120456

Academic Editors: Francesco Sciuto, Salvatore Distefano, Angela Baldanza and Jesus Martinez-Frias

Received: 28 October 2022
Accepted: 14 December 2022
Published: 17 December 2022

1. Introduction

Benthic foraminifera (unicellular protists) have been widely used to reconstruct paleoenvironmental changes since they are very sensitive to ambient conditions including organic matter fluxes, oxygen content, salinity, type of substrate and others [1–6]. Moreover, foraminiferal assemblages are influenced by their immediate environment and have often served as modern and past analogues to characterize paleoenvironments [7–9]. Therefore, documenting and understanding the regional distribution and ecological response of foraminifera is of pivotal importance. The majority of surveys on the current distribution of benthic foraminifera have been carried out in the western part of the

Adriatic Sea [10–19], whereas less is known about their presence on the eastern coast [20–26]. Here we report for the first time the distribution patterns of benthic foraminifera in the Neretva Channel, a semi-enclosed basin located along the southernmost part of the Croatian coast. The Neretva river is the fifth largest Mediterranean river, ranked by annual water discharge [27]. The river mouth and its adjacent semi-enclosed marine environment provide a good example of land–sea interactions, particularly between sediment type and organic matter content in a microtidal, low-wave energy, and river-dominated coastal sedimentary system [28]. While the sediment dynamics and geochemistry were examined [28–30], no investigation of the microfauna was performed. The aims of this study are: (1) to examine the quantitative distribution of the benthic foraminifera taxa in the Neretva Channel and (2) to identify the main factors affecting the spatial compositional changes of the foraminiferal assemblages. This kind of study adds information on benthic foraminiferal ecological preferences useful for a better reconstruction of past environmental conditions.

2. Study Area

The Neretva Channel is bounded to the NE by the Croatian coastline, to the NW by the open Adriatic Sea through the Korcula Channel, and to the SW by the Peljesac Peninsula (Figure 1). The hydrological setting is influenced by the intrusion of the highly saline oligotrophic waters from the open Adriatic Sea [31] and by the freshwater discharge from the Neretva River [28,32,33]. The Neretva is the largest river on the Croatian part of the eastern Adriatic coast, and the only one forming a deltaic system [34]. The Neretva Channel is a microtidal low-wave energy environment characterized by river-dominated sedimentation processes [30,35].

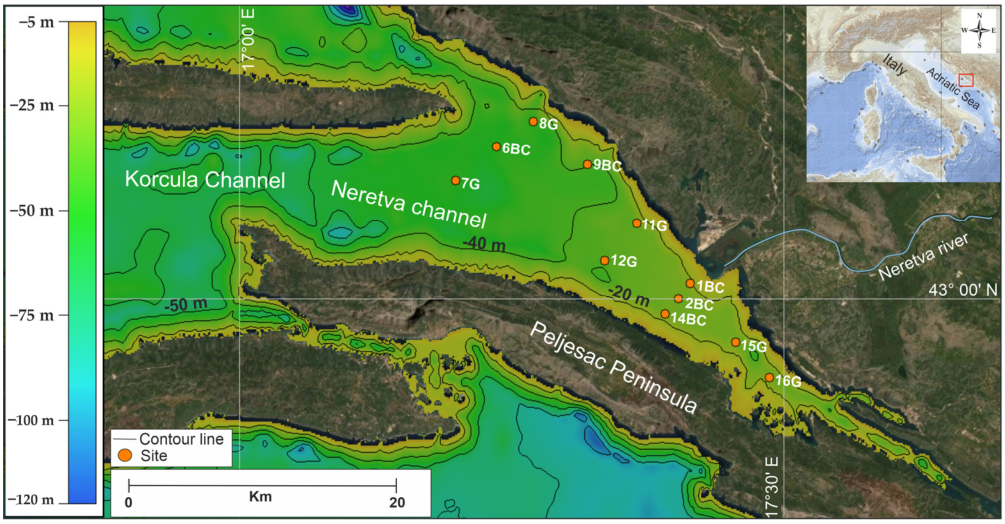

Figure 1. Map of the study area with the locations of the 11 investigated samples (orange circles). Shaded relief image derived from bathymetric data with sun illumination from NW, 45° over the horizon and no vertical exaggeration. Elevation and bathymetry data from EMODnet gridded data (www.emodnet.eu/bathymetry, accessed on 13 October 2022). Bathymetry contour interval is 20 m. Red box in the inset indicates the study area.

The surface sediment is composed mainly of clayey silt, in particular in the area in front of the river delta and in the northeast part of the channel. Sedimentation is uniform in most of the area; this is because the river creates a hypopycnal plume at the mouth that distributes fine-grained particles over the entire channel [23,29]. However, two coarser-grains depositional zones with different natures are observed [28]. In detail, in the north-western part of the channel, the sediment is composed mainly of sand, probably related to the influence of higher energy currents from the Adriatic Sea that remove the finer part of the sediments [28]. The southernmost part of the southeastern sector of the channel is instead characterized by relict sandy-silt sediment as this zone only receives river sediment sporadically during events of strong hydro-dynamism in the channel [28,30,36].

The mineral composition of sediments is quartz, calcite and clay, with a secondary presence of plagioclase and dolomite [30]. Marine sediment compositions are mainly controlled by the local geology, but can also reflect anthropogenic discharges from industrial and urban activities, thus increasing concentrations of trace metals and organic matter [37]. Most of the mainland coast is built of highly permeable limestone without a natural barrier between the groundwater of the karstic fields in the hinterland and the freshwater submarine springs [38]. Higher discharge of the submarine springs in winter causes a spreading of the less saline surface waters into the Neretva Channel and a compensatory inflow in the bottom layer. The strong NE "Bora" wind can, however, reverse that circulation. During the summer, the circulation pattern depends entirely on the wind direction [39].

3. Materials and Methods

Sediment samples were collected in 2006 during the NERES06 cruise on board R/V Bios DVA along three parallel NW–SE transects [28] (Figure 1; Table 1) in the frame of the Project ADRICOSM_NERES: ADRIatic sea integrated COastal areaS and river basin Management system—Environmental Regeneration and Sustainable Development of the delta of the NEretva river.

Table 1. List of the 11 sites considered in this study with geographical coordinates and water depth.

Site	Latitude	Longitude	Water Depth (m)
1 BC	43°00.702′	17°25.080′	24
2 BC	43°00.017′	17°23.998′	29
6 BC	43°05.946′	17°14.193′	47
7 G	43°04.629′	17°11.948′	51
8 G	43°07.120′	17°16.524′	46
9 BC	43°04.878′	17°19.591′	39
11 G	43°02.939′	17°21.937′	32
12 G	43°01.496′	17°22.343′	34
14 BC	43°08.256′	17°22.343′	29
15 G	42°58.147′	17°27.579′	24
16 G	42°56.645′	17°29.626′	26

Here we report micropaleontological results of benthic foraminifera from the upper 0–2 cm surface sediment layer collected in 11 sites using Van Veen grab (G) and box-corer (BC) samplers (Table 1). In detail, small cores (about 30 cm long and 8 cm in diameter) were collected by subsampling the central part of the grab samples, which was assumed as relatively undisturbed.

3.1. Environmental Parameters

The environmental parameters used in this study are from the dataset provided and described in [28]. Here we consider sedimentological (percentage of clay/silt/sand) and geochemical (TOC, C/N) data performed on the same samples analysed for micropaleontological investigation (surface levels 0–2 cm).

3.2. Benthic Foraminiferal Analysis

In this study, we considered the total benthic foraminiferal assemblages (living and dead specimens). The total assemblage represents a more reliable picture of the population as it integrates many multiple generations (seasonal variation) of foraminifera [40,41]. Consequently, the considered foraminiferal content (living and dead specimens) corresponds to average environmental conditions throughout the deposition of the collected sediment layer (0–2 cm).

For foraminiferal investigation, samples were washed over a 63 μm sieve then oven-dried at 50 °C and weighed. Identification and counting analysis were performed under a Leica MZ 8 stereomicroscope on the sediment fraction > 125μm. We considered all specimens present in the whole sample or in representative aliquots using an Otto microsplitter, containing at least 300 specimens. Taxonomy identification of foraminifera was based mainly on systematic studies from Adriatic and extra-Mediterranean areas [42–44]. Online World Modern Foraminifera Database [45,46] was also consulted.

Less abundant species with similar ecological characteristics were merged together into major species groups. *Adelosina mediterranensis* and *Adelosina* sp. were merged into the *Adeloisina* group. Both species are indicative of shallow marine environments (e.g., [47]). Other porcelaneous taxa were grouped in Miliolids (*Miliolinella*, *Pyrgo*, *Quinqueloculina*, *Spiroloculina* and *Triloculina* genera).

Although phylogenetically distinct species, *Lobatula lobatula* (i.e., *Cibicies lobatulus*, [48]), and *Cibicides refulgens* are often grouped together in environmental studies due to their notable morphological similarity and intermediate forms between the two species [49]. They are both typical taxa of the infralittoral environment with strong near-bottom currents [50–53]. Here they are referred to as the *Cibicides* group.

Identified *Elphidium* specimens were divided into two groups based on different life strategies (having a keel or not, being infaunal or epifaunal, according to [24,26,54,55]). Keeled elphidiids species are here represented by *Elphidium crispum* and *Elphidium macellum*. They are known as typical epiphyte shallow marine taxa [54,56,57]. Unkeeled elphidiids species in our data set include only *Porosononion granosum*, an infaunal organism, abundant in marginal-marine environments that tolerates wide salinity changes (euryhaline) [54,58].

The data are reported in the percentage of specimens on the total assemblage (relative abundance %) and the number of specimens per gram of dry bulk sediment for each of the examined samples (BFN) (Supplementary Table S1). Foraminiferal biodiversity was estimated using different diversity indices: Shannon (H) (that varies from 0 for communities with only a single taxon to high values for communities with many taxa, each with comparable abundance); Dominance (D) evidences the occurrence of the opportunistic taxa (it ranges from 0, all taxa are equally present, to 1 one taxon dominates the community completely), and Simpson’s Index of Diversity (1-D) (the value of this index also ranges between 0 and 1, the greater the value, the greater the sample diversity. The index represents the probability that two individuals randomly selected from a sample will belong to different species).

All indices were calculated using the PAlaeontological STatistics (PAST) package [59,60].

3.3. Statistical Analyses

Statistical analyses include all taxa with relative abundance > 3% in at least one sample (total 23 taxa/groups) in order to reduce background noise due to the infrequent taxa.

As physical and chemical variables TOC, grain size and water depth were considered.

The foraminiferal assemblage was analysed by means of a cluster analysis based on Ward’s criterion [61]. In order to investigate patterns of covariance between the foraminiferal data and the chemical and physical variables, we performed a two-block partial least squares analysis (2B-PLS). This statistical technique is suitable for studying matrices with a relatively low sample size and highly correlated variables [62]. Recently it was successfully applied to examine relationships between benthic foraminiferal communities and seafloor morphology in the southern Mediterranean area [63]. The two-block PLS method differs from other established multivariate statistics (e.g., Canonical Correlation Analysis) in that it aims to find latent variables that can explain the covariance between two multivariate matrices, returning variables that explain the covariance between two sets of variables as much as possible [64]. All analyses were performed in R 4.2.0 (R Core Team 2022- Foundation for Statistical Computing, Vienna, Austria)

4. Results

4.1. Environmental Data

Sediment grain size analyses indicated that the Neretva Channel deposits are generally composed of clayey silts with a silty dominant fraction and a low fraction of sand (Figure 2). In particular, the percentage of clay is overall high in the entire channel, with a minimum of 52.30% in site 7 G and a maximum of 69.90% in site 8 G. In the upper 2 cm surface sediment, the coarser materials were found in the southernmost zone (sand 31% in site 15 G) and in the north-western sector of the channel (sand 51% and 39% at sites 7 G and 6 BC, respectively; Figure 3; [28]). As a consequence, the silt fraction was the lowest in the 7 G and 6 BC sites (3.02% and 4.24%, respectively).

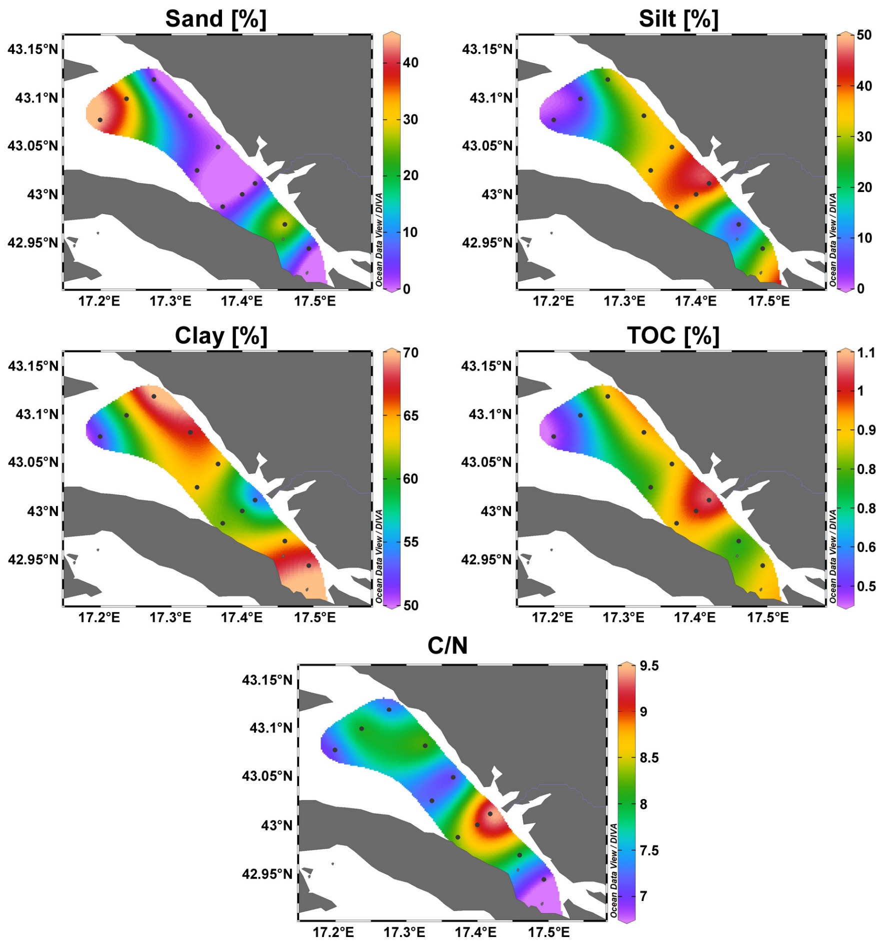

Figure 2. Geochemical and sedimentological composition of surface sediments (grain size, TOC, and C/N). Black dots correspond to study sites; gray and white colors indicate land and sea ares respectively. Modified from [28].

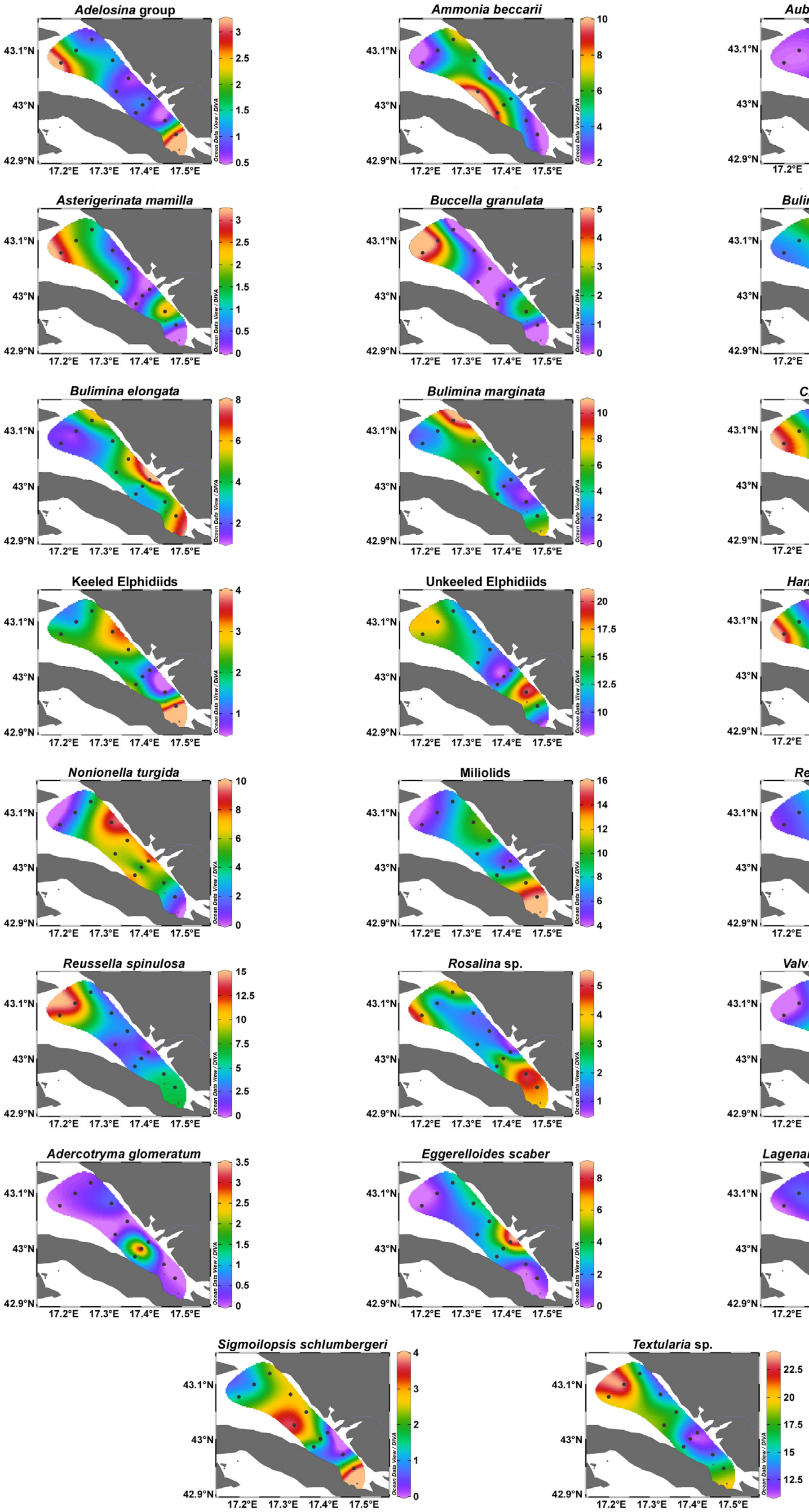

Figure 3. Relative abundance (percentage) and spatial distribution of the most representative species as reported in Table 2. Black dots correspond to study sites; gray and white colors indicate land and sea areas respectively.

Table 2. Relative percentages of the most common species (>3% in at least one sample) identified in the surface sediment layer (0–2 cm).

Sample	**1 BC**	**2 BC**	**6 BC**	**7 G**	**8 G**	**9 BC**	**11 G**	**12 G**	**14 BC**	**15 G**	**16 G**
Adelosina group	0.91	1.15	1.42	3.24	0.95	1.32	0.57	0.81	0.89	0.55	3.08
Ammonia beccarii	4.97	5.95	2.84	2.23	6.64	5.38	3.41	9.80	8.93	3.02	2.20
Aubignyna perlucida	3.66	5.18			0.19	0.45	2.70	1.84	3.87	1.78	1.76
Asterigerinata mamilla		0.19	1.83	3.04	1.33	0.45	0.43	1.43		2.47	0.44
Buccella granulata	0.39	0.77	4.67	4.86		0.34				2.61	
Bulimina basispinosa	2.09	1.34	2.84	2.23	4.17	3.81	6.83	3.06	1.79	1.65	1.76
Bulimina elongata	7.85	2.88	1.42	1.72	5.12	3.36	5.69	4.08	3.27	3.57	6.17
Bulimina marginata	2.36	1.20	2.84	2.53	10.25	6.05	3.70	6.33	4.17	0.55	4.41
Cibicides group	0.65	1.54	4.67	7.09	1.90	2.58	1.28	2.04	3.57	1.92	2.20
Hanzawaia boueana	0.13	0.19	1.42	3.75	0.19	0.34				2.61	
Keeled elphidiids species	1.04	1.15	1.42	2.23	2.09	3.25	2.84	1.84	2.38	0.55	3.96
Nonionella turgida	7.85	4.03	1.62	0.71	3.80	9.19	6.83	6.12	7.44	4.66	1.76
Miliolids	4.70	6.13	5.08	4.55	7.03	10.21	9.66	7.55	8.64	12.07	15.85
Rectuvigerina sp.	8.77	6.91	1.62	0.71	2.85	3.59	3.41	2.65	3.57	4.12	2.64
Reussella spinulosa	0.65	3.65	14.40	11.65	4.93	3.36	3.56	1.63	3.27	5.76	6.17
Rosalina sp.	0.92	3.84	1.42	4.36	3.61	1.46	1.42	1.84	2.08	5.08	4.41
Unkeeled elphidiids species	9.55	8.06	17.04	15.91	12.52	11.66	11.1	12.04	10.42	20.58	13.22
Valvulineria bradyana	7.33	8.06			2.09	3.59	7.40	7.76	5.65	1.92	1.76
Adercotryma glomeratum	0.39	3.45	0.20		0.19	0.56			1.19		
Eggerelloides scaber	8.64	3.07	0.20	0.10	2.66	3.25	2.99	2.24	2.98	0.41	0.44
Lagenammina difflugiformis	6.41	6.53	1.22	0.10	0.76	1.91	1.28	0.61	2.98	1.78	0.44
Sigmoilopsis schlumbergeri	0.39	2.30	1.01	1.42	2.28	2.69	2.70	3.67	1.19	0.27	3.52
Textularia sp.	11.78	11.13	23.73	20.36	15.75	14.01	16.64	17.96	15.48	13.31	17.18

Surficial Total Organic Carbon (TOC) (Figure 2) varies from 0.6% (6 BC) to 1.06% (1 BC). The maximum values of TOC are detected in samples in the sites close to the river mouth (1 BC and 2 BC) (Figure 2). The C/N ratios range from 6.81% (16 G) to 9.6 (1 BC) (Figure 2; [28]). Samples closer to the river mouth display significantly higher C/N ratios (Figure 2) indicative of a terrestrial signature due to the fluvial input [28].

4.2. Benthic Foraminifera

A total of 50 taxa were identified in the surface samples, including 4 groups (*Adelosina*, *Cibicides*, keeled and unkeeled elphidiis) and generic Miliolids (Table S1). The recorded individuals were predominantly calcareous forms (mainly *Ammonia beccarii*, *Bulimina marginata*, *Bulimina elongata*, *Porosononion granosum*, *Nonionella turgida* and *Valvulineria bradyana*) and agglutinated forms (e.g., *Eggerelloides scaber*, *Lagenammina difflugiformis* and *Textularia* sp.).

Regarding microhabitat, the most predominant were infaunal species, [4,14,65–67] such as *Ammonia beccarii*, *Bulimina basispinosa*, *Bulimina elongata*, *Bulimina marginata*, *Nonionella turgida*, *Reussella spinulosa*, *Eggerelloides scaber* and *Textularia* sp. Less abundant species were epifaunal taxa belonging to the keeled elphidiids and *Quinqueloculina* genera [47,54]. Miliolids ranged largely in the studied samples, from 4.55% (7 G) to 15.85% (16 G). The relative abundance of the common species (>3% in at least one sample) were listed in Table 2 and their spatial distribution is shown in Figure 3. These species were selected for statistical analyses.

Diversity indexes for the different assemblages are reported in Table 3 and Figure 4. On average, 43 taxa were identified per sample, ranging from a minimum of 35 (12 G) to a maximum of 50 taxa off the Neretva river mouth (1 BC, 2 BC). The number of specimens per gram of dry sediment mass (BFN) was largely variable, ranging from a minimum of 33 (12 G) to a maximum of 663 specimens (6 BC).

Table 3. Diversity indexes for the foraminifera assemblages in the different samples: number of Taxa, number of specimens/gr sediment (BFN), Shannon–Wiener entropy index (H), Dominance (D) and Simpson's Index of Diversity (1-D).

Sample	Taxa	BFN	Shannon_H	Dominance_D	Simpson_1-D
1 BC	50	38	3.06	0.07	0.93
2 BC	50	38	3.29	0.05	0.95
6 BC	41	663	2.77	0.11	0.89
7 G	42	394	2.87	0.10	0.90
8 G	41	67	3.06	0.07	0.93
9 BC	50	76	3.19	0.06	0.94
11 G	44	45	3.06	0.07	0.93
12 G	35	33	2.94	0.08	0.92
14 BC	38	29	3.07	0.07	0.93
15 G	44	199	3.03	0.08	0.92
16 G	37	54	3.06	0.07	0.93

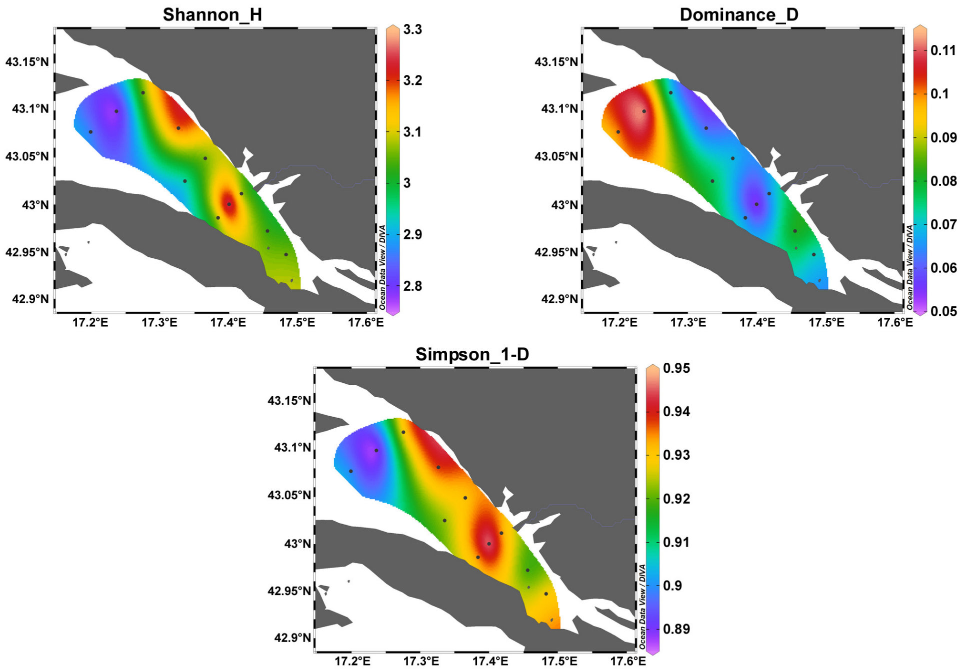

Figure 4. Ecological indices describing the foraminiferal assemblages from the top 2 cm of sediment in the investigated sites (black dots). Gray and white colors indicate land and sea areas respectively

Benthic foraminiferal assemblages are characterized by the Shannon (H) index ranging between 2.77 in 6 BC and 3.29 in 2 BC, with a median of 3.03; Dominance (D) varied between 0.05 in 2 BC and 0.11 in 6 BC, with a median of 0.07; finally, the Simpson index (S) is not significantly different in the investigated area with comparable values throughout the samples, the extremes found in samples 6 BC and 2 BC (0.89–0.95, respectively) have a median of 0.92.

The cluster analysis on foraminiferal fauna enabled the distinction of two major groups of samples (A and B). Both of them can be subdivided into two more (A1, A2; and B1, B2) (Figure 5).

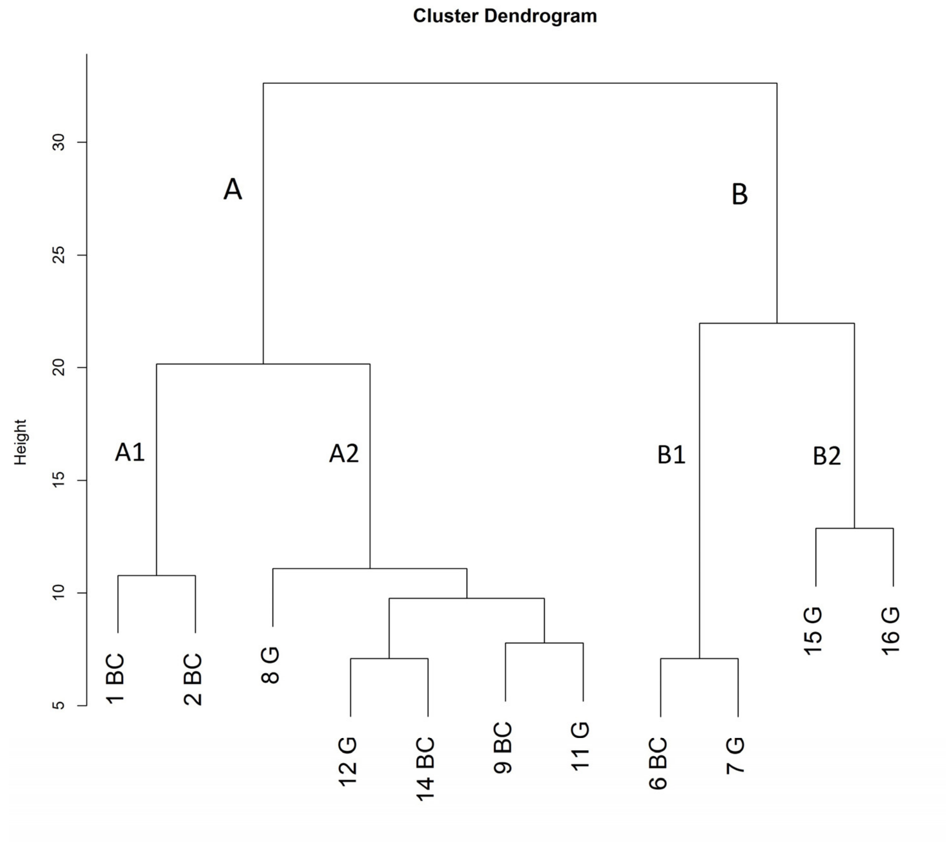

Figure 5. Cluster analysis based on non-standardized relative percentage data of foraminifera > 3% at least on the sample. The dendrogram evidences two major groups (A and B). Both can be subdivided into two additional (cluster A1, A2, B1, B2) representing similarities in the faunistic content of the investigated samples (x axis).

Cluster A1 comprises two box-corer samples (1 BC and 2 BC) sited in front of the Neretva river mouth. In these assemblages, the most common species are *P. granosum* (8.06–9.55%), *V. bradyana* (7.33–8.06%), *Rectuvigerina* sp. (6.91–8.77%), *N. turgida* (4.03–7.85%), *A. beccarii* (4.97–5.95%), *A. perlucida* (3.66–5.18%) and the agglutinants taxa *Textularia* sp. (11.13–11.78%) and *E. scaber* (3.07–8.64%). Abundance ranged from 29 to 38 individuals, H ranged from 3.06 to 3.29, D ranged from 0.05 to 0.07, and S from 0.93 to 0.95.

Cluster A2 includes samples 8 G, 9 BC, 11 G, 12 G and 14 G located along the northern part of the Croatian coastline and in the central sector of the Neretva channel. The benthic assemblages are mainly defined by the presence of *Textularia* sp. (14.01–17.96%), *P. granosum* (11.1–12.5%), Miliolids (7.03–9.66%), *A. beccarii* (5.38–9.80%), *N. turgida* (3.80–9.19%), *B. marginata* (3.70–10.25%), *B. elongata* (3.27–5.12%) and *V. bradyana* (2.09–7.76%). Abundance ranged from 33 to 76 individuals, H ranged from 2.93 to 3.19, D ranged from 0.06 to 0.08, and S from 0.93 to 0.94.

Cluster B1 groups the two deeper samples (6 BC and 7 G), located in the north-western sector, principally represented by *Textularia* sp. (20.36–23.73%), *P. granosum,* (15.9–17%), *R. spinulosa* (11.65–14.40%), *Cibicides* group (4.67–7.09%) and *B. granulata*

(4.67–4.86%). Abundance ranged from 394 to 663 BFN, H ranged from 2.77 to 2.86, D ranged from 0.09 to 0.11, and S from 0.89 to 0.90.

Cluster B2 gathers two grab samples (15 G and 16 G) both located in the southeastern sector of the study area. It was mostly characterized by *Textularia* sp. (13.31–17.18%), *P. granosum* (13.2–20.6%), and *R. spinulosa* (5.76–6.17%). On the whole, in this cluster Miliolids are generally abundant (12.7–15.85%) and are represented by the *Miliolinella subrotunda* (3.52–6.31%). Abundance ranged from 54 to 199 individuals, H ranged from 3.03 to 3.06, D ranged from 0.07 to 0.08, and S from 0.92 to 0.93.

4.3. Two-Block Partial Least Squares

The results from the first axis of the 2B-PLS analysis are reported in Figure 6. The R2 for Block 1 (i.e., *x*-axis of the plot, Foraminifera Community) and Block 2 (i.e., *y*-axis of the plot, Chemical and Physical Variables) were 0.43 and 0.63, respectively. The analysis showed a gradient from the lower left quadrant to the upper right quadrant of the graph, with no notable outliers. Most samples are found in the lower left quadrant, where the most extreme points are represented by samples 1 BC and 2 BC located in front of the Neretva river. The variables most correlated with these observations (considering the covariance between the matrices) are certain taxa of the foraminifera community (led by *V. bradyana*, *E. scaber*, *Rectuvigerina* sp. and *N. turgida*) and chemical–physical variables such as silt content and total organic carbon (TOC%). On the contrary, in the upper right quadrant, only two samples (6 BC and 7 G) are found, which not only occur at greater depths and with a higher sand content, but also showed a different foraminiferal community, led by a different group of taxa (mostly *R. spinulosa*, *B. granulata*, and *Asterigerinata mamilla*). Some taxa (such as *Bulimina* sp., Miliolids, and *Sigmoilopsis schlumbergeri*) contribute little to the covariance, as do physico-chemical variables such as sand content.

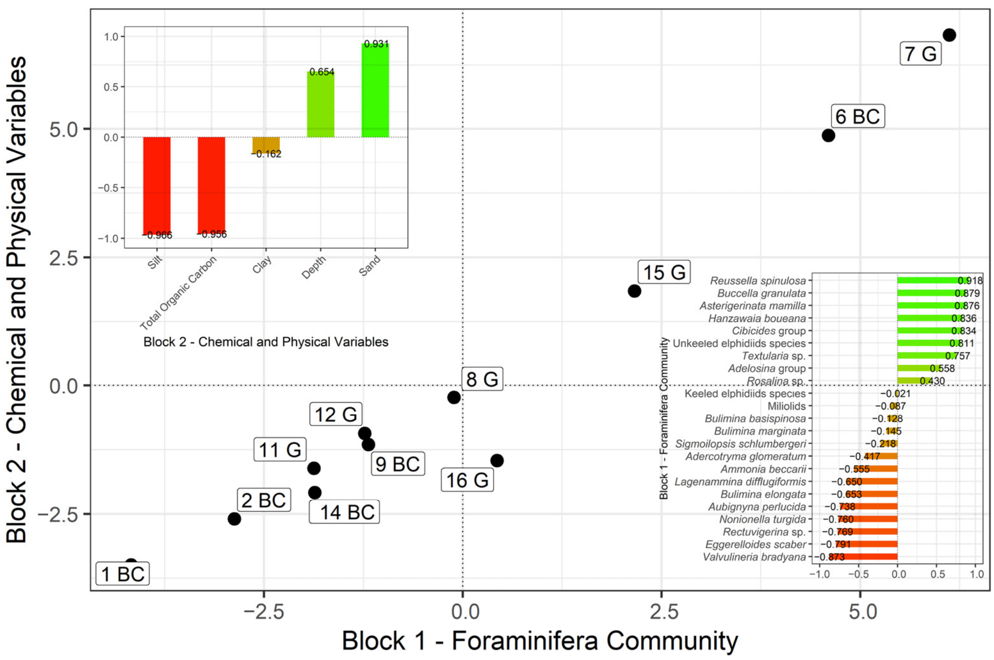

Figure 6. Scatterplot of the first axis of 2B-PLS between foraminiferal community (Block 1) and chemical and physical variables (Block 2); inserts show the correlation within and between blocks.

5. Discussion

In the investigated area, the benthic foraminifera distribution results primarily correlated with three main factors: sediment grain size, total organic carbon and water depth. (Figure 6). This is in agreement with studies performed in tanatocenosis from the

North Adriatic river-influenced shelf [14,19]. Both cluster analysis and 2B-PLS discriminate two distinct faunal groups with two additional sub-groups reflecting different depositional settings (clusters A1, A2, B1, B2).

Foraminiferal assemblages in samples collected in proximity to Neretva river (cluster A1) result primarily controlled by organic carbon content and by fine-grained substrate (silt). The benthic foraminiferal microfauna is characterized by the presence of shallow infaunal taxa (*V. bradyana*, *N. turgida* and *B. elongata*), commonly regarded as eutrophic species feeding on the low-quality organic matter [4,14,65–67]. The detected abundance of these taxa was favoured by the nutrient availability linked to the Neretva river discharge. In particular, the high relative presence of *V. bradyana* (Figure 3) was already documented as associated with high organic carbon content in the Rone prodelta [68], in front of the Ombrone River mouth (Italy) [69] and the Po delta [70]. *N. turgida* (Figure 3), an opportunistic and stress-tolerant species, is able to live in hypoxic sediments enriched in low-quality organic matter [16,70]. Similarly, *B. elongata* (Figure 3) is reported to thrive in shallow marine, silty to sandy substrates under the riverine influence [15,69–71].

In addition, *A. beccarii* and *A. perlucida* show relevant importance in this cluster (Figure 3). *A. beccarii* is well known to colonize environments under river influence, widely distributed in intertidal and subtidal zones [72]; it survives under a wide range of values of dissolved oxygen [73], salinity, and temperature [74]. In the Adriatic Sea, *A. beccarii* inhabits shallow and nutrient-rich environments near the coast under the direct influence of the Po River [17]. *A. perlucida* is an infaunal species tolerant of stressed environments [13], related to low salinity and shallow water settings [75]. Van der Zwaan and Jorissen [65] report that this species is typical of northern Adriatic clayey sediments where nutrient inputs by the rivers lead to periodic oxygen depletion events.

In the same way, the distribution pattern of the euryhaline taxa as *E. scaber* can be correlated to the Neretva freshwater input [76,77], decreasing with distance from the shore (Figure 3). The detected high abundance of *E. scaber* was documented in shallow, highly energetic, and organic-matter-rich environments [54,78]. Additionally, the abundance values of the agglutinated *L. difflugiformis* (mostly in samples 1 BC and 2 BC; Figure 3) are in agreement with fine-grained sediment enriched in organic matter [79]. The decrease in percentages of *Rectuvigerina* sp. from sample 1 BC to 2 BC (Figure 3) well correlates with the decrease in organic carbon supply moving offshore (Figure 2). This trend is in agreement with available studies showing that *Rectuvigerina* is a typical shallow continental shelf genus [80–82], generally living in sandy to muddy shelf environments with relatively high organic matter content [83,84]. It was also recorded in different oxic environments [77,85]. We do not have available data on oxygen content, however, the described assemblages suggest periodical oxygen deficiency. Within these areas, oxygen deficiency can be developed in response to the high organic matter concentrations [65].

The foraminiferal assemblage in samples collected in the central part and in the north-western direction along the Croatian coastline (cluster A2) is mainly composed of species characteristic to the infra-circalittoral zones of the Mediterranean and northern Adriatic seas [12,14,20,21,25,43,55,86,87]. Here, the significant presence of eutrophic taxa such as *N. turgida*, *V. bradyana* and *Bulimina*, associated with the percentages of *A. beccarii* (Figure 3) still reflect the riverine influx in the form of organic matter and sediment inputs, but to a much lesser degree than observed in sub-cluster A1. It results that foraminiferal distribution is affected by the position of the Neretva river plume that spreads along the coast in a NW direction during most of the year, decreasing its influx northward [28].

The data indicate that the principal factor influencing microfauna distribution, (group A) is the organic matter content from the fluvial input. In detail, the differences observed on clusters A1 and A2 are well correlated with the amount and the type of organic matter. Sediments of samples BC 1 and BC 2 (cluster A1) close to the river mouth are characterized by large amounts of terrestrial organic carbon with a clear terrestrial signature [28] whereas sediments at an intermediate distance from the river (cluster A2) contain lower contents of organic carbon showing the transition between terrestrial and marine origins [28].

Water depth and coarse-grained substratum (sand) are identified as the main drivers influencing the foraminiferal content in the northern sector (cluster B1), with open marine water entering the gulf. In this area, the lithology is mainly composed of sand due to the influence of higher energy currents from the Adriatic Sea that remove the finest part of the sediment [28]. Here *R. spinulosa*, *Textularia* sp. and *B. granulata* reach their maximum abundance (Figure 3). These species characterize sandy/muddy substrates along shelf edges subject to bottom currents [88] with slight tolerance of variable salinities [50,74]. Additionally, in the area we detect *A. mamilla* commonly related to high hydrodynamic energy levels with coarse-grained sediments [46,86]. The relatively deeper water and hydrodynamic conditions favoured also the presence of the *Cibicides* group (Figure 3) which is known to be associated with well-oxygenated environments with stable physico-chemical sea bottom conditions [50–53]. Cluster B1 hosts the highest number of species (Table 3), confirming favourable environmental conditions at the sea floor, and allowing the development of diversified benthic foraminiferal communities.

Cluster B2 is located in the southern sector south of the river mouth. This sector is an area where wave-generated longshore currents laterally redistribute the sediments, leading to the presence of relict deposits [28,30]. The relatively low amount of *A. beccarii* (Figure 3) and C/N values (Figure 2) correlate with the sediment grain size in this sector where the river influence is minimal. In this cluster, the higher percentages of Miliolids (Figure 3) may be explained by the shallow depth with low organic matter content at the sea bottom as similarly observed in other Mediterranean shallow marine settings [4,47]. The abundance of *M. subrotunda* supports available records documenting this species in an inner-shallow gulf environment with possible confined conditions [47]. The detected relatively high percentages of *P. granosum,* unkeeled elphidiis species, suggest the preference of this taxon for the coarse sediment and wide salinity change in agreement with observation performed in shallow water depth (8–22 m) around the Po delta area [19,67]. In the literature, this species is found in brackish-hypersaline bays, marshes, coastal lagoons, estuaries, and inner shelves [7,56–58,74]. In our dataset, the relatively low percentages of *P. granosum* observed in samples 1 BC and 2 BC suggest that this species does not correlate with high organic matter content. This agrees with [89] that considers *P. granosum* a third-order opportunist, increasing its abundance as a response to higher organic matter supply, but disappearing with maximum organic matter enrichment [89].

6. Conclusions

Modern benthic foraminiferal assemblages were investigated in the Neretva Channel to evidence their relationships with the environmental factors characterizing this area. Statistical analysis and an integrative partial least square approach (2B-PLS) highlighted that the diversity and distribution of benthic foraminifera studied in 11 sample sites are principally correlated with substrate grain size, organic matter content, and water depth.

The data showed that samples collected in front of the Neretva delta contain opportunistic species, well adapted to high input of organic matter and silt content such as *A. perlucida*, *E. scaber, N. turgida* and *Rectuvigerina* sp. (cluster A1). The areal foraminiferal species distribution indicates that the influence of the river discharge is a function of distance from the shore. At the samples furthest away from the river mouth, the assemblages were characterized by *A. beccarii*, *B. marginata*, *N. turgida* and *Textularia* sp. (cluster A2). These species living there seem to profit from the combination of a more labile organic matter with a transition between terrestrial and marine signatures.

In the north-west sector, thus in connection with the open Adriatic Sea, the coarse (sand) sediment samples include a highly diversified foraminiferal assemblage with the presence of *A. mamilla*, *B. granulata*, *Cibicides* group, *R. spinulosa*, and *Textularia* sp. (cluster B1) typical of well-oxygenated and hydrodynamic environments.

On the other hand, in the inner bay, in the south of the studied area, the samples are mainly composed of *P. granosum* and Miliolids reflecting the inner-shallow gulf with more confined environmental conditions (cluster B2).

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/geosciences12120456/s1, Table S1: Number of specimens per gram of dry sediment mass (BFN) and relative percentage of specimens (%) for each investigated sample.

Author Contributions: Conceptualization and supervision, L.C.; writing—original draft preparation, L.C. and L.F.; quantitative micropaleontological analyses, A.G.; statistical analyses, M.I. and S.B.; bathymetry and map images, S.I.; collection samples and sedimentology, F.G.; funding acquisition, M.R.; data interpretation and discussion, L.C., L.F., A.G., S.B., M.I., S.I. and F.G. All authors have read and agreed to the published version of the manuscript.

Funding: Funds were provided within the framework of the ADRICOSM-NERES project (2006–2007) (Environmental regeneration and sustainable development of the delta of the Neretva river), by the Italian Ministry of Foreign Affairs.

Data Availability Statement: The data presented in this study are available in Table S1 generated during the study.

Acknowledgments: Thanks to Frano Matic, Grozdan Kuspilic and Slavica Matijevc of the Institute of Oceanography and Fisheries, Split Croatia; Gabriele Marozzi and Costante Luttazzi for sampling and work at sea on R/V Bios and Nadia Pinardi for project coordination. We also would like to thank R. A. Martin and an anonymous referee for their constructive comments that improved the quality of the manuscript. We are very grateful to A. Ferretti for their suggestions and M. Marani for the English revision. This is ISMAR-CNR, Bologna scientific contribution 2072.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Murray, J. The niche of benthic foraminifera, critical thresholds and proxies. *Mar. Micropaleontol.* **2001**, *41*, 1–7. https://doi.org/10.1016/s0377-8398(00)00057-8.
2. Jorissen, F.J.; Fontanier, C.; Thomas, E. *Proxies in late Cenozoic Palaeoceanography: Part. 2: Biological Tracers and Biomarkers*; Elsevier: Amsterdam, The Netherlands, 2007; pp. 263-326.
3. Frontalini, F.; Coccioni, R. Benthic foraminifera as bioindicators of pollution: A review of Italian research over the last three decades. *Rev. Micropaléontol*. **2011**, *54*, 115–127. https://doi.org/10.1016/j.revmic.2011.03.001.
4. Goineau, A.; Fontanier, C.; Jorissen, F.J.; Lansard, B.; Buscail, R.; Mouret, A.; Kerhervé; P; Zaragosi, S.; Ernoult, E.; Artéro, C.; et al. Live (stained) benthic foraminifera from the Rhône prodelta (Gulf of Lion, NW Mediterranean): Environmental controls on a river-dominated shelf. *J. Sea Res.* **2011**, *65*, 58–75.
5. Martins, M.V.A.; Frontalini, F.; Laut, L.L.; Silva, F.S.; Moreno, J.; Sousa, S.; Zaaboub, N.; El Bour, M.; Rocha, F. Foraminiferal biotopes and their distribution control in Ria de Aveiro (Portugal): A multiproxy approach. *Environ. Monit. Assess.* **2014**, *186*, 8875–8897. https://doi.org/10.1007/s10661-014-4052-7.
6. Avnaim-Katav, S.; Almogi-Labin, A.; Sandler, A.; Sivan, D. Benthic foraminifera as palaeoenvironmental indicators during the last million years in the eastern Mediterranean inner shelf. *Palaeogeogr. Palaeocl*. **2013**, *386*, 512–530. http://dx.doi.org/10.1016/j.palaeo.2013.06.019
7. Benito, X.; Trobajo, R.; Cearreta, A.; Ibáñez, C. Benthic foraminifera as indicators of habitat in a Mediterranean delta: Implications for ecological and palaeoenvironmental studies. *Estuarine, Coast. Shelf Sci.* **2016**, *180*, 97–113. https://doi.org/10.1016/j.ecss.2016.06.001.
8. Minhat, F.I.; Satyanarayana, B.; Husain, M.-L.; Rajan, V.V. Modern benthic foraminifera in subtidal waters of johor: implications for holocene sea-level change on the east coast of peninsular malaysia. *J. Foraminifer. Res.* **2016**, *46*, 347–357. https://doi.org/10.2113/gsjfr.46.4.347.
9. Kemp, A.C.; Cahill, N.; Engelhart, S.E.; Hawkes, A.D.; Wang, K. Revising estimates of spatially variable subsidence during the AD 1700 Cascadia earthquake using a Bayesian foraminiferal transfer function revising estimates of spatially variable subsidence. *Bull. Seismol. Soc. Am.* **2018**, *108*, 654–673.
10. Capotondi, L.; Bergami, C.; Orsini, G.; Ravaioli, M.; Colantoni, P.; Galeotti, S. Benthic foraminifera for environmental monitoring: A case study in the central Adriatic continental shelf. *Environ. Sci. Pollut. Res.* **2014**, *22*, 6034–6049. https://doi.org/10.1007/s11356-014-3778-7.

11. Capotondi, L.; Mancin, N.; Cesari, V.; Dinelli, E.; Ravaioli, M.; Riminucci, F. Recent agglutinated foraminifera from the North Adriatic Sea: What the agglutinated tests can tell. *Mar. Micropaleontol.* **2019**, *147*, 25–42. https://doi.org/10.1016/j.marmicro.2019.01.006.
12. Coccioni, R.; Frontalini, F.; Marsili, A.; Mana, D. Benthic foraminifera and trace element distribution: A case-study from the heavily polluted lagoon of Venice (Italy). *Mar. Pollut. Bull.* **2009**, *59*, 257–267. https://doi.org/10.1016/j.marpolbul.2009.08.009.
13. Frontalini, F.; Coccioni, R. Benthic foraminifera for heavy metal pollution monitoring: A case study from the central Adriatic Sea coast of Italy. *Estuarine, Coast. Shelf Sci.* **2008**, *76*, 404–417. https://doi.org/10.1016/j.ecss.2007.07.024.
14. Jorissen, F.J. The distribution of benthic foraminifera in the Adriatic Sea. *Mar. Micropaleontol.* **1987**, *12*, 21–48. https://doi.org/10.1016/0377-8398(87)90012-0.
15. Jorissen, F.J. Benthic foraminifera from the Adriatic Sea: Principles of phenotypic variations. *Utrecht Micropaleontol. Bull.* **1988**, *37*, 1–174.
16. Morigi, C.; Jorissen, F.J.; Fraticelli, S.; Horton, B.P.; Principi, M.; Sabbatini, A.; Capotondi, L.; Curzi, P.V.; Negri, A. Benthic foraminiferal evidence for the formation of the Holocene mud-belt and bathymetrical evolution in the central Adriatic Sea. *Mar. Micropaleontol.* **2005**, *57*, 25–49. https://doi.org/10.1016/j.marmicro.2005.06.001.
17. Donnici, S.; Barbero, R.S. The benthic foraminiferal communities of the northern Adriatic continental shelf. *Mar. Micropaleontol.* **2002**, *44*, 93–123. https://doi.org/10.1016/s0377-8398(01)00043-3.
18. Barbieri, G.; Amorosi, A.; Vaiani, S.C. Benthic foraminifera as a key to delta evolution: A case study from the late Holocene succession of the Po River Delta. *Micropaleontology* **2017**, *1*, 1–15.
19. Barbieri, G.; Rossi, V.; Vaiani, S.C.; Horton, B.P. Benthic ostracoda and foraminifera from the North Adriatic Sea (Italy, Mediterranean Sea): A proxy for the depositional characterisation of river influenced shelves. *Mar. Micropaleontolo.* **2019**, *153*, 101772.
20. Ćosović, V.; Zavodnik, D.; Borčić, A.; Vidović, J.; Deak, S.; Moro, A. A checklist of Foraminifera of the Eastern Shelf of the Adriatic Sea. *Zootaxa* **2011**, *3035*, 1–56. https://doi.org/10.11646/zootaxa.3035.1.1.
21. Melis, R.; Celio, M.; Bouchet, V.; Varagona, G.; Bazzaro, M.; Crosera, M.; Pugliese, N. Seasonal response of benthic foraminifera to anthropogenic pressure in two stations of the Gulf of Trieste (northern Adriatic Sea, Italy): The marine protected area of Miramare versus the Servola water sewage outfall. *Mediterr. Mar. Sci.* **2019**, *20*, 120–141. https://doi.org/10.12681/mms.16154.
22. Capotondi, L.; Kaminski, M.A.; Mancin, N. The test wall of Nubeculina Cushman 1924 (Miliolida: Unptates on its agglutinated-porcellaneous wall structure from entire and sections specimens. *Microplaeontology* **2022**, *68*, 557–567.
23. Popadić, A.; Vidović, J.; Ćosović, V.; Medaković, D.; Dolenec, M.; Felja, I. Impact evaluation of the industrial activities in the Bay of Bakar (Adriatic Sea, Croatia): Recent benthic foraminifera and heavy metals. *Mar. Pollut. Bull.* **2013**, *76*, 333–348. https://doi.org/10.1016/j.marpolbul.2013.09.039.
24. Vidović, J.; Ćosović, V.; Juračić, M.; Petricioli, D. Impact of fish farming on foraminiferal community, Drvenik Veliki Island, Adriatic Sea. Croatia. *Mar. Pollut. Bull.* **2009**, *58*, 1297–1309. https://doi.org/10.1016/j.marpolbul.2009. 04.031.
25. Vidović, J.; Dolenec, M.; Dolenec, T.; Karamarko, V.; Rožič, P.. Benthic foraminifera assemblages as elemental pollution bioindicator in marine sediments around fish farm (Vrgada Island, Central Adriatic, Croatia). *Mar. Pollut. Bull.* **2014**, *83*, 198–213. https://doi.org/10.1016/j.marpolbul.2014.03.051.
26. Rožič, P..; Vidović, J.; Ćosović, V.; Hlebec, A.; Rožič, B.; Dolenec, M. A Multiparametric Approach to Unravelling the Geoenvironmental Conditions in Sediments of Bay of Koper (NE Adriatic Sea): Indicators of Benthic Foraminifera and Geochemistry. *Front. Mar. Sci.* **2022**, *9*, 812622. https://doi.org/10.3389/fmars.2022.812622.
27. Ludwig, W.; Dumont, E.; Meybeck, M.; Heussner, S. River discharges of water and nutrients to the Mediterranean and Black Sea: Major drivers for ecosystem changes during past and future decades? *Progr. Oceanog.* **2009**, *80*, 99–217.
28. Giglio, F.; Romano, S.; Albertazzi, S.; Chiarini, F.; Ravaioli, M.; Ligi, M.; Capotondi, L. Sediment Dynamics of the Neretva Channel (Croatia Coast) Inferred by Chemical and Physical Proxies. *Appl. Sci.* **2020**, *10*, 807. https://doi.org/10.3390/app10030807.
29. Romić, D.; Romic, M.; Zovko, M.; Bakic, H.; Ondrasek, G. Trace metals in the coastal soils developed from estuarine floodplain sediments in the Croatian Mediterranean region. *Environ. Geochem. Heal.* **2012**, *34*, 399–416. https://doi.org/10.1007/s10653-012-9449-z.
30. Jurina, I.; Ivanić, M.; Vdović, N.; Troskot-Čorbić, T.; Lojen, S.; Mikac, N.; Sondi, I. Deposition of trace metals in sediments of the deltaic plain and adjacent coastal area (the Neretva River, Adriatic Sea). *J. Geochem. Explor.* **2015**, *157*, 120–131. https://doi.org/10.1016/j.gexplo.2015.06.005.
31. Zore-Armanda, M.; Grbec, B.; Morović, M. Oceanographic properties of the Adriatic Sea. A point of view. *Acta Adriat.* **1999**, *40*, 39–54.
32. Raicich, F. *Note on Flow Rates of the Adriatic Rivers*; Technical Report, RF02/94; Istituto Tasso Grafico Sperimentale Trieste: Trieste, Italy, 1994.
33. Vidjak, O.; Bojanić, N.; Kuspilić, G.; Gladan, Z.N.; Ticina, V. Zooplankton community and hydrographical properties of the Neretva Channel (eastern Adriatic Sea). *Helgoland Mar. Res.* **2007**, *61*, 267–282.
34. Ivanić, M.; Lojen, S.; Grozić, D.; Jurina, I.; Škapin, S.D.; Troskot-Čorbić, T.; Mikac, N.; Juračić, M.; Sondi, I. Geochemistry of sedimentary organic matter and trace elements in modern lake sediments from transitional karstic land-sea environment of the Neretva River delta (Kuti Lake, Croatia). *Quat. Int.* **2018**, *494*, 286–299. https://doi.org/10.1016/j.quaint.2017.03.050.
35. Jurina, I.; Ivanic, M.; Vdovic, N.; Mikac, N.; Sondi, I. Mechanism of the land-sea interactions in the Neretva River delta (Croatia): The distribution pattern of sediments and trace element. *Rapp. Comm. Int. Mer. Medit.* **2010**, *39*, 35.

36. Jurina, I.; Ivanić, M.; Troskot-Čorbić, T.; Barišić, D.; Vdović, N.; Sondi, I. Activity concentrations and distribution of radionuclides in surface and core sediments of the Neretva Channel (Adriatic Sea, Croatia). *Geol. Croat.* **2013**, *66*, 143–150. https://doi.org/10.4154/gc.2013.11.
37. Kljaković-Gašpić, Z.; Bogner, D.; Ujević, I. Trace metals (Cd, Pb, Cu, Zn and Ni) in sediment of the submarine pit Dragon ear (Soline Bay, Rogoznica, Croatia). *Environ. Earth Sci.* **2008**, *58*, 751–760. https://doi.org/10.1007/s00254-008-1549-9.
38. Bahun, S. Review of hydrogeological relations of the Maloston Bay. In Proceedings of the Symposium on Mali Ston Bay, Dubrovnik, Croatia, 12–24 November 1981.
39. Vučak, Z.; Gačić, M.; Dadič, V. Characteristics of the current field in Mali Ston Bay. In Proceedings of the Symposium on Mali Ston Bay, Dubrovnik, Croatia, 12–24 November 1981.
40. Debenay, J.P.; Tsakiridis, E.; Soulard, R.; Grossel, H. Factors determining the distribution of foraminiferal assemblages in Port Joinville Harbor (Ille d'Yeu, France): The influence of pollution. *Mar. Micropaleontol.* **2001**, *43*, 75–118.
41. Yanko-Hombach, V.; Kondariuk, T.; Motnenko, I. Benthic foraminifera indicate environmental stress from river discharge to marine ecosystems: example from the black sea. *J. Foraminifer. Res.* **2017**, *47*, 70–92. https://doi.org/10.2113/gsjfr.47.1.70.
42. AGIP. *Foraminiferi Padani: (Terziario e Quaternario): Atlante Iconografico e Distribuzione Stratigrafica,* 2nd ed.; AGIP Mineraria: Milan, Italy, 1982.
43. Cimerman, F.; Langer, M.R. *Mediterranean Foraminifera*; Academia Scientiarum et Artium Slovenica: Ljubljana, Slovenia, 1991; pp. 1–11.
44. Loeblich, R.; Tappan, H. *Foraminiferal Genera and their Classification*; Van Nostrand Reinhold: New York, NY, USA, 1987.
45. Hayward, B.W.; Le Coze, F.; Vachard, D.; Gross, O. World Foraminifera Database. 2020. Available online: http://www.marinespecies.org/foraminifera (accessed on 1 December 2022).
46. Hayward, B.W.; Cedhagen, T.; Kaminski, M.; Gross, O. World Modern Foraminifera Database. 2011. Available online: http://www.marinespecies.org/foraminifera (accessed on 30 September 2022).
47. Vaiani, S.C. Miliolidae (benthic foraminifera) distribution and relative sea-level variation during the Holocene transgression from subsurface deposits of the Po River delta (Italy). *GeoActa* **2010**, *9*, 43–52.
48. Walker, G.; Jacob, E.; Kanmacher, F. (ed.) *Adam`s Essay on the Microscope*; Dillon and Keating: London, UK, 1798.
49. Schweizer, M. Evolution and molecular phylogeny of Cibicides and Uvigerina (Rotaliida, foraminifera). *Geologica Ultraiectina*, **2006**, *261*, 1–167.
50. Van der Zwaan, G.J. Paleoecology of Late Miocene foraminifera. *Utrecht Micropal. Bull.* **1982**, *25*, 201, Utrecht.
51. Kouwenhoven, T.J. Survival under stress: Benthic foraminiferal patterns and Cenozoic biotic crises. *Geol. Ultraiectina* **2000**, *186*, 1–206.
52. Kaiho, K. Effect of organic carbon flux and dissolved oxygen on the benthic foraminiferal oxygen index (BFOI). *Mar. Micropaleontol.* **1999**, *37*, 67–76. https://doi.org/10.1016/s0377-8398(99)00008-0.
53. Schweizer, M.; Pawlowski, J.; Kouwenhoven, T.; Van Der Zwaan, B. Molecular phylogeny of common cibicidids and related rotaliida (foraminifera) based on small subunit rdna sequences. *J. Foraminifer. Res.* **2009**, *39*, 300–315. https://doi.org/10.2113/gsjfr.39.4.300.
54. Murray, J.W. E*cology and Applications of Benthic Foraminifera*, 2nd ed.; Cambridge University Press: Cambridge, UK, 2006; pp. 1–426.
55. Vidović, J.; Nawrot, R.; Gallmetzer, I.; Haselmair, A.; Tomašových, A.; Stachowitsch, M.; Ćosović, V.; Zuschin, M. Anthropogenically induced environmental changes in the northeastern Adriatic Sea in the last 500 years (Panzano Bay, Gulf of Trieste). *Biogeosciences* **2016**, *13*, 5965–5981. https://doi.org/10.5194/bg-13-5965-2016.
56. Langer, M.R. Epiphytic foraminifera. *Mar. Micropaleontol.* **1993**, *20*, 235–265. https://doi.org/10.1016/0377-8398(93)90035-v.
57. Mateu-Vicens, G.; Khokhlova, A.; Sebastián-Pastor, T. Epiphytic foraminiferal indices as bioindicators in mediterranean seagrass meadows. *J. Foramin. Res.* **2014**, *44*, 325–339.
58. Pérez-Asensio, J.N.; Rodríguez-Ramírez, A. Benthic Foraminiferal Salinity index in marginal-marine environments: A case study from the Holocene Guadalquivir estuary, SW Spain. *Palaeogeogr. Palaeoclim. Palaeoecol.* **2020**, *560*, 110021. https://doi.org/10.1016/j.palaeo.2020.110021.
59. eHammer, Ø.; Harper, D.A.T.; Ryan, P.D. PAST: Paleontological statistic software package for education and data analysis. Palaeontologia Electronica, **2001**, *4*, 9. http://palaeo-electronica.org/2001 1/past/issue1 01.htm.
60. Hammer, Ø.; Harper, D.A.T. *Paleontological Data Analysis*; Blackwell Publishing: Oxford, UK, 2006, p. 351, ISBN 1-4051-1544-0.
61. Legendre, P.; Legendre, L. *Numerical Ecology*; Elsevier: Amsterdam, The Netherlands, **2012**, *24*, 1–990.
62. Carrascal, L.M.; Galván, I.; Gordo, O. Partial least squares regression as an alternative to current regression methods used in ecology. *Oikos* **2009**, *118*, 681–690. https://doi.org/10.1111/j.1600-0706.2008.16881.x.
63. Ferraro, L.; Innangi, S.; Di Martino, G.; Russo, B.; Tonielli, R.; Innangi, M. Seafloor features and benthic foraminifera off Linosa Island (Sicily Channel, southern Mediterranean). *J. Mar. Syst.* **2020**, *211*. https://doi.org/10.1016/j.jmarsys.2020.103421.
64. Rohlf, F.J.; Corti, M. Use of Two-Block Partial Least-Squares to Study Covariation in Shape. *Syst. Biol.* **2000**, *49*, 740–753. https://doi.org/10.1080/106351500750049806.
65. Van Der Zwaan, G.J.; Jorissen, F.J. Biofacial patterns in river-induced shelf anoxia. *Geol. Soc. London, Spéc. Publ.* **1991**, *58*, 65–82. https://doi.org/10.1144/gsl.sp.1991.058.01.05.

66. Di Bella, L.; Pierdomenico, M.; Bove, C.; Casalbore, D.; Ridente, D. Benthic Foraminiferal Response to Sedimentary Processes in a Prodeltaic Environment: The Gulf of Patti Case Study (Southeastern Tyrrhenian Sea). Geosciences **2021**, *11*, 220. https://doi.org/10.3390/geosciences11050220.
67. Rossi, V.; Vaiani, S.C. Benthic foraminiferal evidence of sediment supply changes and fluvial drainage reorganization in Holocene deposits of the Po Delta, Italy. *Mar. Micropaleontol.* **2008**, *69*, 106–118. https://doi.org/10.1016/j.marmicro.2008.07.001.
68. Mojtahid, M.; Jorissen, F.; Lansard, B.; Fontanier, C.; Bombled, B.; Rabouille, C. Spatial distribution of live benthic foraminifera in the Rhône prodelta: Faunal response to a continental–marine organic matter gradient. *Mar. Micropaleontol.* **2009**, *70*, 177–200. https://doi.org/10.1016/j.marmicro.2008.12.006.
69. Frezza, V.; Carboni, M.G. Distribution of recent foraminiferal assemblages near the Ombrone River mouth (Northern Tyrrhenian Sea, Italy). *Rev. Micropaléontol.* **2009**, *52*, 43–66. https://doi.org/10.1016/j.revmic.2007.08.007.
70. Barmawidjaja, D.M.; Jorissen, F.; Puskaric, S.; Van Der Zwaan, G.J. Microhabitat selection by benthic Foraminifera in the northern Adriatic Sea. *J. Foraminifer. Res.* **1992**, *22*, 297–317. https://doi.org/10.2113/gsjfr.22.4.297.
71. Bellotti, P.; Carboni, G.; Di Bella, L.; Palagi, I. Benthic foraminiferal assemblages in the depositional sequence of the Tiber Delta. *Boll. Soc. Paleontol. It. Spec.* **1994**, *2*, 29–40.
72. Alve, E.; Murray, J.W. Marginal marine environments of the Skagerrak and Kattegat: A baseline study of living (stained) benthic foraminiferal ecology. *Palaeogeogr. Palaeoclim. Palaeoecol.* **1999**, *146*, 171–193. https://doi.org/10.1016/s0031-0182(98)00131-x.
73. Moodley, L.; Hess, C. Tolerance of Infaunal Benthic Foraminifera for Low and High Oxygen Concentrations. *Biol. Bull.* **1992**, *183*, 94–98. https://doi.org/10.2307/1542410.
74. Murray, J.W. *Ecology and Palaeoecology of Benthic Foraminifera: Longman Scientific and Technical*; Routledge: London, UK, 1991.
75. Sabbatini, A.; Bonatto, S.; Gooday, A.J.; Morigi, C.; Pancotti, I.; Pucci, F.; Negri, A. Modern benthic foraminifers at northern shallow sites of Adriatic Sea and softwalled, monothalamous taxa: A brief overview. *Micropaleontology* **2010**, *56*, 359–376.
76. Mendes, I.; Dias, J.; Schönfeld, J.; Ferreira, O. Distribution of living benthic foraminifera on the northern gulf of cadiz continental shelf. *J. Foraminifer. Res.* **2012**, *42*, 18–38. https://doi.org/10.2113/gsjfr.42.1.18.
77. Diz, P.; Francés, G. Distribution of live benthic foraminifera in the Ría de Vigo (NW Spain). *Mar. Micropaleontol.* **2008**, *66*, 165–191. https://doi.org/10.1016/j.marmicro.2007.09.001.
78. Di Bella, L.; Conte, A.M.; Conti, A.; Esposito, V.; Gaglioti, M.; Ingrassia, M.; De Vittor, C.; Bigi, S. Potential Resilience to Ocean Acidification of Benthic Foraminifers Living in *Posidonia oceanica* Meadows: The Case of the Shallow Venting Site of Panarea. *Geosciences* **2022**, *12*, 184. https://doi.org/10.3390/geosciences12050184.
79. Burmistrova, I.I.; Khusid, T.A.; Belyaeva, N.V.; Chekhovskaya, M.P. Agglutinated abyssal foraminifers of the equatorial pacific. *Oceanology* **2007**, *47*, 824–832. https://doi.org/10.1134/s0001437007060070.
80. Chendeş, C.; Kaminski, M.A.; Filipescu, S.; Aksu, A.E.; Yaşar, D. The response of modern benthic foraminifera assemblages to water-masses properties along the Southern Shelf of the Marmara Sea. *Acta Paleontolo. Rom.* **2004**, *4*, 69–80.
81. Levy, A.; Mathieu, R.; Poignant, A.; Rosset, M.; Ubaldo, M.; Lebreiro, S. Foraminiféres actuels de le marge continentale portuguaise.-inventaire et distribution. *Mem. Inst. Geol. Min. Esp.* **1995**, *32*, 3–1.
82. De Rijk, S.; Troelstra, S.R.; Rohling, E. Benthic foraminiferal distribution in the mediterranean sea. *J. Foraminifer. Res.* **1999**, *29*, 93–103. https://doi.org/10.2113/gsjfr.29.2.93.
83. Bizon, G.; Bizon, J.J. Ecologie des foraminifères en Méditerranée nord-occidentale. R. Les foraminifères des sédiments profonds. In Ecologie des microorganismes en Méditerranée occidentale. *"Ecomed" Pétrole Tech. Paris 1984*, *301*, 104–139.
84. Mojtahid, M.; Jorissen, F.; Lansard, B.; Fontanier, C. Microhabitat selection of benthic foraminifera in sediments off the rhone river mouth (nw mediterranean). *J. Foraminifer. Res.* **2010**, *40*, 231–246. https://doi.org/10.2113/gsjfr.40.3.231.
85. Ferraro, L.; Bonomo, S.; Alberico, I.; Cascella, A.; Giordano, L.; Lirer, F.; Vallefuoco, M. Live benthic foraminifera from the Volturno River mouth (central Tyrrhenian Sea, Italy). *Rend. Lincei Sci. Fis.* **2018**, *29*, 559–570. https://doi.org/10.1007/s12210-018-0712-9.
86. Jorissen, F.J.; Barmawidjaja, D.M.; Puskaric, S.; van der Zwaan, G.J. Vertical distribution of benthic Foraminifera in the northern Adriatic Sea: The relation with high organic flux. *Mar. Micropaleontol.* **1992**, *19*, 131–146.
87. Hohenegger, J.; Piller, W.E.; Baal, C. Horizontal and vertical spatial micro-distribution of foraminifers in the shallow subtidal Gulf of Trieste, northern Adriatic Sea. *J. Foraminifer. Res.* **1993**, *23*, 79–101.
88. Murray, J.W. Living benthic foraminifera: Biogeographical distributions and the significance of rare morphospecies. *J. Micropalaeontology* **2013**, *32*, 1–58. https://doi.org/10.1144/jmpaleo2012-010.
89. Jorissen, F.; Nardelli, M.P.; Almogi-Labin, A.; Barras, C.; Bergamin, L.; Bicchi, E.; El Kateb, A.; Ferraro, L.; McGann, M.; Morigi, C.; et al. Developing Foram-AMBI for biomonitoring in the Mediterranean: Species assignments to ecological categories. *Mar. Micropaleontol.* **2018**, *140*, 33–45. https://doi.org/10.1016/j.marmicro.2017.12.006.