Prevailing assemblages and depth-driven distribution patterns of pteropods in the Andaman Islands

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Abstract
The present study investigates the pteropod assemblages and their distribution pattern across different depths offshore in the Andaman Islands using the samples collected by FORV Sagar Sampada (Cruise No. 355). 22 pteropod species from 6 families were identified from depths of 50 m, 100 m and 200 m during the study period. Heliconoides inflatus from the family Heliconoididae displayed the highest abundance compared to other species. The family Creseidae was more prevalent at 50 m, whereas Heliconoididae dominated at 100 m and 200 m. Little Andaman station (200 m) had the highest species diversity, while the lowest was at Rangat's west coast (50 m). Multivariate analyses revealed depth-dependent occurrence trends, with PERMANOVA confirming depth (Pseudo-F= 4.79, p= 0.001) as a significant factor in structuring distinct pteropod assemblages.

The Canonical analysis of Principal Coordinates showed strong discrimination for assemblages at 50 m and 200 m (85.71% correct for each) with 81.82% accuracy and a minimal misclassification error rate of 18.18%. The Principal Component Analysis indicated temperature and salinity as the key environmental factors influencing depth-driven distribution patterns. This study provides new insights into the pteropod's vertical zonation and showcases the unique regional distribution patterns observed in the Andaman waters.

Keywords: Pteropod Diversity, Distribution Patterns, FORV Sagar Sampada Cruise, Andaman and Nicobar Islands.

Introduction

The Indian marine ecosystem supports an extensive range of species and is considered one of the most diverse ecosystems of the Indo-Pacific region. The Andaman and Nicobar Islands are situated in the northeastern part of the Indian Ocean at the confluence of the Bay of Bengal, the Indian Ocean and the Pacific Ocean, forming a biodiversity hotspot that hosts approximately 30-35% of India's marine species. The marine ecosystem of these islands comprises of coral reefs, mangrove forests and seagrass meadows, which collectively support approximately 75 species of corals, 50 species of mangroves, 1200 species of marine fishes, 2800 species of marine invertebrates, 20 species of marine mammals and many more. The unique biogeographic features of the Andaman basin make an ecologically significant habitat for a wide array of marine organisms where Indo-Pacific and Indian Ocean species converge.

Pteropods are a group of holoplanktonic gastropods found across the oceans globally[1]. These marine zooplankton show high diversity in tropical regions and abundance in polar waters[7,13,17]. They are most abundant in the epipelagic zone, although some species are also found in mesopelagic waters. Pteropods exhibit Diel Vertical Migration (DVM), descending to deeper waters during daylight to avoid predators and ascending back to the shallow waters at night[25]. They are a crucial intermediary in the marine food web, serving as an essential food source for commercial fish, seabirds and whales[2]. These hermaphrodite plankton typically grow to a size of up to 1 cm[21].

The order Pteropoda is subdivided into two major groups: Thecosomata and Gymnosomata. The key distinguishing feature between these groups is the presence of a shell in Thecosomes during some part of their life cycle, while Gymnosomes lack shells throughout their lives. Unlike other gastropod shells, pteropod shells are composed of aragonite, an unstable form of calcium carbonate ($CaCO_3$). These shells are highly vulnerable to environmental changes and even a slight increase in seawater temperature can cause shell dissolution, decreasing their diversity and potentially affecting their population dynamics[1,2,15].

Thecosomata are one of the important living metazoan zooplankton that leave a record of their presence in ocean sediments as dead shells[15,23]. These shell deposits provide valuable insights about their diversity in the water column and are used by researchers to monitor ocean perturbations[15] and palaeontologists to remodel paleoclimatic environmental conditions[4].

In the context of the Andaman archipelago, the pteropod study was initiated by Bhattacharjee and Ghosh[3] and Bhattacharjee[4]. Their work focused on the distribution of pteropods around the Andaman and Nicobar Islands, primarily for palaeoceanographic reconstructions. Recent contributions by Sijinkumar et al[20] provided significant insights into fossil pteropod shell preservation from Late Quaternary sediments. Although some pteropod studies are available from this region, they mainly focus on bathymetric reconstruction and pteropod preservation profiles[5,6,19]. The present study addresses this knowledge gap by examining the current situation of pteropod diversity in the Andaman and Nicobar Islands. It aims to elucidate thecosome diversity patterns and the impact of environmental factors in influencing their distribution in these waters.

Material and Methods

Study Area: The study was conducted across eight distinct locations in the Andaman and Nicobar Islands, encompassing the east and the west coasts (Fig. 1). The east coast, surrounded by the Andaman Sea, included three sites: Port Blair (PB: 11°25'39.6"N, 92°43'57.6"E), Rangat (RTA: 12°27'15.0"N, 93°07'54.0"E) and Diglipur (DI: 13°13'59.4"N, 93°06'40.2"E). The west coast, bordered by the Bay of Bengal, included five sites: Little Andaman (LA: 10°56'17.8"N, 92°13'57.0"E), Wandoor (WA: 11°28'06.6"N, 92°14'21.0"E), South Andaman (SA: 12°00'02.4"N, 92°24'36.6"E), Rangat (RTB: 12°25'27.0"N, 92°22'06.6"E) and Mayabundar (MA: 12°54'58.2"N, 92°27'43.2"E).

Cruise Details: The multidisciplinary Fishery Oceanographic Research Vessel (FORV) Sagar Sampada, owned by the Ministry of Earth Sciences (MoES), carried out its 355th voyage around the Andaman and Nicobar Islands from December 2016 to January 2017. It was managed and operated by the Centre for Marine Living Resources and Ecology (CMLRE), Kochi. This vessel was equipped with Automated Weather Stations, Multiple Frequency Echo Sounders (200 kHz, 120 kHz and 38 kHz), Side Scan Sonar, AutoSal, Skalar Autoanalyser, SeaBird CTD (Conductivity-Temperature-Depth) Profiler (75kHz), Integrated Fish Finding System, Integrated Trawl Instrumentation System, Smith McIntyre Grab, Dredge, Bongo Net, Multiple Plankton Net (MPN) and VELNet.

Sample Collection and Analysis: For studying the pteropod distribution, shelf sediment samples were collected by FORV Sagar Sampada (Cruise No. 355) using the Smith-McIntyre Grab Sampler from depths of 50 m, 100 m and 200 m at all eight stations. The collected sediments were preserved in 4% formaldehyde solution and dried overnight in a hot air oven at 40ºC for complete desiccation. The samples were sorted in a Petri dish with a fine brush and examined under the LEICA M205C stereomicroscope. Individual pteropod specimens were mounted on a micropaleontological slide and selective specimens were photographed to aid in species identification. Preliminary identification was conducted using the keys provided by van der Spoel et al[23]. This was further refined using the descriptions from d'Orbigny[8], van der Spoel[21,22], Sakthivel[17], Janssen[10,11] and Janssen et al[12].

Statistical Analysis: The pteropod specimens were counted and the data were analyzed using Microsoft Excel and PRIMER 6 software. Abundance (%) and species diversity indices such as Margalef's Species Richness (d), Pielou's Evenness (J'), Shannon-Weiner's Diversity (H') and Simpson's Dominance (D) were estimated to assess the distribution of pteropods in the study area. Bray-Curtis similarity on square-root transformed data was utilized for cluster analysis, two-way Permutational Multivariate Analysis of Variance (PERMANOVA) and Canonical Analysis of Principal Coordinates (CAP).

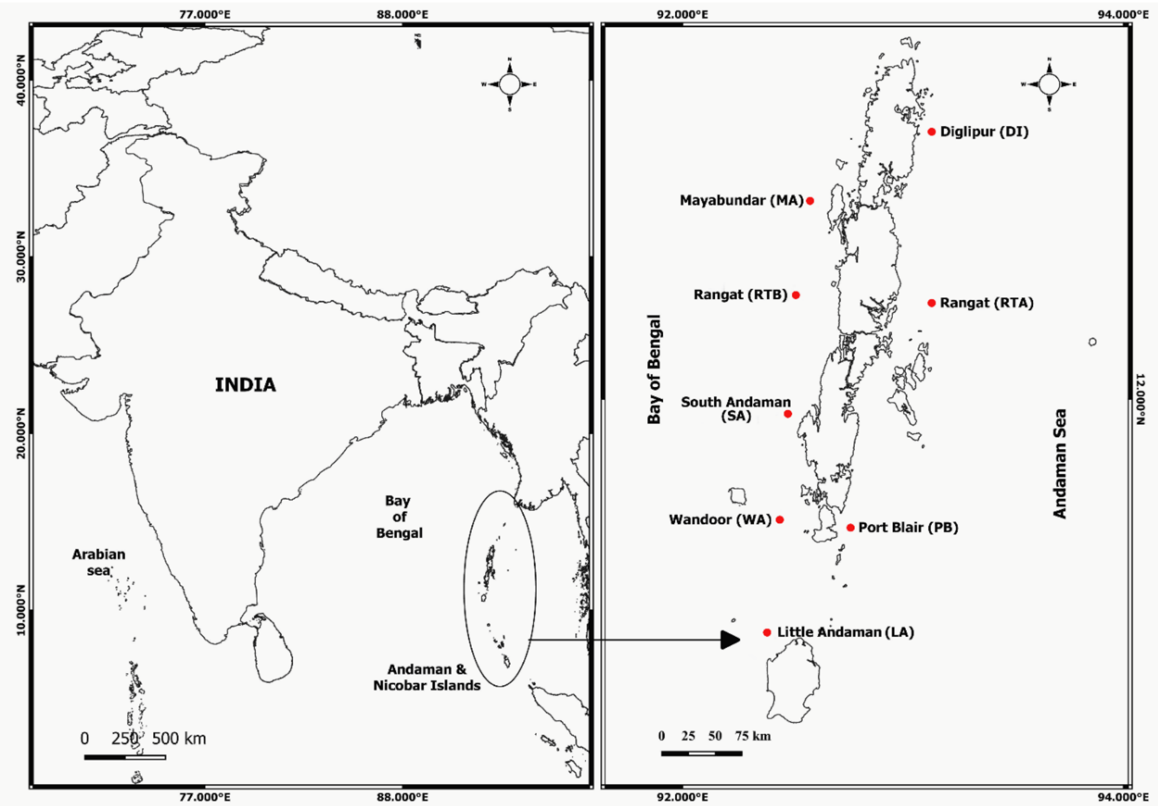

Figure 1: Location map representing the present study area of the Andaman Islands

Additionally, Principal Component Analysis (PCA) was performed to understand the variation of environmental parameters across different stations and their influence on pteropod assemblages.

Results and Discussion

Species Diversity: A total of 22 pteropod species from 6 families were identified in this study (Table 1, Table 2, Plate I). The family Creseidae was represented by three species: *Creseis acicula, C. conica and C. virgula*. The monotypic families Hyalocylidae and Heliconoididae were represented by *Hyalocylis striata* and *Heliconoides inflatus* respectively. The family Cliidae comprised of two species: *Clio convexa* and *C. pyramidata*. The family Limacinidae included three species: *Limacina bulimoides, L. helicina and L. lesueurii*. Lastly, the family Cavoliniidae was represented by one species of the genus *Cavolinia*, nine species of *Diacavolinia*, one species of *Diacria and* one species of *Telodiacria*. Among the families, the highest number of individuals was recorded from Heliconoididae (45.22%), while Hyalocylidae had the lowest (1.18%). *Heliconoides inflatus* was the most abundant species, contributing 45.22%, whereas *Diacavolinia* sp. 5 showed the lowest abundance (0.03%) across all stations.

The representative species of the families Creseidae, Hyalocylidae and Heliconoididae were found at all three depths whereas the family Cliidae was absent at 50 m. Although the family Cavoliniidae was present across all depths, specific species like *Diacavolinia* sp. 1, *Diacavolinia* sp. 4, *Diacavolinia* sp. 5 and *Diacavolinia* sp. 6, were exclusively recorded at 200 m. However, for the family Limacinidae, two species (*Limacina bulimoides* and *L. lesueurii)* were found at all depths, except for *L. helicina* which was absent at 50 m. It was observed that the family Creseidae dominated at 50 m whereas Heliconoididae dominated at 100 m and 200 m (Fig. 2).

The dominance of *Heliconoides inflatus* (45.22%) from the family Heliconoididae aligns with the findings of Bé and Gilmer[1] who reported *H. inflatus* as a widespread pteropod species found in tropical and subtropical regions, specifically in the epipelagic zone. Mathew et al[14] also observed *H. inflatus* to be more abundant in surface waters (<100 m) of the Arabian Sea.

Table 1
Pteropod occurrence in the Andaman Sea (east coast) during the voyage of FORV Sagar Sampada (CR 355). '+': presence, '-': absence, 50: 50 m, 100: 100 m, 200: 200 m; PB: Port Blair, RTA: Rangat (Andaman Sea), DI: Diglipur

Species	Andaman Sea (east coast)						
	PB100	PB200	RTA50	RTA100	DI50	DI100	DI200
Family Creseidae							
Creseis acicula	-	-	+	+	+	+	-
Creseis conica	-	+		+	+	+	+
Creseis virgula	+	-	+	-	+	+	-
Family Hyalocylidae							
Hyalocylis striata	-	-	-	-	-	-	-
Family Cliidae							
Clio convexa	-	-	-	+	-	-	-
Clio pyramidata	+	+	-	+	-	+	-
Family Heliconoididae							
Heliconoides inflatus	+	+	-	-	+	+	+
Family Limacinidae							
Limacina bulimoides	-	+	+	+	-	+	-
Limacina helicina	+	-	-	+	-	-	-
Limacina lesueurii	-	-	+	+	-	-	-
Family Cavoliniidae							
Cavolinia sp.	-	+	-	-	-	+	-
Diacavolinia sp. 1	-	-	-	-	-	-	-
Diacavolinia sp. 2	-	-	-	-	+	+	-
Diacavolinia sp. 3	-	+	-	+	+	+	-
Diacavolinia sp. 4	-	+	-	-	-	-	-
Diacavolinia sp. 5	-	+	-	-	-	-	-
Diacavolinia sp. 6	-	-	-	-	-	-	-
Diacavolinia longirostris	+	+	+	-	+	+	-
Diacavolinia sp. 7	+	+	-	+	+	+	+
Diacavolinia vanutretchti	-	+	-	+	+	+	+
Diacria sp.	+	+	-	+	+	+	-
Telodiacria quadridentata	+	-	-	+	+	+	-

Table 2
Pteropod occurrence in the Bay of Bengal (west coast) during the voyage of FORV Sagar Sampada (CR 355). '+': presence, '-': absence, 50: 50 m, 100: 100 m, 200: 200 m; LA: Little Andaman, WA: Wandoor, SA: South Andaman, RTB: Rangat (Bay of Bengal), MA: Mayabundar

Species	Bay of Bengal (west coast)														
	LA50	LA100	LA200	WA50	WA100	WA200	SA50	SA100	SA200	RTB50	RTB100	RTB200	MA50	MA100	MA200
Family Creseidae															
Creseis acicula	+	+	-	+	+	+	+	-	-	-	+	-	+	+	-
Creseis conica	+	+	+	+	+	+	+	+	-	+	+	+	+	+	+
Creseis virgula	-	+	+	-	+	+	-	+	-	-	-	+	+	+	+
Family Hyalocylidae															
Hyalocylis striata	-	-	-	+	+	+	+	-	-	-	+	-	-	+	-
Family Cliidae															
Clio convexa	-	+	-	-	+	+	-	-	-	-	-	-	-	+	+
Clio pyramidata	-	-	+	-	+	+	-	+	+	-	-	+	-	-	+
Family Heliconoididae															
Heliconoides inflatus	+	+	+	+	+	+	+	+	+	-	+	+	+	+	+
Family Limacinidae															
Limacina bulimoides	-	-	+	-	-	-	-	+	-	+	-	-	-	-	-
Limacina helicina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Limacina lesueurii	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+
Family Cavoliniidae															
Cavolinia sp.	-	-	+	-	+	+	+	+	-	-	+	+	-	-	+
Diacavolinia sp. 1	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Diacavolinia sp. 2	-	-	-	-	+	-	-	+	+	-	-	+	-	-	+
Diacavolinia sp. 3	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Diacavolinia sp. 4	-	-	+	-	-	-	-	-	-	-	-	-	-	-	+
Diacavolinia sp. 5	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Diacavolinia sp. 6	-	-	-	-	-	-	-	-	-	-	-	+	-	-	+
Diacavolinia longirostris	-	+	+	+	+	-	+	+	+	-	+	-	+	+	-
Diacavolinia sp. 7	-	-	+	-	-	-	-	+	-	-	-	+	-	-	+
Diacavolinia vanutretchti	-	-	+	-	+	-	-	+	+	-	+	+	-	-	+
Diacria sp.	-	-	+	+	+	+	-	+	-	-	-	+	-	-	+
Telodiacria quadridentata	-	+	+	-	+	+	-	+	-	-	+	+	+	+	+

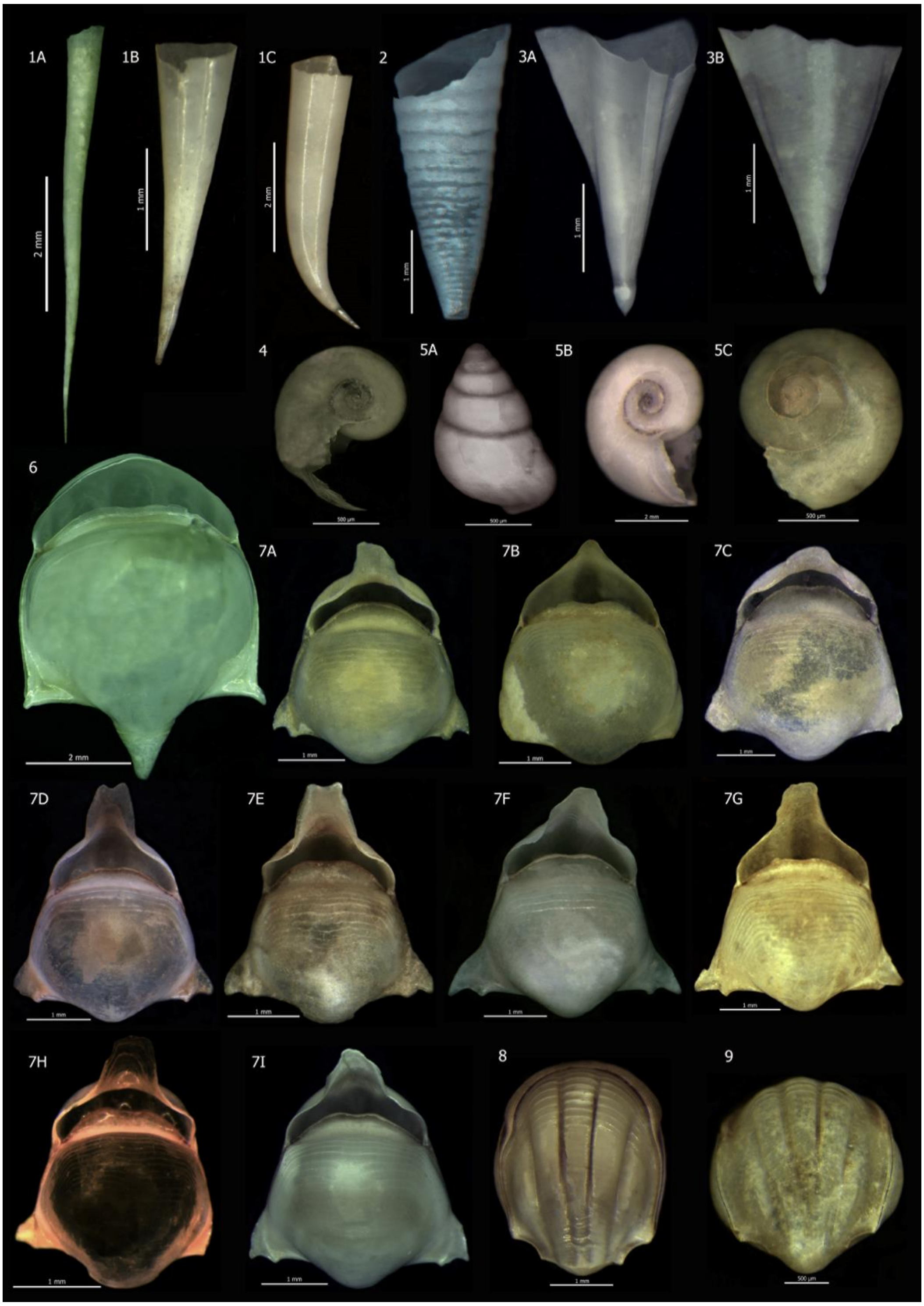

Plate I: 1. Creseis. 1A. C. acicula, 1B. C. conica, 1C. C. virgula; 2. Hyalocylis striata; 3. Clio. 3A. C. convexa, 3B. C. pyramidata; 4. Heliconoides inflatus; 5. Limacina. 5A. L. bulimoides, 5B. L. helicina, 5C. L. lesueurii; 6. Cavolinia sp.; 7. Diacavolinia. 7A. D. sp. 1, 7B. D. sp. 2, 7C. D. sp. 3, 7D. D. sp. 4, 7E. D. sp. 5, 7F. D. sp. 6, 7G. D. longirostris, 7H. D. sp. 7, 7I. D. vanutrechti; 8. Diacria sp.; 9. Telodiacria quadridentata

However, the present study revealed the presence of *H. inflatus* across all sampled depths (50 – 200 m), suggesting a wide-range vertical distribution of the species in the Andaman Islands. The absence of *Limacina helicina* at 50 m and the presence of specific *Diacavolinia* species at 200 m demonstrates the trends of niche-specific pteropod distribution reported by Hunt et al[9] and Burridge et al[7]. They discussed the role of depth gradients in forming distinct ecological zones, leading to depth-stratified distribution of pteropods, as observed in the current study. Our findings differ from the observations of Bernard and Froneman[2] and Seibel et al[18] who found *L. helicina* to be the dominant species in temperate and polar regions.

The dominance of Creseidae at 50 m and Heliconoididae at 100 m and 200 m represents a novel finding for the Andaman region. Moreover, the abundance of *Diacavolinia* at 200 m during the present study contrasts with their abundance in the upper 100 m in the western Pacific as reported by Ohman et al[16]. As shown in table 3, the highest pteropod abundance was observed in Diglipur at 100 m depth (DI100: 10.73%), while the lowest was in Rangat (west coast) at 50 m depth (RTB50: 0.43%). Margalef's Species Richness (d) peaked in Little Andaman at 200 m (LA200: 3.44) and was lowest at RTB50 (0.63).

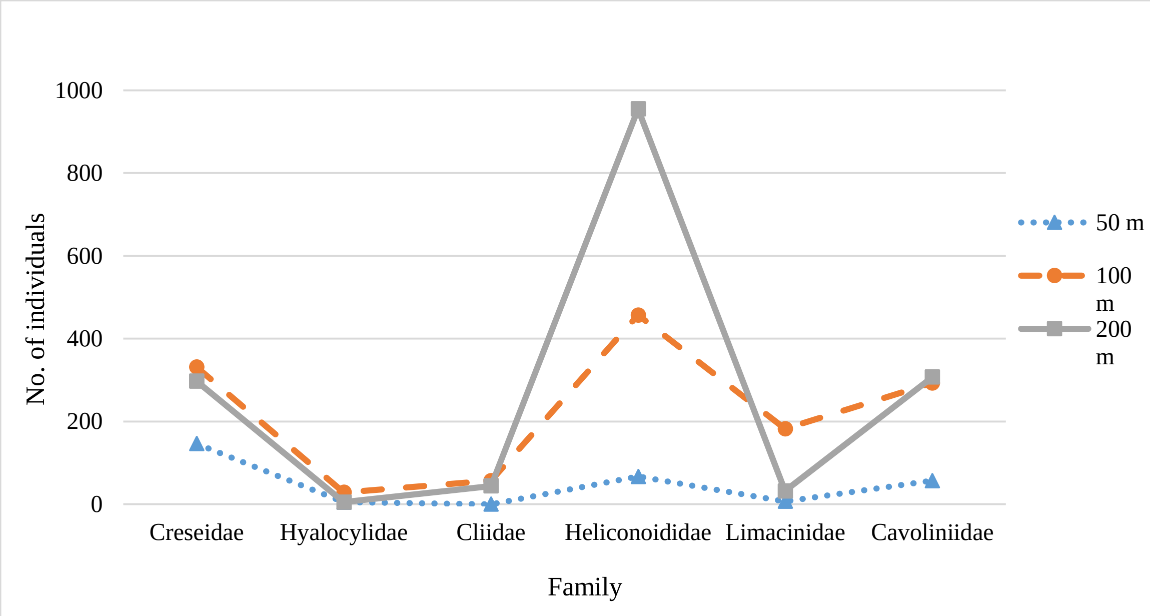

Figure 2: Distribution of pteropod families across the depths (50 m, 100 m, 200 m)

Table 3
Pteropod species diversity indices. Abundance (%), d: Margalef's Species Richness, J': Pielou's Evenness, H': Shannon-Weiner Diversity Index, D: Simpson's Dominance

Stations	Abundance (%)	d	J'	H'	D
PB100	4.19%	2.07	0.94	1.95	0.87
PB200	10.12%	2.89	0.86	2.13	0.85
RTA50	0.67%	2.07	0.99	1.77	0.91
RTA100	6.33%	2.96	0.93	2.31	0.90
DI50	2.08%	3.06	0.98	2.35	0.94
DI100	10.73%	3.21	0.92	2.43	0.91
DI200	9.69%	0.91	0.72	1.00	0.59
LA50	1.28%	0.83	1.00	1.10	0.73
LA100	2.17%	1.96	0.97	1.89	0.88
LA200	6.18%	3.44	0.93	2.45	0.91
WA50	1.31%	1.84	0.96	1.72	0.87
WA100	4.08%	3.38	0.94	2.40	0.92
WA200	6.67%	2.45	0.93	2.14	0.88
SA50	1.53%	1.82	0.93	1.67	0.85
SA100	4.28%	3.04	0.96	2.39	0.92
SA200	2.32%	1.44	0.89	1.43	0.76
RTB50	0.43%	0.63	0.87	0.60	0.52
RTB100	3.55%	2.12	0.94	1.96	0.87
RTB200	6.94%	2.93	0.92	2.29	0.90
MA50	1.31%	1.83	0.97	1.74	0.87
MA100	5.90%	1.96	0.95	1.98	0.87
MA200	8.23%	3.32	0.92	2.44	0.91

Pielou's Evenness (J') was highest in Little Andaman at 50 m (LA50: 1.00) and lowest in Diglipur at 200 m (DI200: 0.72). LA200 showed the highest Shannon-Weiner diversity index (H') of 2.45, whereas it was the lowest at RTB50 (0.60). Meanwhile, Simpson's Dominance (D) was highest in Diglipur at 50 m (DI50: 0.94) and lowest at RTB50 (0.52).

Multivariate Analyses: The Bray-Curtis hierarchical cluster analysis resulted in two major clusters (Fig. 3). Cluster one was observed between the stations MA200 and RTB200, with a similarity of 89.16%, indicating constant environmental conditions at these deep-water stations. This unique cluster formation at 200 m could have resulted from the mesopelagic zone's steady environmental conditions supporting specific pteropod species. The pteropod assemblages at these stations consisted of Heliconoididae, Cavoliniidae, Creseidae, Limacinidae and Cliidae, while Hyalocylidae was absent. The second major cluster, showing 80.55% similarity, included stations LA100 and MA50, characterized by similar assemblages of Creseidae, Heliconoididae and Cavoliniidae.

A considerable similarity was shown by LA50 and SA50 clustering at 79.59%, followed by LA200 and SA100 and RTB100 and WA100, both clustering at 77.89% similarity. Station RTA100 formed a separate clade at 36.47% similarity due to the dominance of Limacinidae, accompanied by Cavoliniidae, Creseidae and Cliidae. Finally, RTA50 and RTB50 formed a distinct cluster of low similarity at 35.08%, representing a unique assemblage pattern that included only Creseidae and Limacinidae at these stations, with RTA50 showing the presence of a few Cavoliniidae species.

A two-way PERMANOVA was performed with depth and station as factors. The results revealed that depth (Pseudo-F= 4.79, p= 0.001) significantly impacted the pteropod assemblage pattern, whereas the effect of station (Pseudo-F= 1.15, p= 0.261) was statistically insignificant. The CAP analysis (Fig. 4) revealed a high classification success with 81.82% accuracy, with strong discrimination for 50 m and 200 m (85.71% correct for each). CAP1 accounted for 82.36% of the variance and CAP2 contributed 23.84%. The analysis exhibited moderate overlap in assemblages, with an 18.18% misclassification error rate that included four stations: DI100 (classified as 200 m), LA100 (classified as 50 m), WA200 (classified as 100 m) and DI50 (classified as 100 m). These four overlapping stations reflected transitional zones and heterogeneous diversity.

The hierarchical clustering and PERMANOVA suggested a prominent depth-driven grouping of pteropod species, with a stable assemblage at 200 m compared to the dynamic variations at 50 m and 100 m. The CAP analysis further elucidated the clear separation of 50 m and 200 m assemblages, suggesting substantial depth-based structuring of pteropods.

The environmental parameters used for PCA included temperature (ºC), salinity (PSU), dissolved oxygen (DO) (ml/L), turbidity (NTU), chlorophyll-a (Chl_a) (mg/m^3), organic carbon (OC) (%) and carbonate (%) (Table 4). The first two principal components accounted for 68.3% of the total variance, with PC1 explaining 40.8% and PC2 explaining 27.4%. As depicted in fig. 5, PC1 was strongly influenced by temperature, turbidity and DO, whereas PC2 was strongly influenced by salinity and OC. Analysis showed that most stations (DI100, DI200, WA50, WA100, WA200, SA50, SA100, SA200, RTB50, RTB100, RTB200, MA50, MA100, MA200) were influenced by either temperature or salinity, or both. Some stations correlated with Chl_a (DI50), OC (RTA50, RTA100), DO (PB100, PB200) and turbidity and carbonate (LA50, LA100, LA200).

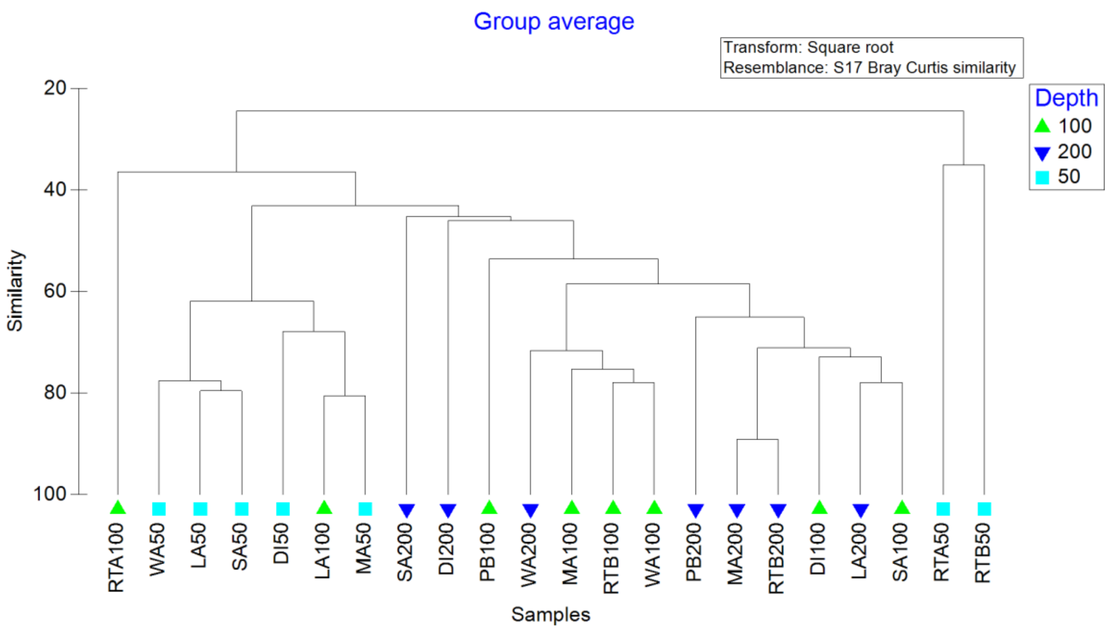

Figure 3: Bray-Curtis cluster dendrogram of pteropod distribution displaying depth-driven grouping of stations

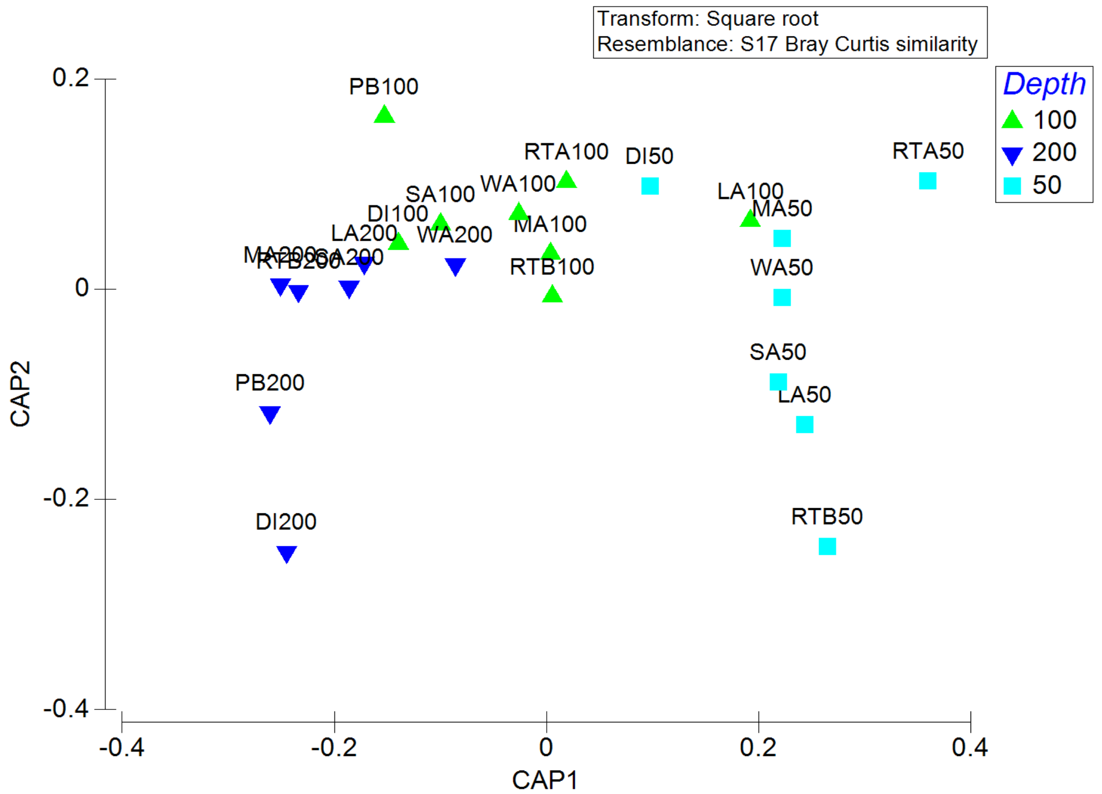

Figure 4: CAP analysis of pteropod distribution

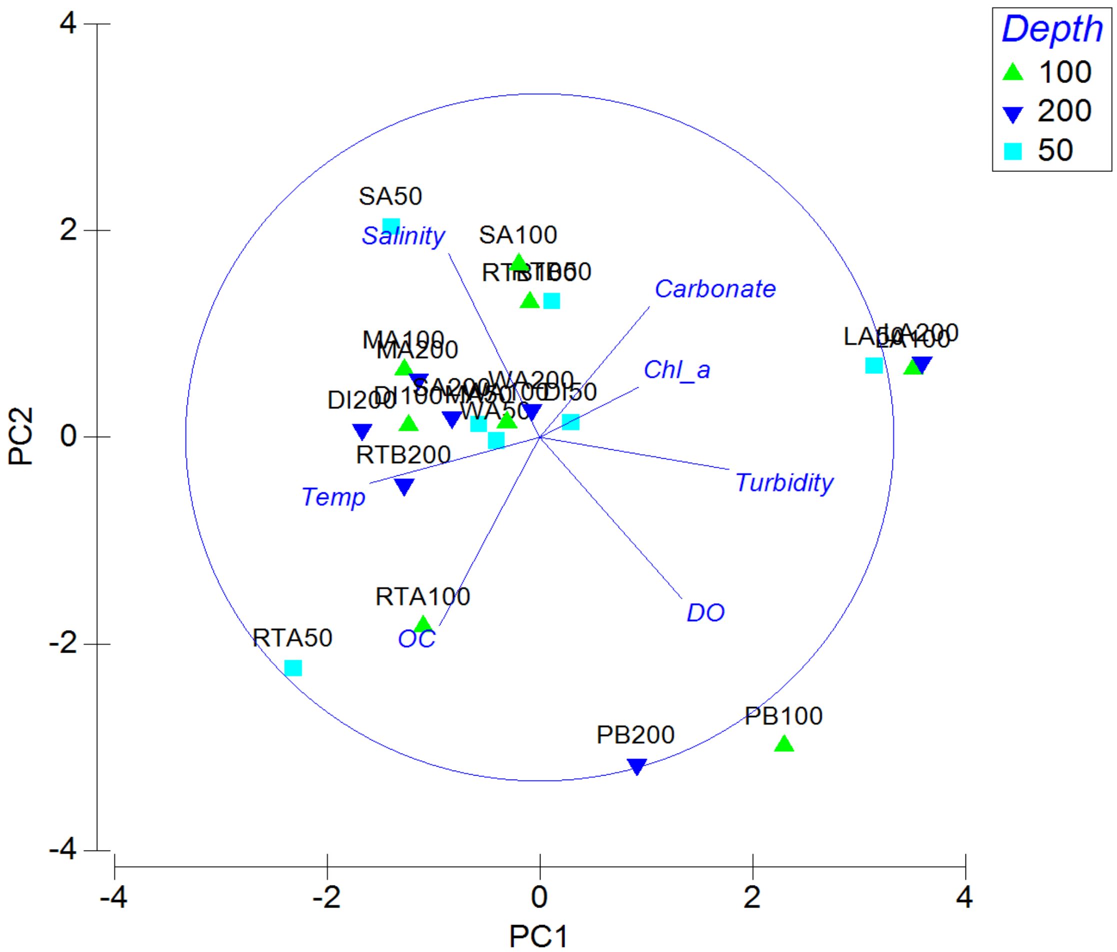

Figure 5: PCA biplot for pteropod distribution depicting the influence of environmental parameters during the study

Table 4
Environmental parameters of the stations used for PCA biplot

Stations	Temperature (ºC)	Salinity (PSU)	DO (ml/L)	Turbidity (NTU)	Chlorophyll-a (mg/m^3)	Organic Carbon (%)	Carbonate (%)
PB100	28.21	31.63	4.55	0.202	0.335	1.6	61
PB200	28.18	31.86	4.55	0.156	0.186	2.38	41
RTA50	28.78	32.33	4.44	0.124	0.184	1.8	10
RTA100	28.42	32.28	4.44	0.105	0.937	1.95	6
DI50	28.27	32.13	4.32	0.142	0.421	0.8	81
DI100	28.27	32.36	4.31	0.108	0.195	0.7	31
DI200	28.29	32.81	4.31	0.132	0.395	1.2	5
LA50	27.97	32.41	4.51	0.188	0.805	0.18	91
LA100	27.97	32.47	4.52	0.215	0.875	0.2	89
LA200	27.9	32.36	4.46	0.234	0.712	0.17	82
WA50	28.13	32.41	4.35	0.121	0.133	1.75	99
WA100	28.11	32.33	4.37	0.111	0.142	0.5	44
WA200	28.17	32.39	4.36	0.133	0.121	0.85	82
SA50	28.38	32.79	4.24	0.115	0.349	0.45	71
SA100	28.33	32.58	4.32	0.113	0.701	0.4	93
SA200	28.32	32.55	4.36	0.121	0.234	1.35	78
RTB50	28.34	32.46	4.33	0.141	0.295	0.25	96
RTB100	28.39	32.47	4.35	0.121	0.501	0.2	80
RTB200	28.41	32.52	4.37	0.121	0.278	1.65	47
MA50	28.41	32.53	4.37	0.133	0.471	1.1	59
MA100	28.41	32.77	4.35	0.134	0.1	0.75	55
MA200	28.29	32.79	4.34	0.112	0.589	1.6	50

Based on the depth-dependent clustering and environmental variable associations in PCA, it is inferred that temperature and salinity are the driving factors of pteropod community composition across the water column. The analyses of environmental factors and pteropod distribution across the water column suggested that low temperature and high salinity in greater depths were the primary factors that created a favourable environment for pteropod survival. This outcome aligns with the findings of Wallace et al[24] and Wormouth[25], who discussed the increment of pteropod abundance with increasing salinity and decreasing temperature in oligotrophic waters of the Sargasso Sea. This result also reflects the observations made by Martinez-Garcia et al[13], who found temperature gradients to be a significant attribute in the vertical distribution pattern of pteropods in the North Atlantic Ocean.

Conclusion

The present study provides insights into pteropod distribution, revealing distinct depth-driven patterns and environmental influences in the Andaman. Our findings demonstrate that temperature and salinity play a key role in structuring pteropod assemblages along the depth gradients. The dominance of the families Creseidae and Heliconoididae and specific species of *Diacavolinia* at different water column depths reveals a clear vertical zonation of pteropod distribution in this region. While there are similarities between the pteropod distribution in this region and other parts of the world, their distribution in Andaman waters is unique.

The regional variation observed in this region emphasizes the necessity of location-specific studies for better knowledge of global pteropod biogeography. As *Heliconoides inflatus* is often used as a bioindicator for ocean monitoring[15], our study suggests that the Andaman waters, especially the deeper regions, are suitable for its survival. This species could serve as a valuable indicator to analyze ocean acidification impacts in Andaman water for future studies.

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References

1. Bé A.W.H. and Gilmer R.W., A zoogeographic and taxonomic review of euthecosomatous Pteropoda, In Ramsay A.T.S., ed., Oceanic Micropaleontology, Academic Press, London, 733-808 **(1977)**

2. Bernard K.S. and Froneman P.W., The sub-Antarctic euthecosome pteropod species *Limacina retroversa*: Distribution patterns and trophic role, *Deep Sea Research Part I: Oceanographic Research Papers*, **56**, 582-598 **(2009)**

3. Bhattacharjee D. and Ghosh R., Current pteropod and hydromedusan distribution from the Andaman and Nicobar Islands, *Records of the Zoological Survey of India*, **93**, 363-374 **(1993)**

4. Bhattacharjee D., Distribution of recent pteropods in surface sediments from the continental margin of India, *Indian Journal of Marine Sciences*, **24**, 208-212 **(1995)**

5. Bhattacharjee D., Late Quaternary pteropod preservation and palaeoceanography of the Andaman Sea, *Current Science*, **73**, 449-452 **(1997)**

6. Bhattacharjee D., State of carbonate preservation of pteropods in surface sediments from the northern Indian Ocean and implications thereof, *Indian Journal of Marine Sciences*, **34**, 153-159 **(2005)**

7. Burridge A.K., Goetze E., Wall-Palmer D., Le Double S.L., Huisman J. and Peijnenburg K.T.C.A., Diversity and abundance of pteropods and heteropods along a latitudinal gradient across the Atlantic Ocean, *Progress in Oceanography*, **158**, 213-223 **(2017)**

8. d'Orbigny A., Mollusques, In Voyage dans l'Amérique méridionale, Bertrand, Paris, 43-750 **(1836)**

9. Hunt B.P.V., Pakhomov E.A., Hosie G.W., Siegel V., Ward P. and Bernard K., Pteropods in Southern Ocean ecosystems, *Progress in Oceanography*, **78**, 193-221 **(2008)**

10. Janssen A.W., Pteropoda (Gastropoda, Euthecosomata) from the Australian Cainozoic, *Scripta Geologica*, **147**, 1-302 **(2012)**

11. Janssen A.W., Pelagic gastropods (Gastropoda: Pterotracheoidea, Janthinoidea, Thecosomata and Gymnosomata) from the Miocene Aquitaine Basin (France), *Cainozoic Research*, **20**, 3-78 **(2020)**

12. Janssen A.W., Sessa J.A. and Thomas E., Pteropoda (Mollusca, Gastropoda, Thecosomata) from the Paleocene-Eocene thermal maximum (United States Atlantic Coastal Plain), *Palaeontologia Electronica*, **22**, 1-34 **(2019)**

13. Martinez-Garcia A., DeGrandpre M.D., Spitz Y.H., Wolfe-Bellin K.S. and Daly K.L., Seasonal distribution of pteropods in relation to physical and biological variables in the North Atlantic, *Deep Sea Research Part II: Topical Studies in Oceanography*, **179**, 104822 **(2021)**

14. Mathew R., Sruthi K.V. and Sanjeevan V.N., Distribution of thecosome pteropods in the eastern Arabian Sea during the winter monsoon, *Marine Biology Research*, **16**, 177-190 **(2020)**

15. Oakes R.L., Peck V.L., Manno C. and Bralower T.J., Degradation of internal shell structure in polar pteropods due to ocean acidification, *Marine Biology*, **166**, 62 **(2019)**

16. Ohman M.D., Ling H.Y. and Smith J.R., Spatial differentiation and vertical distribution of copepods in the southern sector of the California Current System, *Journal of Plankton Research*, **41**, 805-820 **(2019)**

17. Sakthivel M., Taxonomy and distribution of Pteropoda (Gastropoda, Heteropoda) in the Indian Ocean, Proceedings of the Symposium on Warm Water Zooplankton, **1**, 274-287 **(1976)**

18. Seibel B.A., Maas A.E., Tarrant A.M. and Kremer P., Metabolism of thecosome pteropods in low pH conditions, *Deep Sea Research Part II: Topical Studies in Oceanography*, **180**, 104916 **(2021)**

19. Sijinkumar A.V., Nagender Nath B. and Guptha M.V.S., Late Quaternary record of pteropod preservation from the Andaman Sea, *Marine Geology*, **275**, 221-229 **(2010)**

20. Sijinkumar A.V., Patil S., Nath B.N., Guptha M.V.S., Kaithwar A. and Mascarenhas-Pereira M.B.L., Late Quaternary pteropod preservation in the Andaman Sea: Investigating monsoon and productivity changes, *Deep Sea Research Part II: Topical Studies in Oceanography*, **166**, 34-43 **(2019)**

21. van der Spoel S., Euthecosomata, a group with remarkable developmental stages (Gastropoda, Pteropoda), J. Noorduijn en Zoon N.V., Gorinchem, Netherlands **(1967)**

22. van der Spoel S., Growth, reproduction and vertical migration in *Clio pyramidata* Linnaeus, 1767 forma *lanceolata* (Lesueur, 1813), with notes on some other Cavoliniidae (Mollusca, Pteropoda), *Beaufortia*, **21**, 117-134 **(1973)**

23. van der Spoel S., Bleeker J. and Kobayasi H., From *Cavolinia longirostris* to twenty-four *Diacavolinia* taxa, with a phylogenetic discussion, *Bijdragen tot de Dierkunde*, **62**, 127-166 **(1993)**

24. Wallace J.R., Jackson D.M. and Clayton D.G., The spatial distribution of pteropods in the Sargasso Sea and their potential use as environmental indicators, *Marine Biology*, **160**, 3151-3162 **(2013)**

25. Wormouth J.H., Vertical distributions and diel migrations of Euthecosomata in the northwest Sargasso Sea, *Deep Sea Research Part A: Oceanographic Research Papers*, **28**, 1493-1515 **(1981)**.

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