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Coral Reef Health Status *versus* Muricid Bioindicator in the Lakshadweep Archipelago – A Multivariate Approach

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INTRODUCTION

Island ecosystems possess pristine environmental characteristics; human influence poses a serious threat to the fragile and susceptible biological processes on the islands (Sahu et al., 2013; Jha et al., 2015). Isolated oceanic islands support a highly sensitive and fragile coral reef ecosystem that offers unique possibilities to study the ecological changes and consequences that come with human settlement (Jha et al., 2011; Connor et al., 2012; Jha et al., 2013). Coral reefs are vital and core economic assets for any country that lies in the tropical and sub-tropical marine environment. Globally, the estimated economic support from this habitat has been calculated to be $375 billion per year (Cesar and Beukering, 2004; Brander et al., 2007). The important ecological services provided by these coral reef habitats have been identified as fish production, control of soil erosion on land, carbon sequestration, breeding grounds, etc. The coral reefs of Lakshadweep Islands are predominantly occupied by Scleractinian corals at various levels of the benthic substrate such as reef flat lagoon, reef crest, and reef slope. They are under great threat due to natural disturbances (Kumaraguru et al., 2005; Wilson et al., 2005) as well as anthropogenic disturbances (Wilson, 2010). The assessment of the biological indicators of benthic reef habitat is a key factor that helps in understanding the health status of any coral reef ecosystem (Al-Sofyani et al., 2014). The Crown-of-thorns Starfish (*Acanthaster planci* Linnaeus, 1758) is a major coral predator reported from various coral reef ecosystems. Their devastating population outbreaks have posed a great threat to coral reefs of the Indo-Pacific coastal region in the last five decades (Birkeland and Lukas, 1990; Fabricius et al., 2010). Besides the Crown-of-thorns Starfish, zooxanthellae-consuming gastropods are also reported as indicators for assessing the health status of corals in the Red Sea reef ecosystem (Mohamed et al., 2012; Al-Sofyani et al., 2014). Various studies on *Drupella cornus* Röding 1798 from its original combination (Röding 1798) to the corallivorous capability on Scleractinian corals of various coastal environments were presented through a timeline series (**Supplementary Figure 1**). The present study aims to interpret the impact of this indicator species and the relationship of physicochemical variables on the coral species cover along the Lakshadweep Archipelago by using the multivariate analytic tool.

MATERIALS AND METHODS

Study Area and Sample Collection

From Minicoy Island in the south to Chetlet Island in the north, 42 locations (**Figure 1**) were chosen to assess the diversity of coral communities and the impact of *Drupella cornus* on these reef habitats in the Lakshadweep group of Islands. Sessile benthic communities were studied using the line intercept transect method (English et al., 1997) during the post-monsoon Season (December-February) between 2015 and 2020. Five replicates of a 50-m long flexible underwater tape were laid on the reefs at a depth of (1) 10m on the reef slope and, (2) 3m on the reef flat, nearly parallel to the shore. Video transects were also taken for further analysis and the benthos present under the transition points were recorded using international codes (English et al., 1997; Al-Sofyani et al., 2014; Ravindran et al., 2014). In the distinct community structure of the reef habitat of Lakshadweep Islands, live coral species cover was recorded in all the selected study sites. The scleractinian fauna was identified up to the generic level from the video transects and verified (Veron, 2000). The abundance of *Drupella cornus* assembled with the coral colonies below the transect line was estimated manually and documented during the monitoring period. Voucher specimens collected from Minicoy Island (latitude 8.317794°N and longitude 73.031218°E), Lakshadweep Island, were deposited (M-29888/7) in the National Zoological Collection of the Zoological Survey of India (ZSI), Kolkata, India. To check the influence of physicochemical variables on the coral species cover, the data on Sea surface temperature (SST), salinity, chlorophyll-*a*, and total suspended matter (TSM) were collected from the Indian National Centre for Ocean Information Services (INCOIS) live access portal. The pH variable was assessed *in-situ* by using Oakton PCS Testr 35 waterproof tester.

Data Analysis

Benthic raw data was sorted and assessed using the Reef Monitoring Data Entry System of AIMS (ARMDES V1.6 Data Entry Program – Long-term reef monitoring project, Australian Institute of Marine Sciences) (ARMDES, 1996). The percentage cover of live coral and Seaweed cover were taken for this study to assess the live coral index, corresponding to the study sites (Murdoch and Murdoch, 2016) by categorizing them into four different classes viz., (1) Excellent (≥40% of live corals), (2) Good (20-39.9%), (3) Fair (10-19.9%) and (4) Poor or Bad (0-9.9%). Principal component analysis (PCA) and Shade plot with Bray-curtis cluster analysis were carried out using PRIMER software (Version 7.0.5) (Clarke and Gorley, 2015) for identifying preferred coral species by *Drupella cornus* and its similarity matrix in different islands. Redundancy analysis (RDA) (Leps and Smilauer, 2003) was also carried out for identifying the correlation between environmental [SST, salinity, chlorophyll-*a*, and TSM] and biological variables using CANOCO 4.5.

RESULTS

The live coral index is presented in **Figure 1**. The coral index of the lagoon portion of Chetlet, Kadamat, and Minicoy Islands was "Excellent". The coral index was between "Fair" and "Poor" in the reef slope region of all the selected Islands. However, in the case of Minicoy Island, three out of five selected study sites of the reef slope region showed an "excellent" coral index. During this extensive reef monitoring of the different Islands of Lakshadweep Archipelago in connection with the health of the reef ecosystem, localized bleaching on the branching form of corals mediated by the corallivorous snail *Drupella cornus* was observed (**Figure 1A**). This impact was significant on the species, *Pocillopora verrucosa*. **Supplementary Figure 2** shows the impact of the assemblage

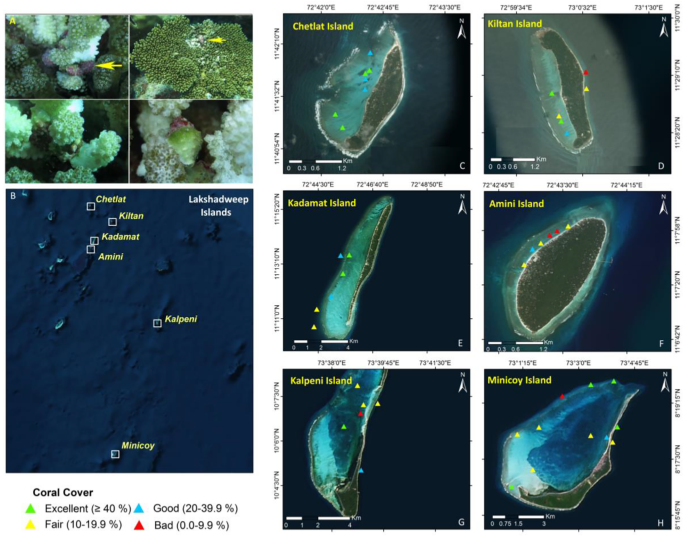

FIGURE 1 | Map showing the study sites. **(A)** *Drupella cornus* on the coral; **(B)** Lakshadweep Archipelago; **(C–H)** Islands of Lakshadweep Archipelago of corallivorous *Drupella* on *Pocillopora verrucosa* as compared to *Acropora* sp. Based on the coefficient of determination value ($R^2 = 0.844$), it was found that 84% of the variance in the dependant variable (i.e. Abundance of *Drupella cornus*) is explained by the derived regression equation (y = 1.6927x + 1.576). A positive correlation between *Drupella cornus* and *Pocillopora verrucosa* abundance was observed from the collected data (**Supplementary Figure 2C**). Moreover, the assemblage of this species was also high in the offshore environment rather than in the lagoon region. *Drupella cornus* abundance contributed more to the coral *Pocillopora verrucosa* than to other corals, according to the PCA. In this assessment, a strong variability (PC1: 62.9% variance) was observed between a group of Islands based on the assemblage of *Drupella cornus* (**Figure 2A**). The most influencing variable as a negative biological indicator was the impact of *Drupella cornus* on *Pocillopora verrucosa* and *Acropora* sp. in the reef slope region. Chetlet Island is separated from all the other Islands due to the presence of only lagoon sites which resulted in the relatively low occurrence of *Drupella cornus* on *Pocillopora verrucosa*. It was also observed that there was a moderate variance (PC2: 29.6% variance) between the group of Islands, and the most influencing variable was the impact of *Drupella cornus* on *Pocillopora verrucosa* followed by *Acropora* sp.

Bray-curtis cluster analysis under paired linkage (**Figure 2A**) was also done based on the assemblage of *Drupella cornus* on *Pocillopora verrucosa* and *Acropora* sp. Two major mixed clusters were observed with 80% similarity. Among these clusters, a cluster was formed between the sites, Minicoy and Kadamat Islands due to the occurrence of *Drupella cornus* on *Acropora* sp. even though the impact of this snail on *Pocillopora verrucosa* was very high in this site. Hence, the remaining cluster was formed due to the higher contribution and occurrence of the snail on *Pocillopora verrucosa* in the reef slope region. On the other hand, due to the lower effect observed in the lagoon region, Chetlet Island was categorized as an outlier. The intensity of the impact of *Drupella cornus* on *Pocillopora verrucosa* was observed to be higher than that on *Acropora* sp. and it was assessed by merging the cluster on the PCA plot (**Figure 2A**).

The PCA (**Supplementary Figure 3**) of coral species abundance from the reef flat to reef slope regions indicated that there was significant variability (PC1: 32.1% variance) between the lagoon and reef slope regions concerning coral species abundance. The most influencing variable on the reef slope was *Pocillopora verrucosa* whereas *Acropora* spp. and *Montipora* sp. contributed more in the lagoon part. This was interpreted as the reason behind the highest intensity of *Drupella cornus* observed on the reef slope area. Moreover, there was little variation (PC2: 19.7% variance) between the lagoon part of a cluster of Islands (Chetlet Island, Kadamat Island, and Kilthan Island) and the rest of the study sites of Lakshadweep concerning the intensity of *Montipora* sp. followed by *Heliopora* sp. It also indicated their monospecific species occurrence in the lagoon part of Chetlet Island and that there was no impact of *Drupella cornus* in this site. Shade plot merged with Bray-curtis cluster analysis (**Figure 2B**) showed the contribution of coral species richness for Islands and benthic substrate (Reef slope and Lagoon). It perfectly supports PCA that the impacted colony, *Pocillopora verrucosa* on a greater intensity in the reef slope where as *Acropora* spp. and *Montipora* sp. in the lagoonal environment. More over, there were three complete clusters formed based on the coral species diversity. One formed in the Southern region irrespective of benthic substrates with 54.56% similarity; the second formed in the middle region with 56.09% similarity; the third one formed completely on the lagoon portion of the northern and middle region with 47.37% similarity (**Figure 2B**).

In addition to the impact of indicator species, the relationship between the environmental (SST, salinity, chlorophyll-*a*, and TSM) and biological variables were also studied and presented as RDA triplots (**Figure 2C**). Arrows indicating in the same direction represent a high positive correlation between those variables, whereas variables with negative correlation are represented by arrows oriented in opposite direction. SST plays a significant negative role in live coral cover. TSM and Chlorophyll-*a* also slightly influenced the coral cover of the Lakshadweep Archipelago. The impact and assemblage of *Drupella cornus* [Offshore abundance] were positively correlated towards the reef slope region of the southern part of the Lakshadweep Archipelago followed by the middle part (Kadamat Island). Based on the coefficient of determination value, a negative correlation (r = -0.11) of the mean percentage of live coral cover with the abundance of *Drupella cornus* is observed from the collected data. There was no significant variation in pH observed between Southern (7.9 to 8.35), Northern regions (7.9 to 8.4) and central region (7.99 to 8.32) of the Lakshadweep Archipelago.

DISCUSSION

In recent years, *Drupella* has been considered a marine organism that promotes coral reef degradation. This is the first study to report the localized bleaching impact caused by *Drupella cornus* in the Lakshadweep Archipelago. Until 2009, the population of *Drupella (Drupella cornus, Drupella fragum, and Drupella rugosa*) were reported only in three major coastal regions *viz.*, Japan, northern Red Sea, and Ningaloo Reef of Western Australia (Ayling, 2000; Cumming, 2009). In addition, *D. eburnea and D. minuta* have also been recorded on the Japanese coast (Tsuchiya, 1992). Cumming (2009) also reported such assemblages of *Drupella* spp. as a normal population (density of 0-2 per m^2), but recently Koido et al. (2017) recorded its assemblage as an outbreak, by collecting 13.8 kg of *Drupella* spp. off the coast of Cape Toi, Miyazaki, Japan. Al-Sofyani et al. (2014) also reported its impact on the coral reef ecosystem of the Red Sea during their spatial assessment of different growth forms of Scleractinian and non-Scleractinian corals. Recently, the population has considerably declined after a bleaching event (Saponari et al., 2021) that happened near the reef habitat of Maldives. This impact was significant on the species, *Pocillopora verrucosa*. Globally, *Drupella* spp. has expanded its geographical range and posed a serious threat to the coral reef ecosystem worldwide.

During the present large-scale benthic reef monitoring near different Islands of the Lakshadweep Archipelago (Minicoy, Kalpeni, Kilthan, Amini, Kadamat and Chetlet Islands), while studying the health of the reef ecosystem, localized bleaching

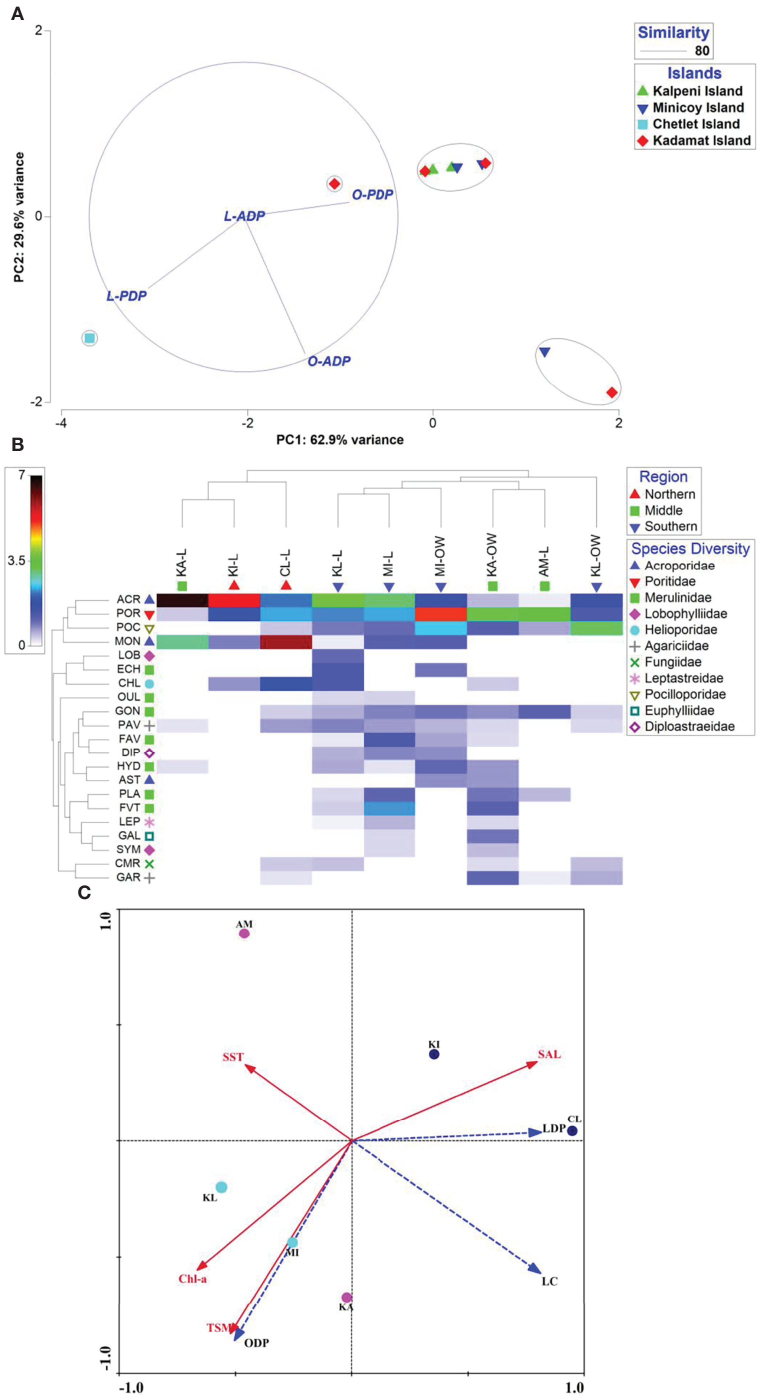

FIGURE 2 | Multivariate analyses. **(A)** PCA and Bray-curtis cluster analysis based on the abundance of *Drupella cornus* on *coral colonies. L Lagoon region; O Openwater Reef slope region; PDP Drupella cornus on Pocillopora verrucosa; ADP Drupella cornus on Acropora sp.;* **(B)** Shade plot combined with Bray-Curtis cluster analysis showing coral species occurrence with respect to the Islands. MI, Minicoy Is.; CL, Chetlet Is.; KA, Kadamat Is.; AM, Amini Is.; KL, Kalpeni Is.; OW, Openwater Reef slope region; L Lagoon region; ACR A*cropora* sp.; POR, *Porites* sp.; GON, *Goniastrea* sp.; PLA, *Platygyra* sp.; LOB, *Lobophyllia* sp.; OUL, *Oulophyllia* sp.; HYD, *Hydnophora* sp.; CHL, Coral *Heliopora*; PAV, *Pavona* sp.; ECH, *Echinopora* sp.; FAV, *Favia* (*Dipsastraea*) sp.; FVT, *Favites* sp.; CMR, Coral Mushroom; LEP, *Leptastrea* sp.; MON, *Montipora* sp.; DIP, *Diploastrea* sp.; POC, *Pocillopora* sp.; GAR, *Gardineroseris* sp.; GAL, *Galaxea* sp.; SYM, *Symphyllia* (*Lobophyllia*) sp.; AST, *Astreopora* sp; **(C)** Redundancy Analysis Triplot visualizing the distribution of live coral cover and *Drupella cornus* abundance in relation to various environmental variables (SST, salinity, chlorophyll-*a* and TSM). Red arrows indicate the environmental variables and blue coloured arrows represent the biological variables [live coral cover (LC), Offshore *Drupella cornus* abundance (ODP) and Lagoon *Drupella cornus* abundance (LDP)]. The circles indicates respective Islands (MI & KL, Minicoy and Kalpeni Islands of southern part of Lakshadweep; KA & AM, Kadamat and Amini Islands of middle part; CL & KI, Chetlet and Kilthan Islands of Lakshadweep Archipelago).

was observed in some coral colonies that were affected by the corallivorous gastropod, *Drupella cornus*. It was observed only in the coral species *Pocillopora verrucosa*. It is inferred that the bleaching effect (Baird, 1999) in the coral colonies is due to the loss of symbiotic algae, *i.e.*, zooxanthellae, as *Drupella cornus* consume them as food. Information is lacking on the species description and the interaction of *Drupella cornus* on coral species from the Indian coastal region. Marimuthu and Tripathy (2018) reported this species for the first time as a biological indicator of the coral reef habitat of Lakshadweep Archipelago. Antonius and Riegl (1997) reported the outbreak of coral disease caused by this species. In the present study, this outbreak was observed in the reef slope area of the Lakshadweep Archipelago.

Ayling (2000) also correlated the outbreak of this indicator organism on the reef habitat with the result of the impact of various natural and anthropogenic factors. Rosenau et al. (2021) pointed out that commercial vessels are considered a potential vector for coral habitat degradation through coral tissue loss. Drupella assemblage may impact reef resilience in association with SST-induced mortality, coral diseases, pollution, and other corallivores (Saponari et al., 2021). Similarly, a redundancy analysis of the temporal data of physical parameters showed SST mediated less coral cover along the coast of Lakshadweep Islands.

Al-Horani et al. (2011) found that the branching forms such as *Acropora* sp. and *Stylophora* sp. were occupied by *Drupella cornus* during their studies on prey selection and feeding rates on corals in the Gulf of Aquaba, Red Sea. On the other hand, *Pocillopora* sp. was reported in other parts of the Red Sea coast (Al-Sofyani et al., 2014). Similarly, it was observed that *Pocillopora verrucosa* was dominantly chosen as prey by *Drupella cornus* in the Lakshadweep group of Islands. Regression analysis also confirmed that a significant positive correlation exists between the abundance of *Drupella cornus* and *Pocillopora verrucosa*. In the case of the Gulf of Mannar, the corals of Acroporidae, *Acropora muricata, A. cytherea*, and *Montipora* sp. were infested with *Drupella cornus* at Shingle Island and Vaan Island (Raj et al., 2016). Hence, it can be inferred that there is a close relationship of the *Drupella* populations between the Lakshadweep Archipelago and the Red Sea (Al-Sofyani et al., 2014) because of similar prey preferences (*Pocillopora* sp.).

CONCLUSION

The spatial variability of the abundance of negative biological indicator, *Drupella cornus* was assessed to find out their assemblage and preferred coral species in the benthic environment of Lakshadweep Archipelago. *Pocillopora verrucosa* was identified as an impacted/preferred coral species during the study period. The dataset on the coral species diversity, interpretation of the impact of *Drupella cornus*, and physical variables on the coral diversity through multivariate analyses would be helpful for marine managers to study the present status of reef habitats and indicator species of the tropical environments.

AUTHORS CONTRIBUTION

Conceived the study, survey, and multivariate analyses: NM; Ecological interpretation and review: NM, JW, and AAA; Wrote the manuscript: NM and AK. All authors contributed to the article and approved the submitted version.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/**Supplementary Material**.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.914240/full#supplementary-material

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