water

MDPI

Article

Paleoenvironmental Changes in the Gulf of Gaeta (Central Tyrrhenian Sea, Italy): A Perspective from Benthic Foraminifera after Dam Construction

Marco Cavaliere [1,*], Vittoria Scipioni [1], Fabio Francescangeli [2], Luciana Ferraro [3] and Fabrizio Frontalini [1]

[1] Department of Pure and Applied Sciences, University of Urbino "Carlo Bo", 61029 Urbino, Italy
[2] Department of Geosciences, University of Fribourg, 1700 Fribourg, Switzerland
[3] Institute of Marine Science, National Research Council, 80133 Naples, Italy
* Correspondence: m.cavaliere6@campus.uniurb.it

Abstract: A 300-year paleoenvironmental reconstruction using benthic foraminifera in the Gulf of Gaeta (central Tyrrhenian Sea, Italy) is here presented. The Gulf of Gaeta dynamics are strongly influenced by the fluvial input, particularly the Volturno River and human activities. The sedimentary archive reveals a strong relation between the variations in the composition of the benthic foraminiferal assemblages and human interventions in the Volturno coastal area. According to the statistical analysis, three main temporal phases are identified and supported by the variations in the enhanced benthic foraminifera oxygen index (EBFOI) values over time. We hypothesize that the main environmental modifications might be ascribed to the construction of two dams, Sorgente Capo Volturno (1909–1916) and Ponte Annibale (1953–1958). The dams have probably altered the supply of sediments causing a physical stress related to the variations in grain-size, the organic matter and the oxygen availability. This temporal reconstruction further supports the ability of foraminifera to register paleoenvironmental changes induced by human activities such as the modification of the physical environment within the sedimentary record.

Keywords: sediment; oxygen; human intervention; Volturno; river input

Citation: Cavaliere, M.; Scipioni, V.; Francescangeli, F.; Ferraro, L.; Frontalini, F. Paleoenvironmental Changes in the Gulf of Gaeta (Central Tyrrhenian Sea, Italy): A Perspective from Benthic Foraminifera after Dam Construction. *Water* **2023**, *15*, 815. https://doi.org/10.3390/w15040815

Academic Editor: Jun Yang

Received: 23 January 2023
Revised: 15 February 2023
Accepted: 16 February 2023
Published: 20 February 2023

1. Introduction

Benthic foraminifera are single-celled organisms widely applied as environmental tools in biomonitoring programs of coastal and estuarine sedimentary environments [1–4]. Because of their abundance, diversity, sensitivity to environmental changes (e.g., variations in organic matter, pollutants, water and sediment physical parameters), as well as their fossilizable tests (i.e., shells), they have been used to investigate short- and long-term paleoclimatic variations and in paleoenvironmental reconstructions [5,6]. The investigation of sediment archives (i.e., cores) allows us to read the historical environmental variations resulting from natural climatic fluctuations and anthropic activities over time [7–9]. In the Anthropocene, foraminiferal-based proxies are capable of recording the dramatic signature of anthropogenic impact even including the physical disturbance on modern ecosystems, distinguishing background (i.e., pre-impacted) from human-altered conditions [7,10,11].

Marine coastal areas receiving loads of continental sediments are strongly related to the human activities (e.g., vegetation or land use change, human settlement and industry) such that they can be registered in the sedimentary records [12]. Rivers' mouths are complex environments where interactions between fresh and marine waters take place [13,14]. Riverine inputs may have a strong impact on the marine areas nearby the mouth that represents possible contamination pathways to oceans and, ultimately to the sediment. In this scenario, monitoring the fluvial inputs (i.e., water and sediments) in terms of quality and quantity is crucial to understand the dispersal mechanisms of sediments, nutrients and pollutants and their effects on the surrounding marine and estuarine environments [15,16].

Changes in the coastal ecosystems are also driven by physical disturbance such as the construction of dams that can unbalance the natural discharge of sediment.

The Tyrrhenian Sea, with a high sedimentation rate, represents a key area for assessing paleo-climatic and -environmental changes over the last centuries [17–20]. In particular, the sedimentary records of Gaeta Gulf (Campania Region, southwestern Tyrrhenian Sea) have been deeply investigated [21–24]. Correlating multi-proxy data and historical archives, Margaritelli et al. [22] recognized several climatic intervals in the last five millennia. During the last centuries, palynological analyses have revealed that clear shifts of vegetation patterns underlined paleoclimate changes in the coastal inland of the Gulf of Gaeta [23]. However, the area has also experienced an increase in human activities with deforestation and the development of agricultural activities (e.g., farming, field harvesting, ornamental species culturing, among others).

During the last decades, waste disposal management turned into a dramatic issue in the Campania Region. Illegal discharges of industrial and urban waste have been documented in continental and marine environments, including illegal dumping and burning of toxic waste [25,26]. The impact events and the common burns of industrial residuals led to the Campania Plain becoming known as the Terra dei Fuochi (Land of Fires), with toxic compounds possibly migrating from soils to groundwater, rivers and estuarine and coastal environments. Moreover, the increase in agricultural activities in the Campania Region has caused a high input of pesticides and fertilizers in aquatic environments with a consequent deterioration of the water quality [27].

The present research aims at utilizing the outcomes of previous studies in the Gulf of Gaeta by focusing on the response of benthic foraminifera to historical human-induced changes in the last ca. 300 years. Our reconstruction ranges between the year 1686, late period of the Little Ice Age (ca. 1250–1850) [22] and the Modern Warm Period (ca. 1950 CE–present). Furthermore, the effect of land-use change is carefully investigated and associated to the variations in the benthic foraminiferal communities along this temporal interval.

2. Materials and Methods

2.1. Study Area

The Gulf of Gaeta is located in the central part of the Tyrrhenian Sea, the deepest basin of the western Mediterranean Sea [28]. The gulf is bordered by the Aurunci Mounts and the Roccamonfina volcano [29] in the northern sector, by the Apennine fold-and-thrust belt in the eastern sector and by the Neapolitan volcanic complex in the southern sector [30] (Figure 1).

The geomorphological and geophysical features of the Gulf of Gaeta are strongly connected to the Volturno River and its discharge (40 m^3 s^{-1}). The Volturno River is the longest river in southern Italy (ca. 175 km in length) and its catchment basin (ca. 1550 km^2) includes territories of Campania, Molise and Lazio regions [31]. The last sector of the Volturno River crosses the Campanian Plain, flowing till the town of Castel Volturno, where its mouth is located. The Gulf of Gaeta seafloor can be described as a typical continental shelf. The Quaternary clastic and volcanic deposits prograde gradually westward, deepening sharply at 120 m depth [16,24,30]. In the Gulf of Gaeta, the water circulation is characterized by the interactions between a cyclonic vortex with the superficial and intermediate waters [16,32]. Similar to the overall Tyrrhenian circulation, two seasonal currents influence the coastal circulation in the Gulf of Gaeta as well as coastal morphology and submerged morphostructures [33,34].

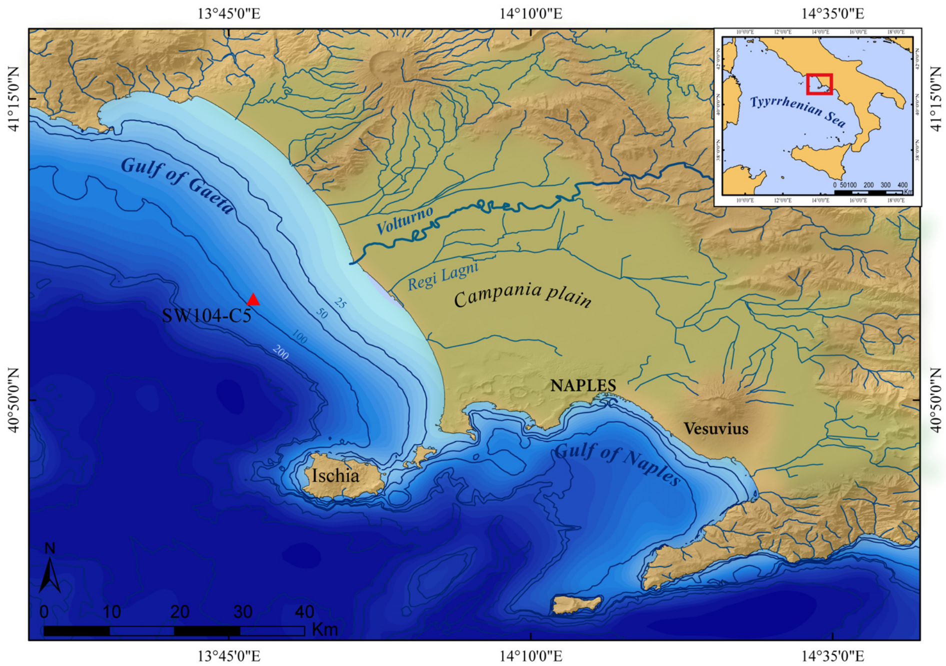

Figure 1. Location map of the Gulf of Gaeta (central Tyrrhenian Sea, Southern Italy) and the position of the SW104-C5 core.

Humans have been exploiting the volcanic and fertile soils of the Campania and Lazio regions since the Paleolithic [35]. The first historical human settlement in the area is documented back to the 9th century BC. Greek and Roman colonies established in the coastal plain of the Volturno River between 200 years BC and 500 years BC, while during the Middle Ages, different kingdoms controlled the area. The last one, the Spanish domination, lasted until 1861, when the region became part of Italy. Until the beginning of the 19th century, the coastal plain was characterized by extensive marshlands [36]. The first remediation actions started in the XVI century under the Borbone Kingdom. The Regi Lagni, a complex network of artificial drainage channels, was built over the last 400 years to make the backwater flow toward the sea. The articulated interventions lasted till the year 1950. Important artificial interventions also took place along the Volturno River with the constructions of dams. In particular, the first dam of Sorgente di Capo Volturno was built in the uppermost part of the river between 1909 and 1916, whereas the Traversa di Ponte Annibale was also built around Capua between 1953 and 1958. Overall, several human interventions occurred along the river for hydraulic energy exploitation and agricultural purposes in the last century. Nowadays, agriculture is the most important activity in the Campania Plain, with intensive and wide areas covered by permanent orchard and olive groves.

The Volturno Plain–Regi Lagni area between the provinces of Naples and Caserta is densely populated and falls within the Regional Interest Priority Site "Litorale Domizio-Agro Aversano" that is characterized by a strong urbanization, intensive agricultural activities and, in the last decades, by an unknown number of illegal activities [37]. Several studies have investigated the quality of the Volturno River waters and sediments by assessing the microbiological and chemical discharges [38–41]. The contamination of the Volturno River is mainly due to polychlorinated biphenyls, organochlorine pesticides and polycyclic aromatic hydrocarbons (total amount discharged yearly is 87.1 kg/year, 19.7 kg/year and 3158.2 kg/year, respectively) produced by vehicle traffic, agricultural waste and combustion processes [40].

2.2. Core Sampling and Geochronology

The 108 cm long-core SW104-C5 sea sediment was collected with a SW-104 gravity core (Carma) in 2013 at 93 m water depth in the Gulf of Gaeta, 13 km offshore from the Volturno's mouth (40°58′24,993″ N, 13°47′03,040″ E) (Figure 1).

The geochemical analyses of the sea sediments were carried out at the ISMAR-CNR of Bologna (Italy). The ^{210}Pb and ^{137}Cs were used for establishing the geochronology of the core. The bottom of the core was dated back to 1686 AC. More details about the age model and geochronology techniques of the core can be found in Margaritelli et al. [22].

2.3. Benthic Foraminiferal Analysis

For the benthic foraminiferal analysis, twenty-three sediment samples were chosen at ca. 4.3 cm intervals corresponding to 14.2 yr., in order to well represent the temporal sequence between 2013 (uppermost layer: 0–1 cm) and 1686 (bottom layer: 98–99 cm). In the laboratory, sediment samples were gently washed with tap water through a 63 µm mesh sieve and dried at 40 °C. About 300 specimens were dry-picked from the fraction >125 µm and placed on plastic microslides for morphological identification. Benthic foraminiferal species were taxonomically identified largely following the works of Sgarrella and Moncharmont Zei [42] and Milker and Schmiedl [43]. The current nomenclature was double-checked against the database the World Register of Marine Species [44].

At each core interval, the relative abundance (i.e., %), the species richness (S), the Shannon index biased correct (H'_{bc}) [45], the equitability (J) and the enhanced benthic foraminifera oxygen index (EBFOI) were calculated. The EBFOI is a modification of the BFOI [46] to improve the estimation of dissolved oxygen contents in the sediment [47]. Here we used Equation (1) that considers suboxic indicators to the Kaiho equation applicable when oxic indicators are present [47]:

$$EBFOI = 100(O/(O + D + S/2) \quad (1)$$

where O, D and S are the sum of oxic, dysoxic and suboxic indicators at each interval. The oxic requirements of benthic foraminiferal species (i.e., oxic, dysoxic or suboxic) were attributed following previous literature [42,47–52] and reported in Table S1. The following oxygenation concentration thresholds and relation of oxygenation were considered for EBFOI: 100 to 50 high oxic, 50 to 0 low oxic, 0 to −40 suboxic, −40 to −50 dysoxic, −55 anoxic.

The packages "Entropy" [53] and "vegan" [54] in RStudio were used to determine S, E and $H'_{bc.}$ The package "rioja" [55] was used to plot vertical temporal profiles.

2.4. Statistical Analysis

The relative abundances of benthic foraminiferal species were used to identify groups of layers by a constrained hierarchical clustering analysis (HCA) along the core depth (i.e., years) and a similarity tree was produced using the Euclidian distance. CONISS was used as the clustering method [56]. The analysis was performed using the package "vegan" [54] and the plot produced by the package "rioja" [57] in RStudio.

The maps were made using the software ArcMap 10.5 (Esri, Redlands, CA, USA). The geographic review of the area was based on different historical maps [58–60].

3. Results

3.1. Diversity Indices and Species Abundance Variations

On the basis of the available geochronology, a mean sedimentation rate of 0.30 cm/yr was calculated.

A total of 77 benthic foraminiferal species, belonging to 43 genera, were recognized. The benthic foraminiferal abundance and the relative abundance for each species were reported in Table S2. The S values ranged between 20 (1876) and 36 (1936) without a clear trend. The H'_{bc} values spanned between 2.5 (1876) and 3.1 (1950) and increased over time.

A similar trend was exhibited by J, which varied between 0.80 (1928–1936) and 0.88 in 1989 (Figure S1).

The most abundant species in terms of relative abundance were, on average, *Valvulineria bradyana* (10.7%), *Bulimina gibba* (10.6%), *Cassidulina carinata* (9.5%), *Hyalinea balthica* (7.75%), *Melonis barleeanum* (6.8%), *Spiroplectinella wrighti* (6.1%), *Bulimina marginata* (5.5%), *Uvigerina mediterranea* (4.9%), *Ammonia beccarii* (4.02%), *Bolivina alata* (3.95%), *Melonis pompilioides* (2.94%), *Bigenerina nodosaria* (2.85%), *Globocassidulina subglobosa* (2.31%), *Elphidium crispum* (2.2%) and *Uvigerina peregrina* (2.01%) (Table S2). *Valvulineria bradyana* showed an overall decreasing trend of abundance along the core, with a maximum of 21.8% in 1853 and a minimum of 3.6% in 1989 (Figure 2). *Bulimina gibba* abundance exhibited an increasing trend from 1913 to 1928 and then a steady drop up to 2013 (Figure 2). *Cassidulina carinata* presented an increasing trend in the lower part of the core then it decreased till 1958 when the abundance rose up again till 2013 (Figure 2). *Spiroplectinella wrighti* exhibited a constant abundance till 1913 when it dropped and remained low up to the top of the core. Similarly, *Elphidium crispum* displayed an overall constant abundance till 1950, when it drastically disappeared. *Uvigerina peregrina* showed constantly very low values from the bottom of the core till 1936 when it markedly increased in abundance (Figure 2). A similar trend was observed for *Uvigerina mediterranea* (Figure 2). Amongst the minor species, a clear trend was shown by *Bolivina catanensis* that increased in recent times (after 1981) and *Porosononion granosum* that basically disappeared after 1942, as did *E. crispum* (Figure 2).

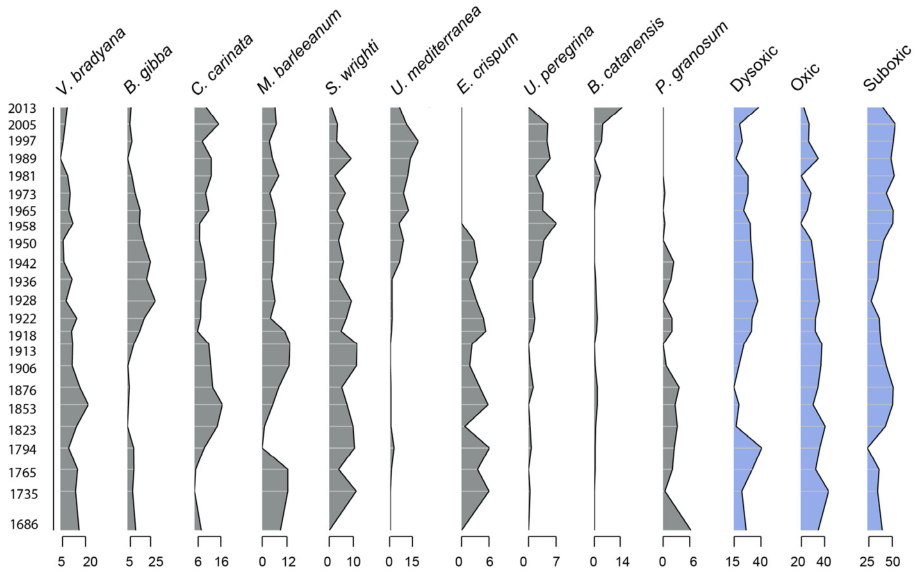

Figure 2. Temporal relative abundance variations of selected benthic foraminiferal species and oxic, dysoxic and suboxic groups. Note the horizontal scales (%) are not homogeneous.

3.2. Changes in the Benthic Foraminiferal Composition

The HCA showed a clear separation of the samples into two main clusters, namely cluster I from 1686 to 1913 and cluster II from 1918 to 2013 (Figure 3a). Cluster II can be further subdivided in two sub-clusters (sub-cluster II a: 1918–1950; and sub-cluster II b: 1958–2013) (Figure 3). Cluster I (1686–1913) was characterized by relatively higher abundances of *V. bradyana*, *C. carinata*, *M. barleeanum*, *B. marginata*, *M. pompilioides* and *E. crispum* (Figure 2) than in Cluster II. A significant increase in abundance of *B. gibba*, *B. alata*, *B. nodosaria* and *U. peregrina* was observed in sub-cluster IIa (1918–1950). Compared to cluster I, a decrease in *V. bradyana*, *C. carinata*, *H. balthica*, *B. marginata*, *M. pompilioides* and *G. subglobosa* was observed in sub-cluster IIa (Figure 3a). In sub-cluster IIb (1958–2013) an increase in abundance of *C. carinata*, *H. balthica*, *B. marginata*, *U. mediterranea*, *B. nodosaria*, *G. subglobosa* and *U. peregrina* occurred. At the same time, there was a further decrease in abundance of *V. bradyana*, *B. gibba* and *M. pompilioides*, while *E. crispum* was absent (Figure 3a).

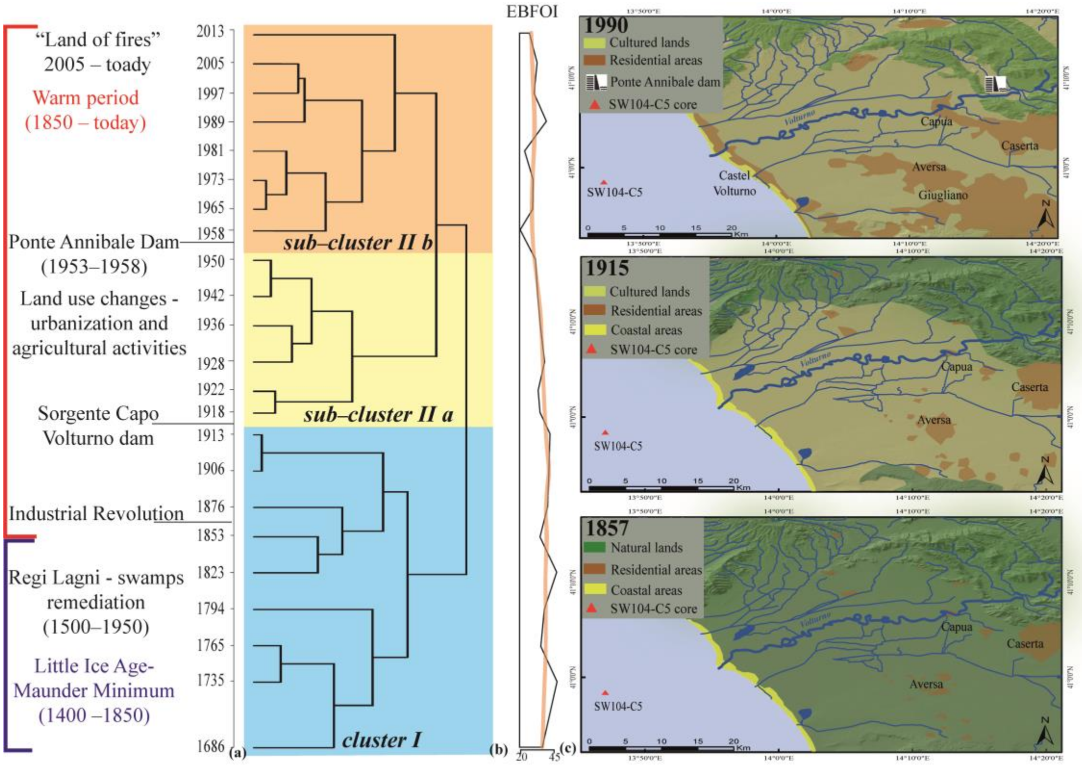

Figure 3. Paleoclimate periods (blue and red from Margaritelli et al. [22]) and anthropogenic interventions. (**a**) Hierarchical cluster analysis based on benthic foraminiferal relative abundances; (**b**) Enhanced benthic foraminifera oxygen index (EBFOI) temporal variations with a smooth curve (in orange) based on local polynomial regression fitting added to evidence the main trend; (**c**) Paleoenvironmental reconstruction and land-use changes in 1857 [58], 1915 [59] and 1990 [60].

On average, suboxic taxa (42%) were the most abundant, followed by oxic (31%) and dysoxic (27%) ones (Table S1). Suboxic taxa did not show a clear trend, while oxic taxa decreased after 1913, mirrored by the increased dysoxic taxa. The maximum value (47) of the EBFOI was recorded in 1823 and 1735, while the lowest one (19) was recorded in 1958 (Figure 3b). Overall, the EBFOI exhibited relatively higher values (close to high oxic conditions) until 1913. Then, there was a decrease in EBFOI (low oxic conditions) from 1918 to present (Figure 3b).

3.3. Historical Environmental Changes: The Imprint of Human Activities

The analysis of historical maps of the study area revealed important information about the land-use changes during different historical periods (i.e., 1858, 1914 and 1990). In the 19th century, the whole area was mainly covered by natural lands, with only a few residential areas (i.e., the city of Caserta and the towns of Capua and Aversa) and a wide coastal area characterized by a sandy beach (Figure 3c). At the beginning of the 20th century, the largest part of the plain was already used for agriculture purposes. At the end of the 20th century, natural lands remained only in the inner mountainous area (i.e., northern area). The whole plain was urbanized (i.e., development of the towns of Capua, Giugliano and, along the coast, Castel Volturno) or used as cultured lands. The coastal area was reduced, and an intense loss of sandy beach was observed.

4. Discussion

The present study allows us to decipher the paleoenvironmental changes in the Gulf of Gaeta (Tyrrhenian Sea) during the last ca. 300 years using benthic foraminiferal assemblages. The severe changes in the land use during the last centuries in the Campania Region have been confirmed through the historical-cartographic review of the area that allows us to observe how the natural lands, which covered the main part of the northern area of the Campania Region till 1850, were completely converted into agricultural and residential areas during the Industrial Period (Figure 3c). A crucial role in the Volturno River and Gulf of Gaeta ecological dynamics must be attributed to the construction of dams and the Regi Lagni reclamation. The reclamation was achieved by filling lowlands with alluvial materials from river waters that were canalized and diverted [61,62]. Such interventions (i.e., reduction in wetlands) led to the urbanization of the coastal area and also increased the amount of fine sediments transported toward the sea, the nutrients supply (i.e., organic matter), as well as the water turbidity [63].

Based on the HCA, three main phases (i.e., clusters and sub-clusters) corresponding to marked faunal turnovers have been identified and their separations can be associated to the dam construction. Specifically, the two major faunal turnovers taking place in 1913–1918 and 1950–1958 well correspond to the building of the dams of the Sorgente Capo Volturno (1909–1916) and the Ponte Annibale (1953–1958) (Figure 3a).

4.1. Natural Conditions and the Regi Lagni Reclamation

The benthic assemblages along the core were dominated by suboxic taxa with an upward increase in dysoxic taxa. The 1686–1913 phase is mainly characterized by a high abundance of *V. bradyana*, *C. carinata* and *E. crispum*. *Valvulineria bradyana* is a typical species of coastal terrigenous circalittoral and epibathyal muds [64]. This taxon is normally favored in a low O_2 environment and by high amount of organic matter [65,66]. *Cassidulina carinata* has been reported as widespread in circalittoral and bathyal muds deeper than 100 m [42]. Both these taxa have been identified as opportunists and tolerating low-oxygen conditions [49]. Although the occurrence of dysoxic indicators during this phase, the EBFOI has, overall, higher and constant values (close to high oxic conditions). Indeed, in the same interval highest abundance of oxic indicators was recorded including *S. wrighti* and *E. crispum*, species that are sensitive to organic enrichment and commonly found in low-polluted sites [49,67].

The co-occurrence of both opportunistic and sensitive species suggests a very complex environment and dynamic conditions where the effects of human interventions are overlain with climatic changes in the Mediterranean Sea. Accordingly, in this period (1686–1913), the Volturno coastal plain experienced significant changes with the reclamation of swamp zones and the Regi Lagni intervention that was represented by historic drainage channels for rainwater and spring water toward the sea and modified the continental fluvial regime [68]. These hydraulic restorations started during the Borbone Kingdom, but they have been completed in different stages up to the present day and from 1850, the reclamation has proceeded with the use of landfill of lowland areas [68]. From a wider-climatic perspective, this interval records the upper part of the Little Ice Age (ca. 1250 to 1850) and in particular, the Maunder event, a cold phase with reduced solar activity during the Little Ice Age [22]. Based on micropaleontological analyses, Margaritelli et al. [22] revealed a shift of carnivorous vs. herbivorous planktonic foraminifera and the beginning of forest recovering (e.g., mixed oak forest and evergreen trees and shrubs) at 1850 [69].

This interval also covers an important phase, the Industrial Revolution (1850–1950 sensu [22]) typified along the studied core by an increase in warm-water-oligotrophic planktonic foraminiferal taxa (i.e., *Globigerinoides ruber*) and the dominance of herbivorous–opportunistic planktonic foraminifera associated to more humid climatic conditions. These wetter and warmer climate conditions were also supported by the pollen record [69].

4.2. The Aftermath of the Construction of the Capo Volturno Dam

Beside the marked variations along the water column and in the continental environment as previously revealed from the planktonic foraminiferal and pollen assemblages [22], prominent changes took place in the sea bottom as inferred by the variations in the composition of the benthic foraminiferal assemblages from 1918–1950. In this interval, the benthic foraminiferal assemblages are in fact markedly different from the previous period with an increase in dysoxic indicators. *Bulimina gibba*, a common species in muddy and poorly oxygenated substrates, was the dominant species. In this time interval, a rapid increase in other triserial taxa (e.g., *Uvigerina*) was also observed; their elongated forms are commonly associated to less oxygenated substrates [46]. This was supported as well by the decrease in the EBFOI. These changes can be mainly ascribed to the construction of the Sorgente of Capo Volturno between 1909 and 1916 that might have increased the quantity of finer materials discharged by the Volturno River leading to the development of lower oxygen conditions (Figure 3b). Similarly, a foraminiferal turnover characterized by a strong increase in uvigerinids and buliminids was observed after 1920 in the Gulf of Salerno [70]. Like our findings, the variation was related to enhanced availability of organic matter at the seafloor along with a strong reduction in sandy riverine materials and, ultimately, to the construction of a dam on the Sele River in 1934.

4.3. Changes Associated with the Ponte Annibale Dam

In the most recent period (i.e., 1958–2013), there was a clear increase in triserial taxa (such as *U. mediterranea,* and *U. peregrina*). The ecological behavior of these species would support an increase in the availability of organic matter (nutrients) and/or a decrease in oxygen content, mainly driven by the enhanced terrigenous discharge. In this period, we observe the highest dominance of dysoxic and suboxic indicators, and the disappearance of oxic indicators, such as *E. crispum* and *P. granosum*. The shift in the benthic foraminiferal assemblages that takes place between 1950–1958 also exhibits the lowest value of EBFOI (Figure 3b). These changes perfectly match the completion of the construction of the Ponte Annibale dam (i.e., 1953) that has been suggested to have reduced the river sediment supply to the coast [68]. The decrease in sand supply to the river mouth occurred after the construction of the Ponte Annibale dam (1953) and caused a shoreline retreat (up to 28.3 m/yr) [61,71]. The EBFOI also evidences a phase from 1950 to 1980 with relatively lower values of oxygen availability at the seafloor.

This interval was also characterized by a significant increase in planktonic species such as *Globigerinita glutinata* and *Turborotalita quinqueloba* [22]. These taxa have been reported to thrive in areas influenced by continental runoff and nutrient-rich waters, suggesting high surface productivity [22,72]. Similar to our findings, an increase in *B. aculeata* in the Gulf of Salerno (south Tyrrhenian Sea) has been related to enhanced productivity but also suboxic or dysoxic conditions in pore and bottom waters [20,70]. Accordingly, these authors inferred a marked decrease in coarse-grained materials, which might have changed the nutrient supply at the seafloor as a consequence of construction of dams in the central-southern Tyrrhenian coastal areas during the last century. This interval was also characterized by an intensive urbanization and particularly of cultivation of the continental area of the Gulf of Gaeta. In fact, pollen analyses revealed the dominance of *Pinus* reflecting extensive plantation of pine forests. It also suggested an overall increase in cultivated plants, such as *Olea*, *Juglans*, *Vitis*, *Corylus*, Cannabaceae and cereals, all considered anthropogenic pollen indicators, further supporting the exploitation of land for agriculture purposes [23,69].

5. Conclusions

The present study identifies three main intervals (i.e., 1686–1913, 1918–1950 and 1958–2013) based on the variation of benthic foraminiferal assemblages in the Gulf of Gaeta (Tyrrhenian Sea). The first interval reflects mostly natural conditions with higher oxygen availability. Significant changes in the benthic foraminiferal assemblages and a lowering of the oxygen availability were associated with the construction of the Sorgente of Capo

Volturno between 1909 and 1916 that might have increased the quantity of finer materials discharge by the Volturno River. A further shift in the benthic foraminiferal assemblages and a lowering of oxygen availability took place between 1950–1958. These changes perfectly match the completion of the construction of the Ponte Annibale dam in 1953 that has been suggested to have reduced the sand supply to river mouth. This investigation reveals that dam construction unbalancing the sediment input and reducing the coarse sediment supply might have determined significant alterations in the composition of benthic foraminiferal assemblages and further supports the capability of benthic foraminifera to record paleoenvironmental variations, even induced by anthropization including the land-use changes and the construction of dam.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w15040815/s1, Figure S1: Plot of diversity indices (S), H'bc and equitability (J); Table S1: Oxic requirements of benthic foraminiferal species (i.e., oxic, dysoxic or suboxic); Table S2: Abundance and relative abundance of benthic foraminifera species.

Author Contributions: Conceptualization, M.C. and F.F. (Fabrizio Frontalini); methodology, F.F. (Fabrizio Frontalini); software, F.F. (Fabio Francescangeli); validation, M.C., F.F. (Fabrizio Frontalini) and F.F. (Fabio Francescangeli); formal analysis, V.S., F.F. (Fabio Francescangeli) and L.F.; investigation, V.S.; resources, F.F. (Fabrizio Frontalini) and L.F.; data curation, M.C.; writing—original draft preparation, F.F. (Fabrizio Frontalini) and M.C.; visualization, M.C.; supervision, F.F. (Fabrizio Frontalini). All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

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

Acknowledgments: Marine core C5 and SW104-C5 were collected during Oceanographic Cruise I-AMICA2013_01 Project PON03 I-AMICA "High Technology Infrastructure for the Climate Environmental Integrated Monitoring" (http://www.i-amica.it, accessed on 14 January 2019).

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

References

1. Frontalini, F.; Semprucci, F.; Armynot du Châtelet, É.; Francescangeli, F.; Margaritelli, G.; Rettori, R.; Spagnoli, F.; Balsamo, M.; Coccioni, R. Biodiversity trends of the meiofaunal and foraminiferal assemblages of Lake Varano (Southern Italy). *Proc. Biol. Soc. Wash.* **2014**, *127*, 7–22. [CrossRef]
2. Armynot du Châtelet, E.; Francescangeli, F.; Frontalini, F. Definition of benthic foraminiferal bioprovinces in transitional environments of the Eastern English Channel and the Southern North Sea. *Rev. Micropaléontol.* **2018**, *61*, 223–234. [CrossRef]
3. Francescangeli, F.; Milker, Y.; Bunzel, D.; Thomas, H.; Norbisrath, M.; Schönfeld, J.; Schmiedl, G. Recent benthic foraminiferal distribution in the Elbe Estuary (North Sea, Germany): A response to environmental stressors. *Est. Coast. Shelf Sci.* **2021**, *251*, 107198. [CrossRef]
4. Cavaliere, M.; Barrenechea Angeles, I.; Montresor, M.; Bucci, C.; Brocani, L.; Balassi, E.; Margiotta, F.; Francescangeli, F.; Bouchet, V.M.P.; Pawlowski, J.; et al. Assessing the ecological quality status of the highly polluted Bagnoli area (Tyrrhenian Sea, Italy) using foraminiferal eDNA metabarcoding. *Sci. Total Environ.* **2021**, *790*, 147871. [CrossRef]
5. Hayward, B.W.; Wilson, K.; Morley, M.S.; Cochran, U.; Grenfell, H.R.; Sabaa, A.T.; Daymond-King, R. Microfossil record of the Holocene evolution of coastal wetlands in a technologically active region of New Zealand. *Holocene* **2010**, *20*, 405–421. [CrossRef]
6. Francescangeli, F.; Portela, M.; Armynot du Chalet, E.; Billon, G.; Andersen, T.J.; Bouchet, V.M.P.; Trentesaux, A. Infilling of the Canche Estuary (eastern English Channel, France): Insight from benthic foraminifera and historical pictures. *Mar. Micropal.* **2018**, *142*, 1–12. [CrossRef]
7. Alve, E.; Lepland, A.; Magnusson, J.; Backer-Owe, K. Monitoring strategies for re- establishment of ecological reference conditions: Possibilities and limitations. *Mar. Pollut. Bull.* **2009**, *59*, 297–310. [CrossRef]
8. Dos, S.; de Jesus, M.; Frontalini, F.; Bouchet, V.M.P.; Yamashita, C.; Sartoretto, J.R.; Figueira, R.C.L.; de Mello, E.; Sousa, S.H. Reconstruction of the palaeo-ecological quality status in an impacted estuary using benthic foraminifera: The Santos Estuary (São Paulo state, SE Brazil). *Mar. Environ. Res.* **2020**, *162*, 105121. [CrossRef]

9. Barrenechea Angeles, I.; Romero-Martínez, M.L.; Cavaliere, M.; Varrella, S.; Francescangeli, F.; Piredda, R.; Mazzocchi, M.G.; Montresor, M.; Schirone, A.; Delbono, I.; et al. Encapsulated in sediments: eDNA deciphers the ecosystem history of one of the most polluted European marine sites. *Environ. Int.* **2023**, *in press*. [CrossRef]
10. Francescangeli, F.; Armynot du Chatelet, E.; Billon, G.; Trentesaux, A.; Bouchet, V.M. Palaeo-ecological quality status based on foraminifera of Boulogne-sur-Mer harbour (Pas-de-Calais, Northeastern France) over the last 200 years. *Mar. Environ. Res.* **2016**, *117*, 32–43. [CrossRef]
11. da Silva, L.C.; Alves, M.M.V.; Figueira, R.; Frontalini, F.; Pereira, E.; Senez-Mello, T.M.; Castelo Wellen, F.L.; Saibro, M.B.; Francescangeli, F.; Mello e Sousa, S.H.; et al. Unravelling Anthropocene Paleoenvironmental Conditions Combining Sediment and Foraminiferal Data: Proof-of-Concept in the Sepetiba Bay (SE, Brazil). *Front. Ecol. Evol.* **2022**, *10*, 852439. [CrossRef]
12. Horrocks, M.; Nichol, S.L.; D'Costa, D.M.; Augustinus, P.; Jacobi, T.; Shane, P.A.; Middleton, A. A late quaternary record of natural change and human impact from Rangihoua Bay, bay of islands, northern New Zealand. *J. Coast. Res.* **2007**, *233*, 592–604. [CrossRef]
13. MacDonald, D.G.; Carlson, J.; Goodman, L. On the heterogeneity of stratified-shear turbulence: Observations from a near-field river plume. *J. Geophys. Res. Oceans.* **2013**, *118*, 6223–6237. [CrossRef]
14. Horner-Devine, A.R.; Hetland, R.D.; MacDonald, D.G. Mixing and transport in coastal river plumes. *Annu. Rev. Fluid Mech.* **2015**, *47*, 569–594. [CrossRef]
15. Wright, L.D. Sediment transport and deposition at river mouths: A synthesis. *GSA Bull.* **1977**, *88*, 857–868. [CrossRef]
16. De Pippo, T.; Donadio, C.; Pennetta, M. Morphological control on sediment dispersal along the southern Tyrrhenian coastal zones (Italy). *Geol. Romana.* **2003**, *37*, 113–121.
17. Budillon, F.; Esposito, E.; Iorio, M.; Pelosi, N.; Porfido, S.; Violante, C. The geological record of storm events over the last 1000 years in the Salerno Bay (Southern Tyrrhenian Sea): New proxy evidences. *Adv. Geosci.* **2005**, *2*, 123–130. [CrossRef]
18. Sacchi, E.; Conti, M.A.; D'Orazi Porchetti, S.; Logoluso, A.; Nicosia, U.; Perugini, G.; Petti, F.M. Aptian dinosaur footprints from the Apulia platform (Bisceglie, southern Italy) in the framework of the periadriatic ichnosites. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2009**, *271*, 104–116. [CrossRef]
19. Lirer, F.; Sprovieri, M.; Ferraro, L.; Vallefuoco, M.; Capotondi, L.; Cascella, A.; Petrosino, P.; Insinga, D.D.; Pelosi, N.; Tamburrino, S.; et al. Integrated stratigraphy for the late Quaternary in the eastern Tyrrhenian Sea. *Quat. Int.* **2013**, *292*, 71–85. [CrossRef]
20. Lirer, F.; Sprovieri, M.; Vallefuoco, M.; Ferraro, L.; Pelosi, N.; Giordano, L.; Capotondi, L. Planktonic foraminifera as bio-indicators for monitoring the climatic changes that have occurred over the past 2000 years in the southeastern Tyrrhenian Sea. *Integr. Zool.* **2014**, *9*, 542–554. [CrossRef]
21. Bonomo, S.; Cascella, A.; Alberico, I.; Sorgato, S.; Pelosi, N.; Ferraro, L.; Lirer, F.; Vallefuoco, M.; Agnini, C.; Pappone, G.; et al. Reworked Coccoliths as runoff proxy for the last 400 years: The case of Gaeta Gulf (Central Tyrrhenian Sea, Central Italy). *Palaeogeogr. Palaeoclimatol. Palaeoecol.* **2016**, *459*, 15–28. [CrossRef]
22. Margaritelli, G.; Vallefuoco, M.; Di Rita, F.; Capotondi, L.; Bellucci, L.G.; Insinga, D.D.; Petrosino, P.; Bonomo, S.; Cacho, I.; Cascella, A.; et al. Marine response to climate changes during the last five millennia in the central Mediterranean Sea. *Glob. Planet. Change* **2016**, *142*, 53–72. [CrossRef]
23. Di Rita, F.; Lirer, F.; Bonomo, S.; Cascella, A.; Ferraro, L.; Florindo, F.; Insinga, D.D.; Lurcock, P.C.; Margaritelli, G.; Petrosino, P.; et al. Late Holocene forest dynamics in the Gulf of Gaeta (central Mediterranean) in relation to NAO variability and human impact. *Quat. Sci. Rev.* **2018**, *179*, 137–152. [CrossRef]
24. Misuraca, M.; Budillon, F.; Tonielli, R.; Di Martino, G.; Innangi, S.; Ferraro, L. Coastal Evolution, Hydrothermal Migration Pathways and Soft Deformation along the Campania Continental Shelf (Southern Tyrrhenian Sea): Insights from High-Resolution Seismic Profiles. *Geosciences* **2018**, *8*, 121. [CrossRef]
25. D'Alisa, G.; Armiero, M.; De Rosa, S.P. Political ecology: Rethink Campania's toxic-waste scandal. *Nature* **2015**, *509*, 427. [CrossRef]
26. Legambiente. Rapporto Ecoma I Numeri e le Storie Della Criminalità Ambientale Legambiente: Roma, Italy. 2014. Available online: http://www.amblav.it/download/0417_ecomafia_introduzione.pdf (accessed on 31 March 2020).
27. Triassi, M.; Montuori, P.; Provvisiero, D.P.; De Rosa, E.; Di Duca, F.; Sarnacchiaro, P.; Díez, S. Occurrence and spatial-temporal distribution of atrazine and its metabolites in the aquatic environment of the Volturno River estuary, southern Italy. *Sci. Total Environ.* **2022**, *803*, 149972. [CrossRef]
28. Astraldi, M.; Gasparini, G.P. The seasonal characteristics of the circulation in the Tyrrhenian Sea. In *Seasonal and Interannual Variability of the Western Mediterranean Sea Coastal and Estuarine Studies*; La Violette, P., Ed.; American Geophysical Union: Washington, DC, USA, 1994; Volume 46, pp. 115–134.
29. Radicati di Brozolo, F.; Di Girolamo, P.; Turi, B.; Oddone, M. 40Ar/39Ar and K-Ar dating of K-rich rocks from the Roccamonfina volcano, roman comagmatic region, Italy. *Geoch. Cosmo. Acta* **1988**, *52*, 1435–1441. [CrossRef]
30. de Alteriis, G.; Fedi, M.; Passaro, P.; Siniscalchi, A. Magneto-seismic interpretation of subsurface volcanism in the Gaeta Gulf (Italy, Tyrrhenian Sea). *Ann. Geophys.* **2006**, *49*, 4–5. [CrossRef]
31. Iermano, I.; Liguori, G.; Iudicone, D.; Nardelli, B.; Colella, S.; Zingone, A.; Saggiomo, V.; Ribera d'Alcalà, M. Filament formation and evolution in buoyant coastal waters: Observation and modelling. *Prog. Oceanogr.* **2012**, *106*, 118–137. [CrossRef]
32. Bonomo, S.; Cascella, A.; Alberico, I.; Ferraro, L.; Giordano, L.; Lirer, F.; Vallefuoco, M.; Marsella, E. Coccolithophores from near the Volturno estuary (central Tyrrhenian Sea). *Mar. Micropaleontol.* **2014**, *111*, 26–37. [CrossRef]

33. Moretti, M.; Sansone, E.; Spezie, G.; Vultaggio, M.; De Maio, A. Alcuni aspetti del movimento delle acque del Golfo di Napoli. *Annali IUN* **1977**, *45–46*, 207–217.
34. Sorgente, R.; Di Maio, A.; Pessini, F.; Ribotti, A.; Bonomo, S.; Perilli, A.; Alberico, I.; Lirer, F.; Cascella, A.; Ferraro, L. Impact of Freshwater Inflow From the Volturno River on Coastal Circulation. *Front. Mar. Sci.* **2020**, *7*, 293. [CrossRef]
35. Nava, M.L.; Giampaola, D.; Laforgia, E.; Boenzi, G. Tra il Clanis e il Sebeto: Nuovi dati sull'occupazione della piana campana tra il Neolitico e l'eta del Bronzo. *Atti della XL Riun. Sci. Ist. It. di Preist. e Prot.* **2007**, *1*, 101–126.
36. Amorosi, A.; Pacifico, A.; Rossi, V.; Ruberti, D. Late Quaternary incision and deposition in an active volcanic setting: The Volturno valley fill, southern Italy. *Sediment. Geol.* **2012**, *282*, 307–320. [CrossRef]
37. Rezza, C.; Albanese, S.; Lima, A.; De Vivo, B. Geochemical Characterization, Isotopic Approach and Environmental Risk Assessment in the Domizio Flegreo and Agro Aversano Area (Campania Region). Available online: https://www.researchgate.net/publication/278689393_Geochemical_characterization_isotopic_constraints_and_environmental_risk_assessment_in_the_Domizio_Flegreo_and_Agro_Aversano_area_Campania_region (accessed on 22 December 2022).
38. Mancini, L.; Cero, C.D.; Gucci, P.; Venturi, L.; Carlo, M.D.; Volterra, L. Il fiume Volturno-la definizione dello stato di salute del corpo idrico. *Inquinamento* **1994**, *10*, 70–83.
39. Parrella, A.; Isidori, M.; Lavorgna, M.; Dell'Aquila, A. Stato di qualità del fiume Volturno integrato da indagini di tossicità e genotossicità. *Ann. Ig.* **2003**, *15*, 147–157.
40. Montuori, P.; De Rosa, E.; Sarnacchiaro, P.; Di Duca, F.; Provvisiero, D.P.; Nardone, A.; Triassi, M. Polychlorinated biphenyls and organochlorine pesticides in water and sediment from Volturno River, Southern Italy: Occurrence, distribution and risk assessment. *Environ. Sci. Eu.* **2020**, *32*, 123. [CrossRef]
41. Montuori, P.; De Rosa, E.; Di Duca, F.; Provvisiero, D.P.; Sarnacchiaro, P.; Nardone, A.; Triassi, M. Estimation of Polycyclic Aromatic Hydrocarbons Pollution in Mediterranean Sea from Volturno River, Southern Italy: Distribution, Risk Assessment and Loads. *Int. J. Environ. Res. Public Health.* **2021**, *18*, 1383. [CrossRef]
42. Sgarrella, F.; Moncharmont Zei, M. Benthic foraminifera of the Gulf of Naples (Italy): Systematics and autoecology. *Boll. Soc. Paleontol. Ital.* **1993**, *32*, 145–264.
43. Milker, Y.; Schmiedl, G. A taxonomic guide to modern benthic shelf foraminifera of the western Mediterranean Sea. *Palaeontol. Electron.* **2012**, *15*, 1–134. [CrossRef]
44. Hayward, B.W.; Le Coze, F.; Vachard, D.; Gross, O. World Foraminifera Database. Foraminiferida. 2022. Available online: https://www.marinespecies.org/aphia.php?p=taxdetails&id=22528 (accessed on 22 December 2022).
45. Chao, A.; Shen, T.-J. Nonparametric estimation of Shannon' s index of diversity when there are unseen species in sample. *Environ. Ecol. Stat.* **2003**, *10*, 429–443. [CrossRef]
46. Kaiho, K. Benthic foraminiferal dissolved-oxygen index and dissolved-oxygen levels in the modern ocean. *Geology* **1994**, *22*, 719–722. [CrossRef]
47. Kranner, M.; Harzhauser, M.; Beer, C.; Auer, G.; Piller, W.E. Calculating dissolved marine oxygen values based on an enhanced Benthic Foraminifera Oxygen Index. *Sci. Rep.* **2022**, *12*, 1376. [CrossRef] [PubMed]
48. 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 the organic flux. *Mar. Micropalentol.* **1992**, *19*, 131–146. [CrossRef]
49. 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. [CrossRef]
50. Altenbach, A.V.; Pflaumann, U.; Schiebel, R.; Thies, A.; Timm, S.; Trauth, M. Scaling percentages and distributional patterns of benthic foraminifera with flux rates of organic carbon. *J. Foram. Res.* **1999**, *29*, 173–185.
51. Fontanier, C.; Jorissen, F.J.; Licari, L.; Alexandre, A.; Anschutz, P.; Carbonel, P. Live benthic foraminiferal faunas from the Bay of Biscay: Faunal density, composition, and microhabitats. *Deep Sea Res. Part I Oc. Res. P.* **2002**, *49*, 751–785. [CrossRef]
52. Frezza, V.; Guillem, M.V.; Gaglianone, G.; Baldassarre, A.; Brandano, M. Mixed carbonate-siliclastic sediments and benthic foraminiferal assemblages from Posidonia oceanica seagrass meadows of the central Tyrrhenian continental shelf (Latium, Italy). *It. J. Geosci.* **2011**, *130*, 352–369. [CrossRef]
53. Hausser, J.; Strimmer, K. *Estimation of Entropy, Mutual Information and Related Quantities*; R Package Version; R Fundation for Statistical Computing: Vienna, Austria, 2014.
54. Oksanen, O.; Blanchet, F.G.; Kindt, R.; Legendre, P.; Minchin, P.R.; O'Hara, B.; Simpson, G.L.; Solymos, P.; Stevens, H.; Wagner, H.H. *Vegan: Community Ecology Package*; R Fundation for Statistical Computing: Vienna, Austria, 2016.
55. Juggins, S. Rioja: Analysis of Quaternary Science Data. R Package Version 1.0-5. 2022. Available online: https://cran.r-project.org/web/packages/rioja/rioja.pdf (accessed on 31 October 2022).
56. Grimm, E.C. CONISS: A FORTRAN 77 program for stratigraphically constrained cluster analysis by the method of incremental sum of squares. *Comp. Geosci.* **1987**, *13*, 13–35. [CrossRef]
57. Juggins, S. Rioja-Package. Analysis of Quaternary Science Data. 2020. Available online: https://cran.r-project.org/package=rioja. (accessed on 31 October 2022).

58. Annali Delle Bonificazioni—Anno I—1858. Pianta Generale del Bacino Inferiore del Volturno con la Indicazione Delle Opere di Strade e di Canali Eseguite dal Real Governo. Available online: http://www.cesbim.it/2015/04/pianta-generale-del-bacino-inf-del-volturno-con-la-indicazione-delle-opere-di-strade-e-di-canali-eseguite-dal-real-governo-annali-delle-bonificazioni-anno-i-1858/ (accessed on 31 October 2022).
59. Istituto Geografico Militare. *Cartografia 1:25000*; Istituto Geografico Militare: Florence, Italy, 1914.
60. Satellite Imagery, Google Earth, 1990. Available online: https://earth.google.com/web/@10.75336992,34.7685858,620.74481137a,19580026.14889823d,35y,0h,0t,0r/data=Ci4SLBIgOGQ2YmFjYjU2ZDIzMTFlOThiNTM2YjMzNGRiYmRhYTAiCGxheWVyc18w (accessed on 31 October 2022).
61. Ruberti, D.; Vigliotti, M.; Di Mauro, A.; Chieffi, R.; Di Natale, M. Human influence over 150 years of coastal evolution in the Volturno delta system (southern Italy). *J. Coast Cons.* **2018**, *22*, 897–917. [CrossRef]
62. Ruberti, D.; Buffardi, C.; Sacchi, M.; Vigliotti, M. The late Pleistocene-Holocene changing morphology of the Volturno delta and coast (northern Campania, Italy): Geological architecture and human influence. *Quat. Int.* **2022**, *625*, 14–28. [CrossRef]
63. Incarbona, A.; Ziveri, P.; Di Stefano, E.; Lirer, F.; Mortyn, G.; Patti, B.; Pelosi, N.; Sprovieri, M.; Tranchida, G.; Vallefuoco, M.; et al. Calcareous nannofossil assemblages from the Central Mediterranean Sea over the last four centuries: The impact of the Little Ice Age. *Clim. Past* **2010**, *6*, 817–866. [CrossRef]
64. Blanc-Vernet, L. Contribution à l'étude des Foraminifères de Mèditerranée. *Rec. Trav. St. Mar. Endoume* **1969**, *48*, 5–281.
65. Bergamin, L.; Di Bella, L.; Carboni, M.G. *Valvulineria bradyana* (Fornasini) in organic matter-enriched environment. *Il Quaternario.* **1999**, *12*, 51–56.
66. 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. [CrossRef]
67. Frezza, V.; Argenti, L.; Bonifazi, A.; Chiocci, F.L.; Di Bella, L.; Ingrassia, M.; Martorelli, E. Benthic Foraminiferal Assemblages and Rhodolith Facies Evolution in Post-LGM Sediments from the Pontine Archipelago Shelf (Central Tyrrhenian Sea, Italy). *Geosciences* **2021**, *11*, 179. [CrossRef]
68. Alberico, I.; Cavuoto, G.; Di Fiore, V.; Punzo, M.; Tarallo, D.; Pelosi, N.; Ferraro, L.; Marsella, E. Historical maps and satellite images as tools for shoreline variations and territorial changes assessment: The case study of Volturno Coastal Plain (Southern Italy). *J. Coast. Cons.* **2018**, *22*, 919–937. [CrossRef]
69. Di Rita, F.; Lirer, F.; Margaritelli, G.; Michelangeli, F.; Magri, D. Climate and human influence on the vegetation of Tyrrhenian Italy during the last 2000 years: New insights from microcharcoal and non-pollen palynomorphs. *Geogr. Fis. Din. Quaternaria.* **2019**, *42*, 203–214. [CrossRef]
70. Vallefuoco, M.; Lirer, F.; Ferraro, L.; Pelosi, N.; Capotondi, L.; Sprovieri, M.; Incarbona, A. Climatic variability and anthropogenic signatures in the Gulf of Salerno (southern-eastern Tyrrhenian Sea) during the last half millennium. *R. Acc. Lincei.* **2012**, *23*, 13–23. [CrossRef]
71. Donadio, C.; Vigliotti, M.; Valente, R.; Stanislao, C.; Ivaldi, R.; Ruberti, D. Anthropic vs. natural shoreline changes along the northern Campania coast, Italy. *J. Coast. Cons.* **2018**, *22*, 939–955. [CrossRef]
72. Checa, H.; Margaritelli, G.; Pena, L.D.; Frigola, J.; Cacho, I.; Rettori, R.; Lirer, F. High resolution paleo-environmental changes during the Sapropel 1 in the North Ionian Sea, central Mediterranean. *Holocene* **2020**, *30*, 1504–1515. [CrossRef]