

Zooplankton phototaxis in oceanic squid fishing grounds in the Arabian Sea

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Effects of night-illumination on zooplankton abundance were compared with day/night variations in oceanic squid fishing grounds in central Arabian Sea. Zooplankton abundance showed significant variation in relation to three different light conditions with 52% of the total abundance happening during night and 25% during night with illumination. Siphonophores, chaetognaths, copepods and decapod larvae displayed negative phototaxis. Present results indicate that the response to light stimulus observed among the zooplankton groups were mostly due to the prey-seeking or predator avoidance behavior.

[Keywords: Arabian Sea, Zooplankton, Phototaxis, Night-illumination, Ecology, Behaviour]

Introduction

The main structuring force of the zooplankton populations in the marine environment is often related to its direct reaction to light. Changes in light intensity at dusk and dawn are reported to be the major factor controlling vertical migration of zooplankton¹. Diel vertical migration (DVM) of zooplankton transports a substantial quantity of biomass to different depth levels at speeds ranging from 2 to 8 cm/s². Such migration patterns of zooplankton influence the movement of nocturnal planktivorous fish³ which in turn affect the movement of their piscivorous predators including squids. Squids are attracted to light at night and are effectively aggregated to the artificial lights for commercial harvest in oceanic regions. Though many studies report DVM of zooplankton, few attempts have been made on the quantitative assessment of zooplankton under artificial illumination in oceanic squid fishing grounds⁴. Present study attempts to quantify the variations of major groups of tropical zooplankton at day-light, darkness and with artificial night-illumination in squid fishing grounds in central Arabian Sea.

Material and Methods

Zooplankton samples were collected from oceanic light fishing grounds with plankton net (KC Denmark, Model 23.100-WP-2; 200 micron net) operated from a 20 m OAL squid jigger equipped with 16 metal halide lights (1.5 kW each) during

exploratory squid jigging surveys from September 2010 to May 2012. The study covered 25 stations in the oceanic waters from 8°N to 17°N latitudes and 64°E to 76°E longitudes along the Eastern and central Arabian Sea at depth ranging from 650 to 3800 m. At each station, zooplankton sampling covered a period of 15 hours (1500-0600 h) during the course of which surface hauls (10 minutes duration) were collected under three different situations. To account for diurnal differences in zooplankton assemblages, day sampling (D) was carried out before squid jigging at 1500 h. To record the effect of light on zooplankton assemblage, samples were collected at 2200 h from the illuminated area (night-illumination-NI) and from the dark area outside the lighted zone (night-N). Volume of water filtered was determined using a digital flow meter attached to the plankton net. The filtered zooplankton were fixed in buffered formaldehyde solution, identified to group level, enumerated and abundance was expressed as individuals m⁻³. Mean abundances during D, N, and NI were compared using ANOVA and significant results were subjected to *post hoc* analysis using Duncan's Multiple Range Test.

Multivariate analyses were done using PRIMER software (Plymouth Marine Laboratory, UK). Zooplankton abundance between D, N and NI were subjected to Bray-Curtis similarity analysis⁵.

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Results and Discussion

Twenty-two groups of zooplankton were collected in surface tows during D, N and NI (Table 1). Fifty two percentage of the total zooplankton abundance was recorded during night without illumination, 25% in night with illumination and the remaining during day-time. Total zooplankton abundance under NI presented a reduction of more than 50% compared to N collections with a NI:N ratio of 0.5 and the abundance was least in D samples. Abundances in the three different sampling periods were significantly different ($p < 0.05$) (Table 1). Bray-Curtis index showed separate clusters; one each for day and night (including NI) with N and NI having 94% similarity (Fig. 1).

Among zooplankton, copepods and ostracods were the most abundant contributing to more than 90% of the total abundance. During D tows, hydromedusae, ostracods, cladocerans, lucifers, contributed to >40% of the total abundance, whereas, salps, mysids, gastropod larvae, fish eggs and larvae and cephalopods formed <8%. Cladocerans were recorded only during the day tows and mysids were totally absent in day tows. Significant differences ($p < 0.05$) in mean abundance between D, N and NI were observed only in siphonophores, chaetognaths, copepods and

decapod larvae and all of them were more in N samples.

Comparisons of zooplankton groups during different sampling times indicated that the NI:N ratio of zooplankton abundance was least for euphausiids (0.2) and equal for chaetognaths, copepods, ostracods, salps, doliolum, gastropod larvae and fish eggs and larvae (Fig. 2). Amphipods, heteropods and hydromedusae recorded NI:N ratios above 1, indicating that these are organisms attracted to illumination. Amphipods recorded about four fold increases in abundance at NI compared to N.

The zooplankton abundance showed a decreasing order from N to NI and to D, demonstrating negative phototaxis of zooplankton to natural and artificial illumination besides day/night rhythm. DVM in zooplankton, where they ascend to minimum depths in water column during night and descend to maximum depth during day-time is a phenomenon well documented in zooplankton behaviour⁶. Among the normal, reverse and twilight DVM patterns known, it is inferred that the presently studied zooplankton exhibited, normal vertical migration. While many physical and biological factors are implicated, such diel light cycles observed in zooplankton migration and the resulting greater biotic abundance near surface at night are primarily determined by a compromise between predator avoidance and foraging opportunities⁷.

Table 1—Total zooplankton abundance in individuals m^{-3} , comparison of mean abundance in day (D), night (N) and night-illumination (NI) and estimated night:day (N:D) ratio.

Non-identical superscripts, row-wise, indicate significant differences at $P < 0.05$ level.

| Groups | D | N | NI | N:D |
|--------------------------|----------------------------|-----------------------------|-----------------------------|------|
| <i>Hydromedusae</i> | 15 | 8 | 10 | 0.5 |
| <i>Siphonophore</i> | 24 ^a | 101 ^b | 92 ^b | 4.2 |
| <i>Polychaetes</i> | 4 | 8 | 4 | 1.7 |
| <i>Chaetognaths</i> | 198 ^a | 999 ^b | 416 ^{ab} | 5.0 |
| <i>Copepods</i> | 13003 ^a | 34232 ^b | 17017 ^{ab} | 2.6 |
| <i>Ostracods</i> | 4242 | 4289 | 1573 | 1.0 |
| <i>Cladocerans</i> | 339 | 0 | 0 | 0.0 |
| <i>Mysids</i> | 0 | 27 | 15 | - |
| <i>Amphipods</i> | 220 | 92 | 333 | 0.4 |
| <i>Lucifer</i> | 89 | 66 | 52 | 0.7 |
| <i>Euphausiids</i> | 6 | 20 | 3 | 3.3 |
| <i>Salps</i> | 5 | 42 | 19 | 8.4 |
| <i>Doliolum</i> | 4 | 16 | 8 | 3.9 |
| <i>Appendicularians</i> | 181 | 370 | 241 | 2.0 |
| <i>Heteropods</i> | 3 | 4 | 7 | 1.5 |
| <i>Pteropods</i> | 13 | 34 | 35 | 2.6 |
| <i>Amphioxus</i> | 4 | 8 | 5 | 1.7 |
| <i>Decapod larvae</i> | 62 ^a | 229 ^b | 139 ^{ab} | 3.7 |
| <i>Cephalopod larvae</i> | 0 | 1 | 1 | 6.2 |
| <i>Gastropod larvae</i> | 87 | 1399 | 662 | 16.1 |
| <i>Fish Eggs</i> | 4 | 212 | 64 | 58.0 |
| <i>Fish larvae</i> | 2 | 14 | 7 | 8.6 |
| Mean $N \pm SE$ | 529 \pm 133 ^a | 1205 \pm 262 ^b | 841 \pm 136 ^{ab} | 2.3 |

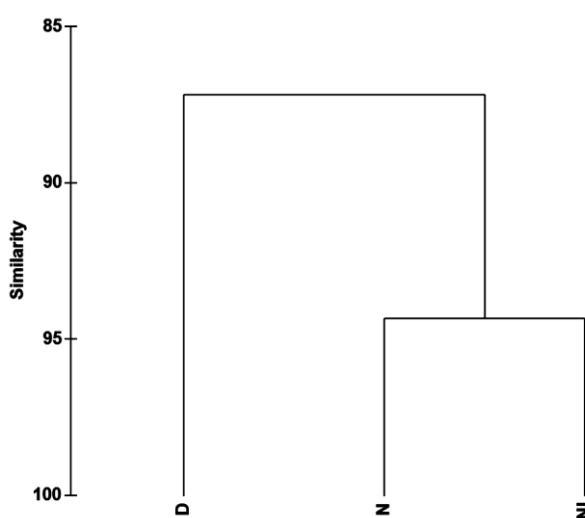


Fig. 1—Bray-Curtis similarity dendrogram for zooplankton groups during day (D), night (N) and night-illumination (NI) as individuals m^{-3} .

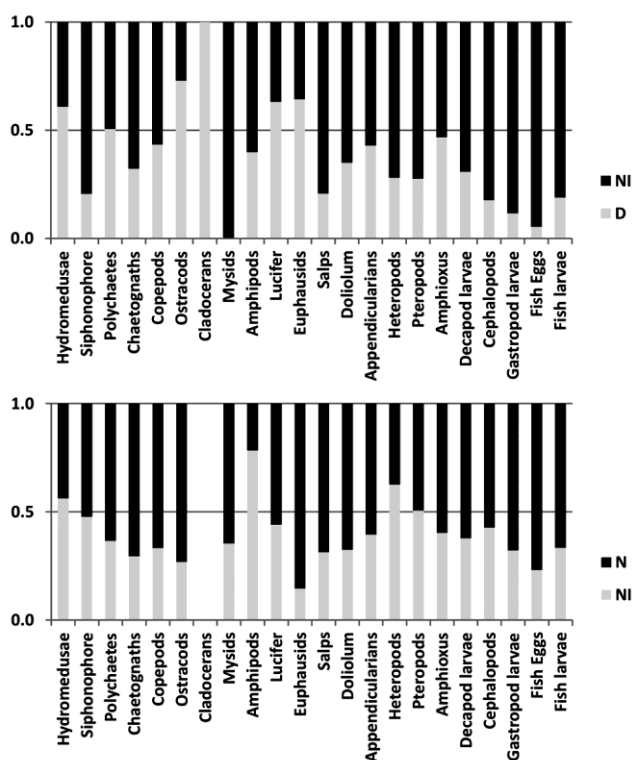


Fig.2—Proportions of zooplankton groups during day (D), night (N) and night-illumination (NI) as individuals m^{-3}

In the Arabian Sea, planktonic herbivores like, copepods, pteropods and euphausiids (principally herbivorous) except the cladocerans as well as omnivorous mysids, peaked during the night displaying negative phototaxis. Among these, the larger crustacean zooplankton such as mysids and euphausiids, which can swim ceaselessly, displayed strong negative behavioural response to illumination during night. Higher night catches are reported for euphausiids, because of increased visibility of the net in the water column during day light⁸ and also due to DVM of larger fast swimming euphausiids⁹. Shaw and Robinson, (1998)¹⁰ were able to demonstrate a five-fold increase in the N:D catch ratios when sampling was conducted closer to new moon phases due to the increase in night abundance of euphausiids.

Mysids primarily exhibit benthic behaviour during day-time and many studies have demonstrated near-bottom diurnal aggregation of mysids as well as definite upward migration at darkness¹¹. *In situ* experiments using various cycles of artificial light provided additional evidence indicating the importance of light in the migratory behaviour of mysids¹². Abrupt illumination caused them to seek greater depths, where they remained until the lights were turned off. Therefore, the reduced abundance in NI in the oceanic light fishing grounds may be due to their descent as a

result of negative phototaxis.

On the contrary, cladocerans were observed only during the day-time. Positive response to light is a phenomenon generally observed for this zooplankton group inhabiting the photic water layer, and is related to the vertical distribution of their population as well as its potential food¹³. Additionally, poor swimming capacity may also attribute to their absence at NI.

The conspicuous groups in the zooplankton assemblages were the crustaceans of which, the predominant were the class copepoda. Adult copepods and their developmental stages are reported to contribute more than 90% of the zooplankton community in many marine zooplankton assemblages¹⁴. In the northern Arabian Sea, higher zooplankton biomass at night in the upper 50 m water column was attributed to increased copepod abundance, along with the abundance of chaetognaths and pteropods¹⁵. Maycas *et al.*, (1999)¹⁶ discussed the importance of large copepods in the daily vertical transfer of organic and inorganic matter consequent to their large-scale vertical migration (500 m in average) and their large biomass, as a result, large copepods were always absent from the top 100 m during the daytime. Whereas most of the small copepods remained in the top 200 m at any time with very limited migration and concentrated near the surface throughout the night. Most plankton move towards a preferred 'optimum' intensity or spectral composition of illumination which differs according to the species and ontogenetic stage. The reduction in the copepod abundance during NI as observed in the present study can be related to the escape mechanism demonstrated by the larger group to overcome the negative impact of illumination stress by vertical migrations¹⁷. Further, it is observed that in many of the herbivorous zooplankton, sight is not essential for feeding, as they gather their food by various processes of filtration and can feed effectively in darkness. The negative phototaxis under artificial illumination indicates that their chances of survival are greater if they avoid well-illuminated water because sight is more important to most of their predators for detection of prey. Sustained swimming at greater than approximately 10 body lengths/s is unlikely in strongly migrating smaller copepods, implying their presence in the light fishing grounds in low biomass.

Under night-illumination, significant reduction in abundance of chaetognaths was also observed in the squid fishing grounds. Plankton analysis during surveys conducted in northeastern Arabian Sea¹⁵

clearly demonstrated the strong trophic relationship between the abundance of chaetognaths (predator) and their main prey, copepods. Therefore, the negative phototaxis observed in copepods (prey) can be a major influencing factor on the abundance and distribution of their predators. Present observations also indicate that the night-time abundances of chaetognaths as well as pteropods greatly exceeded the day-time abundances in the surface tows indicating diel vertical migration. In laboratory experiments, the twilight or night-time ascent in chaetognath, *Sagitta hispida* to shallow upper layers was reported to have initiated when they are exposed to light intensities below a threshold. This was manifested in abrupt upward swimming movement of these organisms from the deep at sunset by increased activity or because of negative geotaxis¹⁸. This threshold light intensity for ascend lies above the photoreception threshold in this species and corresponded to the irradiance value found only at sunset in natural environment. Therefore it can be assumed that for animals adapted to light intensities below this threshold level, up-swimming increased markedly whenever light intensities dropped below this threshold. Besides the trophic relationship, the increase in illumination in the oceanic squid-fishing grounds above the threshold limits may also explain the decrease in abundance.

Night-illumination resulted in four-fold increase in Amphipod abundance when compared to post-sunset period; they were also abundant during day-light. Duhamel *et al.* (2000)¹⁹ noted that the amphipods in zooplankton assemblages off the Kerguelen Islands are mostly dominant during day-light hours and were the only macro-zooplankton observed in the upper 50 m layers. Gelatinous carnivore, siphonophore showed statistically significant difference between D and N illuminations. Many of the siphonophores appear to follow the vertical migration of the zooplankton on which they feed and in the Arabian Sea, the shift in depth of occurrence of copepods, which is the important prey of gelatinous carnivores²⁰, could be a reason for the reduction in the predator (siphonophores) abundance as they might have chosen a course following their prey. These groups are also reported to display different migratory behaviour and present extensive diel vertical migration²¹ as a negative phototactic mechanism. Decapod larvae are also sensitive to the diel light cycle²² and in estuaries, larval upward vertical migration occurs more frequently during nocturnal high tides²³. Planktonic larval stages of many

benthic organisms are initially photopositive enabling them to avoid benthic predators and before settlement they become negatively phototactic. Hence the differences in the abundance of larvae under different illumination can be considered to be driven in large part by their adaptation for active avoidance of predation.

Surface zooplankton in the central Arabian Sea showed significant variation in their abundance in relation to three different light conditions. Majority of the zooplankton groups were more abundant during the night and among these siphonophores, chaetognaths, copepods and decapod larvae displayed significant negative phototaxis. Only a few groups were day-dominant, and among these, hydromedusae and amphipods were strongly attracted to artificial illumination. Cladocerans which were day-dominant were not attracted to artificial illumination. The light-based behavioural patterns observed among the zooplankton groups are mostly attributed to the prey-seeking or predator avoidance behaviour patterns besides their preference to certain light spectra.

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