Original Research Article

Community structure of intertidal macrofauna: spatial autocorrelation of two rocky coasts of Gujarat, India

ABSTRACT

The present study describes the community structure of intertidal macrofauna on two rocky coasts of the Kathiawar Peninsula, Gujarat State. Data were recorded for three ecological attributes: density, abundance, and frequency of intertidal fauna. The results highlighted spatial autocorrelation between the two study sites. The Mantel correlogram suggests a significant positive correlation along the Veraval coast, likely due to its exclusively rocky intertidal habitats, which provide consistent favorable habitats and contribute to similar species distributions and community structures throughout the area. Conversely, the Adri coast indicates a negative correlation. That can be attributed to the heterogeneous habitat of its intertidal zones, which include both sandy and rocky patches. The mixed habitat types on the Adri coast create distinct regions that likely lead to more diverse and less predictable species distributions, thus resulting in a negative correlation. Present study emphasized the need of more ecological studies of a diverse marine ecosystem.

Keywords: intertidal macrofauna;dominant phyla; spatial autocorrelation; Gujarat;India.

1. INTRODUCTION

Marine biodiversity is basically studied in coastal seas and around islands. Across all levels of biological organisation, about 60% of the human population resides in the coastal zone, which constitutes 18% of the surface of Earth [16]. All levels of biological organization, such as genes, species, and populations, as well as ecosystems, constitute marine biodiversity, which is the sum of highly interconnected ecosystemcharacteristics or components. Each level of diversity has distinct functional and structural characteristics [2]. Marine biodiversity plays a significant role in the global biodiversity landscape, particularly when it comes to deep diversity or essentially different forms of life that are distinguished not by individual species but by whole phyla.
Phyla represent essentially distinct forms of life because they constitute the second level of taxonomic categorization after kingdoms [9]. Macrofauna is crucial to many ecological processes, including food webs, pollution metabolism, nutrient cycling, secondary production, burial, and dispersal [11]. Ecological dominance is characterised as one or more species having a significant controlling influence over all other species based on their size, production, or associated activities [14]. Understanding the spatial distribution patterns may help to better comprehend the scale at which biological interactions, or ecological processes, take place. Assessing the spatial distribution of species and patterns of biodiversityis a fundamental aspect of ecology[15–6].The study of past and present organism spatial distributions is crucial to understanding all patterns of geographic variation in nature,from genes to entire communities and ecosystems. Biological diversity is influenced by factors that change across geographic gradients, such as area, isolation, latitude, depth, and elevation [7].

Global collaboration, internet databases, and statistical tools have all grown in importance in recent years, advancing the field and enabling researchers to uncover marine macroecological patterns and ascertain the variables determining the breadth of a species geographic distribution. While there have been some efforts to utilise species distribution to define ecological units, the majority of research has concentrated on a particular group of species or at the community level [8]. The spatial organization of biological populations and communities underscores the limitations of simple statistical techniques in ecological investigations. It explores methods for spatially organizing biological populations using techniques such as partial mantel tests, mantel correlogram, multivariate variograms, univariate approaches, and mapping ecological factors [5]. A basic method for spectral analysis of multispecies data from many species at different time scales or stratigraphic levels was introduced. Any ecological similarity measurement can be used with the Mantel correlogram-based technique [4]. The current study focused on the dominant phylum of the Veraval and Adri coasts, examining seasonal variations in ecological attributes such as density, abundance, and frequency. The results also indicated spatial autocorrelation at both sites using Mantel correlogram analysis. The Mantel correlogram was selected as the analytical method because it allows for a detailed examination of the spatial autocorrelation between data from the two sites. A mantel correlogram is a technique used in ecology and biogeography to examine the spatial autocorrelation of two sets of data.

2. MATERIAL AND METHODS

The present study was conducted on two rocky shores of the Kathiawar Peninsula in Gujarat: the Veraval coast, spanning approximately 4 kilometers (20°54'35" N, 70°21'08" E), and the Adri coast, spanning 1.5 kilometers (20°96'07" N, 70°27'94" E) (Fig. 1). Sites were studied seasonally, from winter to post-monsoon, during low tide in the intertidal area.

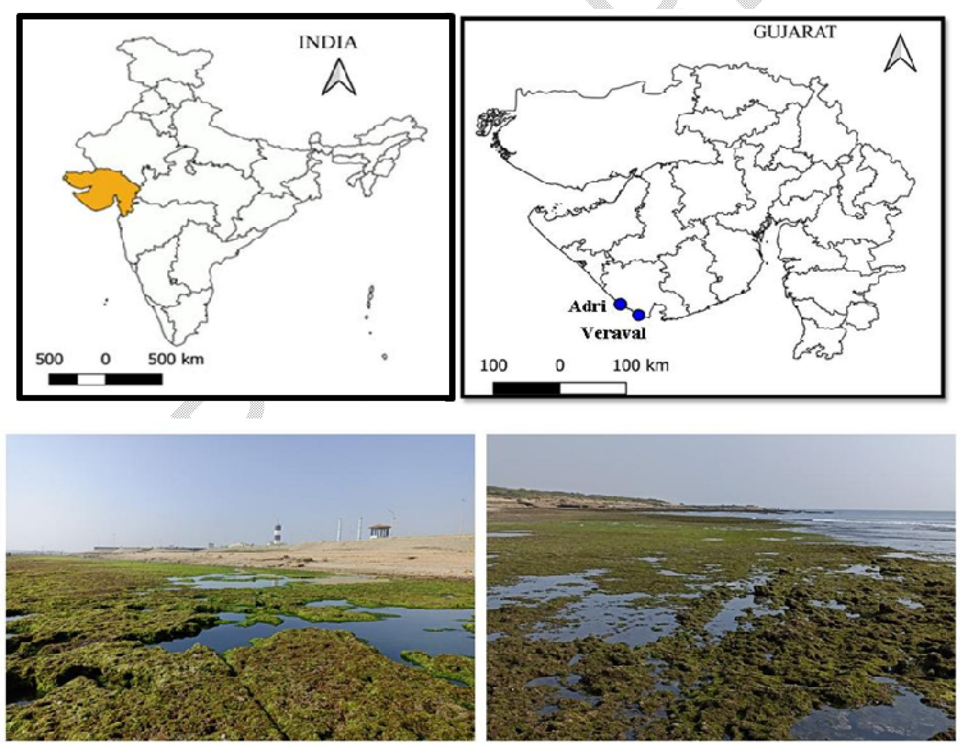

Fig. 1. Map of the study site: Veraval Coast, Adri Coast, Gujarat.

The intertidal macrofauna species have been assessed using the quadrat sampling method. A 0.25 m² quadrat frame was systematically placed at regular intervals using stratified random sampling to assess the macrofauna population in each zone of both coasts, with data recorded for three ecological attributes: density, abundance, and frequency.The coastal area of Veraval has a mostly rocky type of intertidal habitat and outcrops studded with rock. The upper, middle, and lower intertidal zones are predominantly rocky, while the supratidal zone is characterized by extensive rock cover interspersed with smaller areas of sandy patches (Fig. 1).

Adri coastal region featuring a blend of rocky and sandy intertidal environments, specifically, the supratidal zone is predominantly covered by sand, while the upper, middle, and lower intertidal zones each exhibit a rocky-sandy composition, reflecting distinct ecological zones along the coastal area (Fig. 1).

3. RESULTS AND DISCUSSION

The present study conducted a comparative analysis of intertidal macrofauna along the Adri and Veraval coasts, revealing intriguing patterns in the distribution of dominant phyla. The data highlights eight distinct phyla, with observable variations in their numbers between the two coasts: Porifera, Cnidaria, Platyhelminthes, Nemertea, Annelida, Arthropoda, Mollusca, and Echinodermata. Mollusca, with a notable total of 53 species, emerge as the most prevalent phylum on the Veraval Coast.

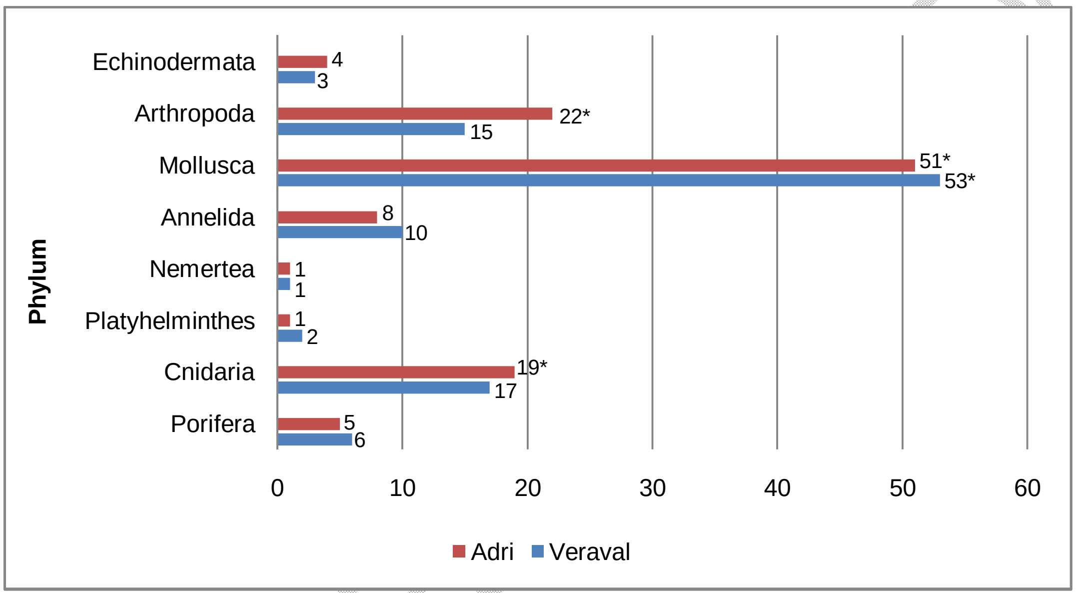

Fig. 2. Macrofauna species along the Veraval and Adri coast

This suggests that the substrate type and favourable conditions along the Veraval coast are highly favourable for the mollusc population. Other contributing phyla included Cnidaria (17 species), Arthropoda (15 species), and Annelida (10 species), indicating that the intertidal habitat provides favourable conditions for this phylum as well. However, the other phyla like Porifera (6 species), Echinodermata (3 species), Platyhelminthes (2 species), and Nemertea (1 species) (Fig. 2) reveal that these organisms either have more specialised habitat needs or face competitive challenges on the studied coast.Conversely, the Adri coast presents a different pattern. Mollusca, the most dominant with 51 species, shows similarity compared to Veraval. This suggests that the microscale habitats and climatic conditions are ideal for sustaining mollusc species a constant throughout the seasons [3]. However, Arthropoda is a more prevalent phylum in Adri, with 22 species, suggesting that this coastal region provides optimal conditions for arthropods, possibly due to factors such as food availability, habitat diversity, and lower predation pressure. Cnidaria has 19 species, indicating a more suitable environment for these organisms. Other phyla observed were Annelida (8 species), Porifera (5 species), Echinodermata (4 species), Platyhelminthes (1 species), and Nemertea (1 species) (Fig. 2), highlighting their specific habitat requirements and favourable conditions.This consistency might imply that these phyla are less sensitive to the variations in coastal conditions between Veraval and Adri. On both coasts, Platyhelminthes and Nemertea have minimum species (Platyhelminthes: 2 in Veraval and 1 in Adri; Nemertea: 1 in both), indicating that these phyla are rare or have very specific characteristics that are not widely available in either coastal region.

The overall dominance of Mollusca on both coasts underscores the ecological importance of this phylum in coastal ecosystems. However, the higher prevalence of Arthropoda and Cnidaria in Adri highlights regional differences that could be attributed to ecological variations such as habitat structure and interspecies interactions. This data not only emphasizes the rich biodiversity along these coasts but also points to the complex interplay of environmental factors that shape the distribution of marine life. Understanding these patterns is crucial for marine conservation efforts, as it helps identify critical habitats and inform strategies to protect and conserve marine biodiversity.

The graph displays information on the frequency, density, and abundance of different marine phyla along the Veraval coast during the seasons of monsoon (M), post-monsoon (PM), winter (W), and summer (S) (Fig. 3, 4, and 5). This data provides insights into the ecological dynamics of phyla and highlights the seasonal fluctuations in their presence. The data from the Veraval coast display an extensive representation of density, abundance, and frequency across different seasons, reflecting the intricate ecological dynamics of coastal ecosystems. This data reveals distinct patterns in the density, abundance, and frequency of marine phyla across seasons. The data shows that along the Veraval coast, Mollusca maximum density was reported in all seasons, especially high in winter, and minimum density was noted during the monsoon and post-monsoon.

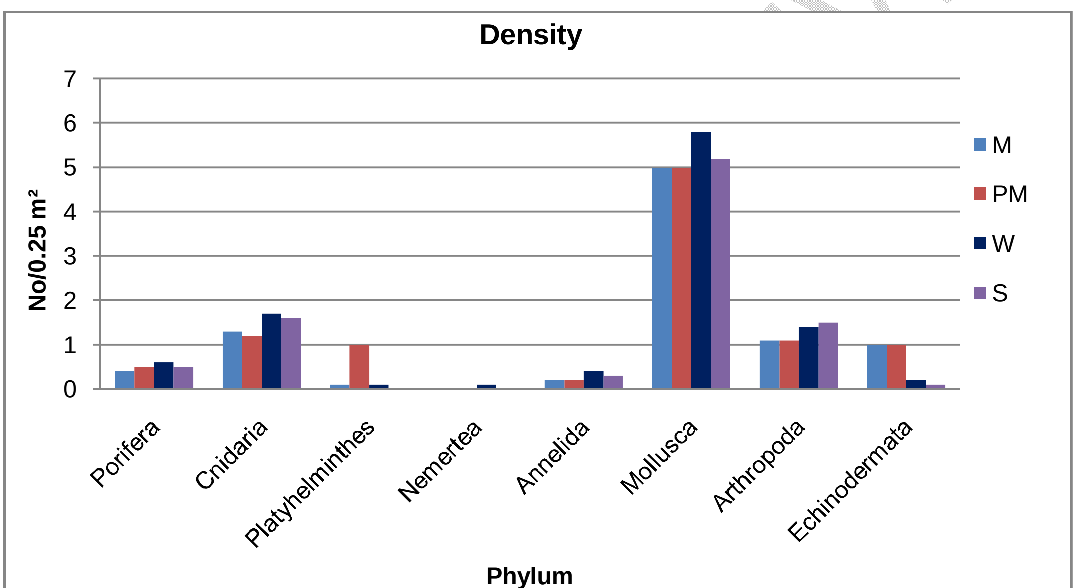

Fig. 3. Seasonal variations in density of studiedmacrofauna species along Veraval coast

The maximum density of Arthropoda and Cnidaria was noted during the summer and winter, while the minimum density was reported in the monsoon and post-monsoon, respectively. The minimum density of Nemertea was reported in winter, and Annelida, Porifera, had the highest density reported in winter and the lowest density in other seasons. Platyhelminthes and Echinodermata had the highest density reported in the monsoon and post-monsoon and the lowest density in winter and summer (Fig. 3).Phylum Mollusca was the most dominant in all seasons compared to other phyla. The maximum abundance of Mollusca was reported in summer and post-monsoon, especially high in winter, and the minimum abundance was noted during the monsoon. The highest abundance of Cnidaria was noted post-monsoon and during the monsoon, and the lowest during summer. The maximum abundance of Arthropoda was recorded post-monsoon and in summer, while the lowest was reported in winter. The minimum abundance of Nemertea was reported in the winter, and Porifera was reported to have the highest abundance in winter and the lowest abundance in other seasons.The highest abundance of Annelida was noted in the summer and the lowest during the winter and the lowest abundance of Platyhelminthes was reported in all seasons and was not recorded in the post-monsoon period.The lowest abundance of Echinodermata was recorded across all other seasons, while the highest abundance was recorded during the monsoon (Fig. 4).

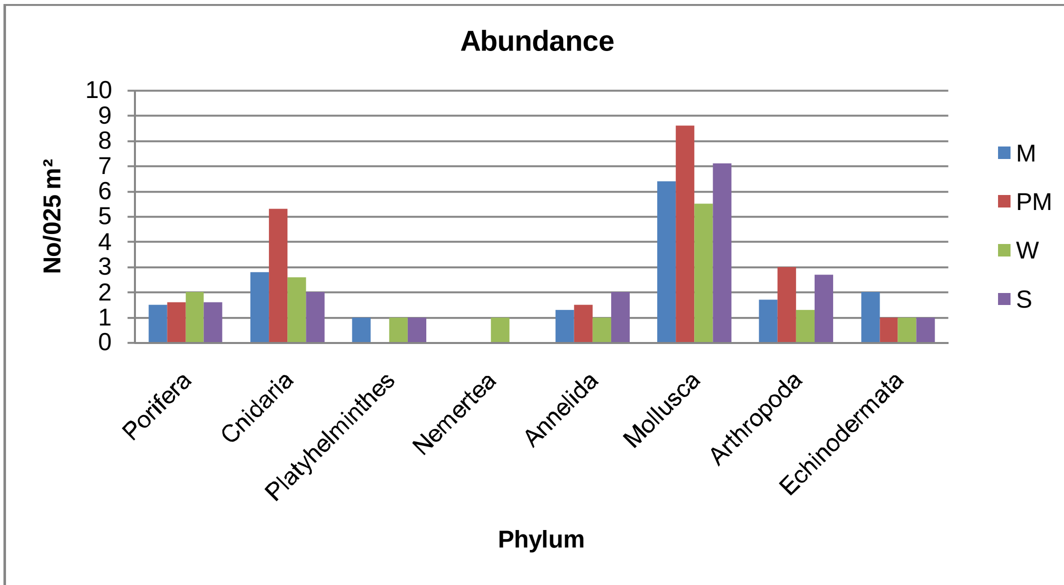

Fig. 4. Seasonal variations in abundance of studiedmacrofauna species along Veraval coast

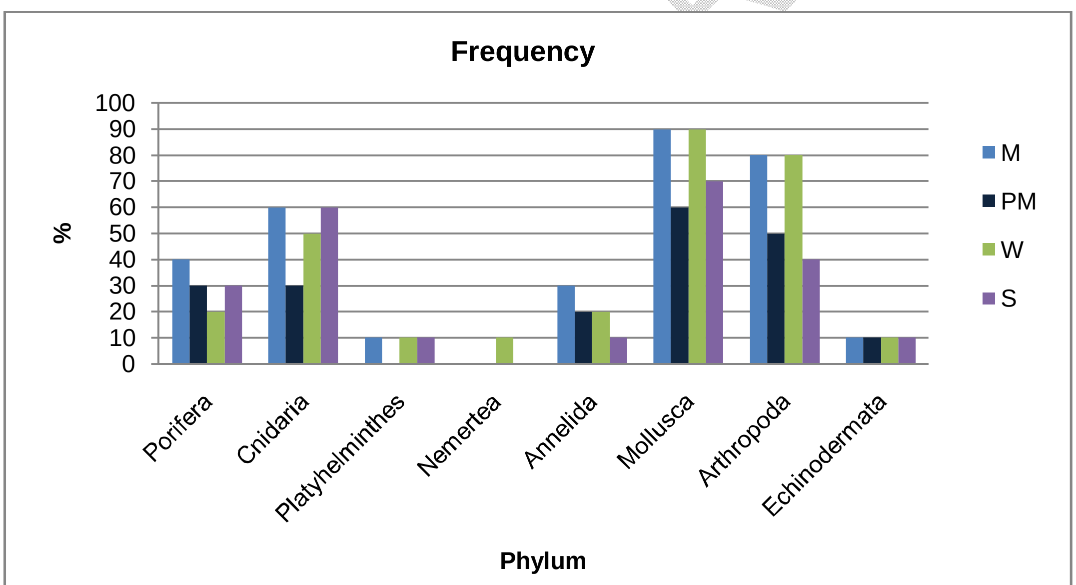

Fig. 5. Seasonal variations in frequency of studiedmacrofauna species along Veraval coast

Mollusca maximum frequency was reported in winter and monsoon, and minimum frequency was noted during post-monsoon. The minimum frequency of Arthropoda was noted during the summer and the maximum frequency was reported in the winter and the monsoon. The maximum frequency of Cnidaria was noted during the summer and monsoon, while the minimum frequency was reported post-monsoon, respectively. The minimum frequency of Nemertea was reported in winter, and Annelida had the highest frequency reported in the monsoon and the lowest frequency in the summer. Porifera has the highest reported frequency in the monsoon and the lowest frequency in the winter, while both Platyhelminthes and Echinodermata have low frequencies in all seasons (Fig. 5).

Overall, the data from the Veraval coast illustrates varying ecological preferences and adaptations among different marine phyla, reflecting the complex dynamics of coastal ecosystems. The data emphasises the diverse ecological preferences and adaptations among marine phyla in coastal ecosystems. Understanding these patterns is critical, as the data reveal the way distinct species react to environmental changes along the Veraval coast.

The data from the Adri coast reveals distinct patterns in the density, abundance, and frequency of marine phyla across different seasons. Mollusca emerge as the most dominant phylum, consistently showing high density values across all phyla throughout the year. The minimum density of Mollusca was noted during the post-monsoon and the maximum density was reported in all seasons, especially high in the summer. The maximum density of Arthropoda and Cnidaria was noted during the winter, while the minimum density was reported in the monsoon and post monsoon, respectively. The minimum density of Nemertea was reported in winter and summer, which was nearly reported absent all seasons.The highest density of Annelida and Porifera was recorded in winter and the lowest density was reported in other seasons. For Platyhelminthes and Echinodermata, the highest density was reported in winter, and the lowest density was recorded during summer and post-monsoon (Fig. 6).

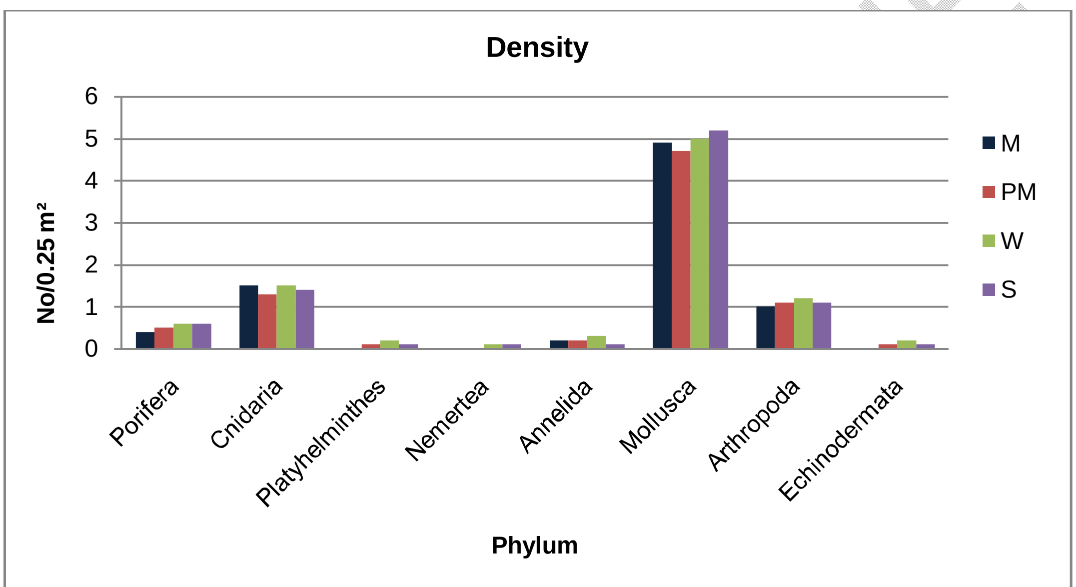

Fig. 6. Seasonal variations in density of studiedmacrofauna species along Adri coast

In comparison to other phyla, the Mollusca phylum was the most prevalent during all seasons. The highest abundance of Mollusca was reported in summer and the lowest abundance was noted during the winter. The maximum abundance of Cnidaria was noted during the winter and the minimum abundance occurred during the monsoon. The maximum abundance of Arthropoda was recorded post-monsoon and in winter, while the lowest was reported in summer. The minimum abundance of Nemertea was reported in the winter and summer, as it is nearly reported absent in other seasons. Porifera had the highest abundance reported in winter and the lowest abundance in post-monsoon. The highest abundance of Annelida was noted in the monsoon and the lowest during all seasons. Platyhelminthes had the highest abundance during the monsoon and the lowest abundance during all seasons. The minimum abundance of Echinodermata was noted in all other seasons (Fig. 7).Mollusca range frequency was highest in the winter and monsoon and lowest in the post-monsoon. The maximum frequency of Arthropoda was reported in the summer, the minimum frequency was noted during the winter, while the high frequency of Cnidaria was noted during the summer and post-monsoon, and the low frequency was reported during the monsoon, respectively. The minimum frequency of Nemertea was reported in the winter, which was noted to be nearly absent in other seasons. Annelida had the highest frequency reported in the winter, summer, and monsoon and the lowest frequency in the post-monsoon.Porifera had the maximum frequency reported in the winter, summer, and monsoon and the minimum frequency in the post-monsoon.The low frequency of Platyhelminthes was noted in the summer, monsoon, and post-monsoon, whereas a high frequency of Echinodermata was recorded during the monsoon and a low frequency in other seasons (Fig. 8).

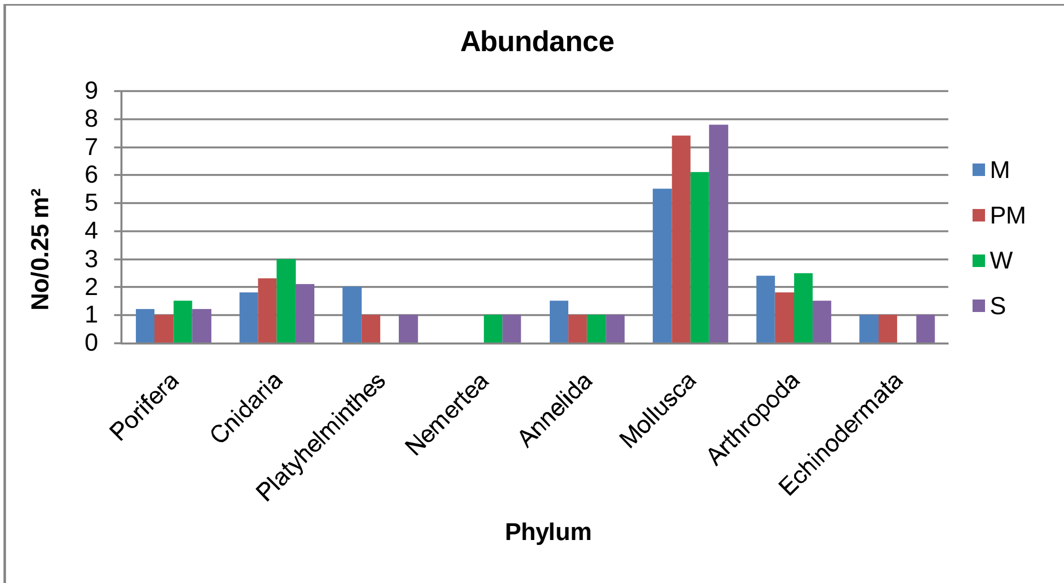

Fig. 7. Seasonal variations in abundance of studiedmacrofauna species along Adri coast

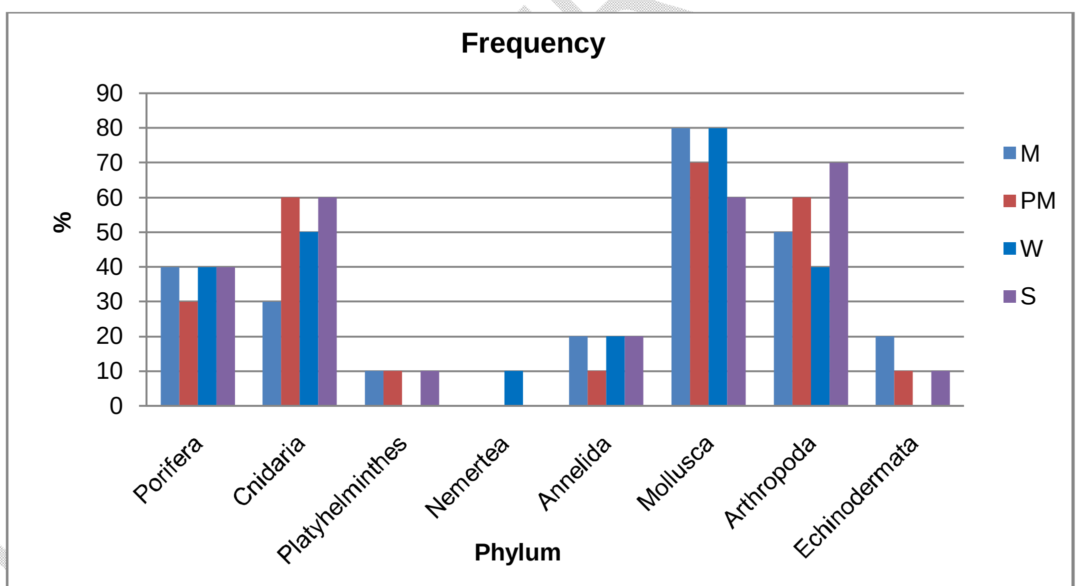

Fig. 8. Seasonal variations in frequency of studiedmacrofauna species along Adri coast

These patterns highlight the diverse ecological dynamics and varying ecological communities occupied by marine phyla on the Adri coast, which are influenced by seasonal changes and specific habitat requirements. A comparison of marine phyla data between the Veraval coast and Adri coast reveals significant differences in the distribution patterns of various phyla across seasons. Mollusca consistently show higher values in density, abundance, and frequency on both coasts, indicating its robust presence in diverse microhabitats. Cnidaria exhibits notable fluctuations in density and abundance, with varying frequencies across seasons on both coasts, suggesting responsive adaptations to habitat and environmental changes. Porifera displays moderate values across seasons on both coasts, reflecting its stable but adaptable presence.Platyhelminthes and Nemertea show minimal presence and variability across seasons, with occasional peaks in abundance observed on both coasts. Annelida demonstrates moderate values in density and abundance, with stable frequencies on both coasts, indicative of its resilient adaptation to coastal environments. Arthropoda exhibits moderate to high values in density and abundance, with variable frequencies across seasons, reflecting its adaptable nature to changing environmental conditions. Echinodermata show consistent but low values in density, abundance, and frequency on coasts, suggesting specific habitat preferences. These comparisons highlight the influence that regional ecological factors, such as favourable conditions and habitat, have on the suitability of determining distribution patterns.

3.1 Spatial autocorrelation of two sites

Spatial structures, such as patches or gradients, are crucial in ecological theories and population sampling. Spatial heterogeneity is the consequence of living things aggregating into uniform and random distributions in nature. The components of an ecosystem are more likely to be impacted by the same producing process, highlighting the importance of spatial heterogeneity in ecological systems [5].

Spatial autocorrelation analysis of the rocky intertidal macrofauna species from the Veraval and Adri coasts in Gujarat, India, was performed using the Mantel correlogram technique in version 4.03 of the PAST software (https://past.en.lo4d.com/download). The intertidal habitat along the Veraval shore is predominantly rocky, with rocky outcrops interspersed with rock. The supratidal zone is covered by rock, while certain areas of the upper, middle, and lower intertidal zones are covered by sand. In contrast, the Adri coastal region has both rocky and sandy intertidal habitats, as well as sand-studded rocky outcrops. The supratidal zone is sandy, while the upper, middle, and lower intertidal zones are rocky-sandy. Geographic variation patterns in biological populations are being extensively utilised to characterise regional variation and infer conclusions about population structure using the method of spatial autocorrelation analysis [12-13-16].

3.1.1 The method of spatial autocorrelation – Mantel correlogram

For multivariate data, the Mantel correlogram is a sophisticated method of correlogram computation. In order to investigate this matter, numerical simulations based on randomly dispersed, normally distributed data are used to compare the Mantel correlogram results to those of other techniques [1].An ecological and biogeographic method for analysing the spatial autocorrelation of two data sets is the mantel correlogram. It assesses whether the similarity in one set of data corresponds to the spatial distance between locations where the data was collected. This can help identify patterns of spatial clustering or dispersion. The actual interpretation of the correlogram will depend on the specific patterns. The mantel correlogram chart illustrates the relationship between the ecological attributes of phyla and their positions in a distance matrix. Density data related to these attributes and distances has been evaluated using the quadrat method of random sampling.

In this chart (Fig. 9) showing data for the Veraval coast, colour coding is used to represent various levels of correlation. Light yellow indicates a weak negative correlation, while pale yellow indicates a moderate negative correlation. Orange is used to denote a strong negative correlation. On the positive side, light blue shows a moderate positive correlation, and dark blue indicates a strong positive correlation. This detailed colour scheme facilitates the interpretation of the data by visually distinguishing the different degrees of correlation between the ecological attributes of the phyla and their positions within the distance matrix. By using this colour-coded system, the chart provides a clear and intuitive understanding of the relationships being analyzed.

For the Adri coast, in this chart (Fig. 10), the colours indicate different levels of correlation. Yellow signifies a weak negative correlation, while orange denotes a moderate negative correlation. Red is used to represent a strong negative correlation. On the positive side, light blue indicates a moderate positive correlation, and dark blue signifies a strong positive correlation. Each colour helps to visually differentiate the varying degrees of correlation between the ecological attributes of the phyla and their positions within the distance matrix. This colour-coded system allows for an easier interpretation of the data presented in the mantel correlogram.

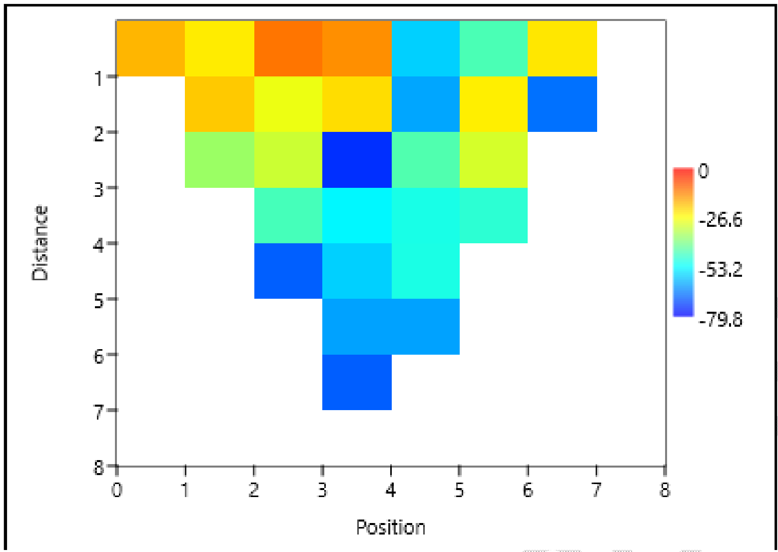

Fig. 9. Veraval site

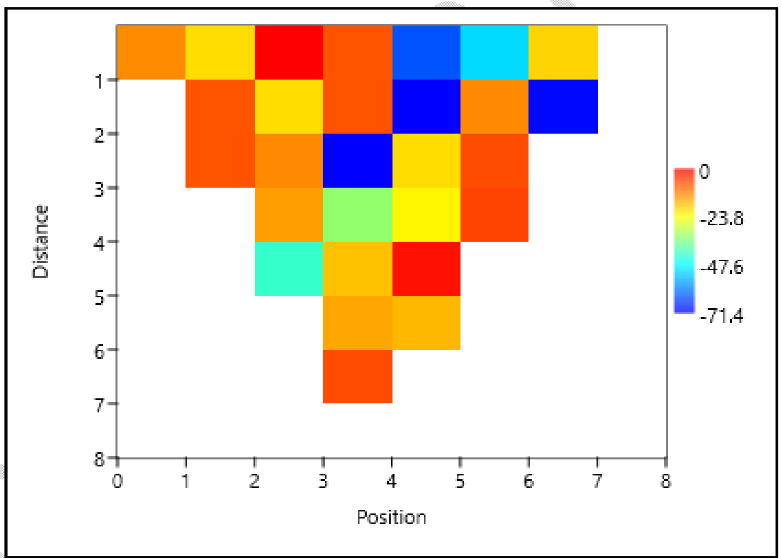

Fig. 10. Adri site

In this figure 9, the light blue and dark colours are more prominent as compared to the red colour so the Mantel correlogram indicates a strong positive correlation along the Veraval coast, which is most likely attributable to its rocky intertidal environments. Figure 10 shows that orange and dark red are more compared to blue so it implies the Adri coast exhibits a negative correlation. This difference may be due to the Adri coast having rocky and sandy coastal regions.The Mantel correlogram identified distribution patterns of species similarity based on distance and the colour-coded correlations. Positive Correlations: A positive Mantel correlation at a specific distance phylum indicates that sites within that distance are more similar in species composition than expected by chance. This could suggest the presence of dispersal limitations or other factors affecting distribution within that range. Negative Correlations: A negative Mantel correlation indicates that sites within that distance phylum are more dissimilar than expected by chance, which might be due to competitive interactions or environmental heterogeneity.

4. CONCLUSION

The present study focused on the dominant phyla along the rocky intertidal zones of the Veraval and Adri coasts of the Kathiawar Peninsula, Gujarat. Phylum mollusca was the most dominant phylum on both coasts. The substratum and intertidal zones along both coasts provide favourable habitats that support a rich diversity of macrofauna species. The Mantel correlogram indicates a strong positive correlation along the Veraval coast, which is most likely attributable to its rocky intertidal environments. On the other hand, the Adri coast exhibits a negative correlation. This difference may be due to the Adri coast having a blend of sandy and rocky coastal regions, which implies a distinct distribution pattern compared to the predominantly rocky habitats of the Veraval coast. This difference in habitats within the intertidal zone leads to different species distributions, resulting in spatial autocorrelation. Although these coastal regions are geographically close and distinguished by unique intertidal habitats and zonation patterns, both coasts display distinct coast characteristics, species richness, and diversity.

REFERENCES

1. Borcard D, and Legendre P. Is the Mantel correlogram powerful enough to be useful in ecological analysis? A simulation study. Ecology.2012;93(6),1473-1481.http://dx.doi.org/10.2307/23213776
2. Cochrane SK, Andersen JH, Berg T, Blanchet H, Borja A, Carstensen J, Renaud PE. What is marine biodiversity? Towards common concepts and their implications for assessing biodiversity status. Frontiers in Marine Science.2016;3-248.http://dx.doi.org/10.3389/fmars.2016.00248
3. Dodiya DP, and Poriya P. Distribution Patterns of Key Gastropods (Mollusca) Species Along the Intertidal Zone of Adri Coast, Kathiawar Peninsula, India. Environment and Ecology.2023;41(4),2266-2273.http://dx.doi.org/10.60151/envec/WHTV1322
4. Hammer O. Spectral analysis of a Plio-Pleistocene multispecies time series using the Mantel periodogram. Palaeoecology. 2007;243(3-4),373-377http://dx.doi.org/10.1016/j.palaeo.2006.08.009
5. Legendre P, and Fortin MJ. Spatial pattern and ecological analysis. Vegetatio.1989;80-107-138.https://doi.org/10.1007/BF00048036
6. Longhurst A. Ecological Geography of the Sea, second ed., Academic Press; London, 2007.
7. Lomolino MV, Riddle BR, BrownJH. third ed., Biogeography, vol. 1, Sinauer Associates, Inc. Sunderland, MA, 2005.
8. Reygondeau G. Current and future biogeography of exploited marine groups under climate change. Predicting Future Oceans: Sustainability of Ocean and Human Systems Amidst Global Environmental Change. 2019;87-101. https://doi.org/10.1016/b978-0-12-817945-1.00009-5
9. Rogers AD, Appeltans W, Assis J., BallanceLT, Cury P, Duarte C, and Aburto-Oropeza O. Discovering marine biodiversity in the 21st century. Advances in Marine Biology.2022;(93)-23-115.doi: 10.1016/bs.amb.2022.09.002
10. Saxena A. Marine biodiversity in India: Status and issues. International day for biological diversity (Marine diversity).2012.
11. Snelgrove P. The biodiversity of macrofaunal organism in marine sediments. Biodiversity and Conservation.1998;7:1123-1132.https://doi.org/10.1023/A:1008867313340
12. Sokal RR, and Oden NL. Spatial autocorrelation in biology. 1. Methodology.The Biological Journal of the Linnean Society. 1978;10:199-228.https://doi.org/10.1111/j.1095-8312.1978.tb00013.x
13. Sokal RR. and Wartenberg DE. A test of spatial autocorrelation using an isolation by distance model. Genetics.1983;105:21.https://doi.org/10.1093%2Fgenetics%2F105.1.219
14. United Nations Glossary of Environment Statistics.Studies in methods, series F. New York; 1997.
15.Underwood JA. Experiments in Ecology. Their Logical Design and Interpretation Using Analysis of VarianceCambridge University Press, Cambridge;1997.
16. Wartenberg D. Mutivariate spatial autocorrelation: A method for exploratory geographical analysis. Geographical Analysis.1985;17:263-283.http://dx.doi.org/10.1111/j.1538-4632.1985.tb00849.x