in tissues and will have a different set of normal frequencies; but the frequencies are likely to be different between normal and cancerous cells. Besides this, a study on the combinational treatment of chemotherapy and irradiation at natural frequency may be useful.

Modal analysis indicates that the natural frequency obtained for normal cells is always higher than that of the cancer cells (both breast and prostate cancer cells) at each of the corresponding modes. Variation in cell dimension does not significantly alter the natural frequency of the cells. Modes of vibration of the cancer and normal cells show variation between them. Furthermore, the natural frequency increases with increasing Young's modulus and density of the cells. In conclusion, the study shows that by exploiting the natural frequency of the cancer cells as a tool for treatment, the burden associated with chemotherapy and drug resistance may be overcome by specifically targeting the cancer cells.

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Integrated role of SST, PAR and CDOM in summer reef bleaching during 2010 and 2011 along the Lakshadweep Islands

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The role of sea-surface temperature (SST), photosynthetically active radiation (PAR) and chromophoric dissolved organic matter (CDOM) on bleaching events along the Lakshadweep archipelago was studied for the summer of 2010 and 2011. The present study revealed similar SST pattern (30.8–31.9°C) and high PAR availability (48–50 E m^{-2} day^{-1}) during the summer weeks of 2010 and 2011. However, the CDOM content varied significantly between 0.5 and 7 during

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2010 and 2011. Stress from the elevated SST and PAR levels coinciding with low CDOM content (ultra violet radiation (UVR) transparent water column) might have resulted in large-scale bleaching during 2010. Low PAR and high CDOM (UVR opaque water column) might have prevented Lakshadweep corals from large-scale bleaching during 2011. Statistical analysis also confirmed that the high bleaching event of 2010 was due to coupled stress imparted by SST, PAR, CDOM and the unusually calm state of the sea.

Keywords: Bleaching, dissolved organic matter, photosynthetically active radiation, sea-surface temperature.

CORAL reefs are hypothesized to be the first to indicate the adverse effects of global climate change[1]. Though causatives like acidification, disease outbreak, predation and eutrophication are considered as the major factors responsible for coral degradation, increased sea-surface temperature (SST) on bleaching was reported frequently[2,3]. Indian reefs have experienced about 29 widespread bleaching events since 1989, of which the 1998 and 2002 events were severe[4,5]. Thermal history of reef site and environmental background largely control the upper thermal threshold for bleaching[6,7]. Earlier studies showed that majority of the bleaching events in Lakshadweep archipelago occurred when the summer SST exceeded by 0.5°C from long-term climatology[8]. Though SST has a major influence in massive bleaching events[9–11], many small-scale bleaching events were reported because of combined impact of various environmental factors[12].

The role of sunlight in hampering the physiology of corals has been explained from recent studies. Absorption of ultraviolet radiation (UVR) component of sunlight can inhibit the photochemical system of symbiont zooxanthelle resulting in extensive bleaching[13]. Similarly, the high exposure to light also results in DNA damage by producing reactive oxygen species[14,15]. UVR can penetrate deeper into clear ocean waters and as corals survive mostly in clear tropical waters, it is necessary to understand the impact of UVR on corals at local level. Evidences from many studies have confirmed that the chromophoric dissolved organic material (CDOM) contributes significantly to UV attenuation in coastal and open ocean waters[16,17]. Light absorption by CDOM is highest at high-energy short-wavelength UVR, and continuous absorption of high-energy radiation results in degradation of CDOM called photo-bleaching[18]. High photo-degradation of CDOM is of great ecological significance as the depletion of CDOM reportedly makes corals susceptible to bleaching from high UVR penetration[19].

The present study is from the Lakshadweep reef system considering summer 2010 and 2011 as case study periods to understand the influence of environmental parameters (SST, CDOM and photosynthetically active radiation (PAR)) in coral bleaching.

The Lakshadweep group of islands constitutes about 36 islands, 12 atolls, 3 reefs and 5 submerged banks. They are distributed in the Arabian Sea at 225–450 km from the Kerala coast (8–12°3′N and 71–74°E). The study area is zoned into 40 sites coinciding with benthic data and satellite observations (Figure 1).

Belt transects of 20×5 m^2 were established haphazardly[20] in the Lakshadweep archipelago during the summer (April–May) months of 2010 and 2011. Coral bleaching was measured using the standard methods[21], and observations were recorded as percentage bleaching. Replicate transects were laid in those sites with larger reef distribution. Coral reefs within a depth of 2–10 m only were surveyed in the present study as much of the radiation attenuates with increasing depth. High exposure to light and temperature is only up to a few metres from the surface. Monthly average CDOM, PAR and SST data from MODIS AQUA 4 km dataset for a period of five years (2005–09) were obtained from ocean colour data repository (www.oceancolor.gsfc.nasa.gov). Five-year summer season climatology of these parameters was derived using the band math function of ENVI 4.7. Pixel values from weekly averaged MODIS 4 km SST, PAR and CDOM datasets of pre-summer (January and February) and summer (March and May) months of 2010 and 2011 were retrieved using ENVI 4.7 and plotted using Surfer version 11, to illustrate the weekly variability of major environmental parameters with progressing time period. Spatially averaged wind data (0.25°) for 2010 and 2011 along the study sites were archived from tropical microwave imager (TMI) dataset. Seasonally averaged distribution of environmental parameters for summer 2010 and 2011 was derived from the weekly dataset and seasonal data were evaluated against the 5-year climatology to identify any anomaly in distribution of environmental parameters during 2010 and 2011. Anomalies in SST, PAR and CDOM availability were analysed against coral bleaching rate using Pearson correlation analysis in statistical tool R. The relationship between various environmental parameters and coral bleaching was also illustrated through heat map plotted using ggplot routine in R.

During the summer 2010, about 21 out of the 40 observed coral sites were identified with coral bleaching and related symptoms (paling). Figure 2 illustrates the bleaching scenario in the study region during 2010 and 2011. Maximum bleaching (78.2%) was registered in summer 2010 at site 19 and minimum bleaching was observed at site 11 with a bleaching rate of 11%. However, the 2011 summer experienced mild bleaching and paling at 13 sites and the intensity of bleaching was far less compared to 2010. Highest bleaching rate was recorded during the summer 2011 (12%) at site 24 and lowest bleaching was recorded from site 9 with bleaching rate of 1%. This discrepancy in the bleaching rate at different sites during 2010 and 2011 clearly showed that the 2011 summer was relatively less stressful than 2010.

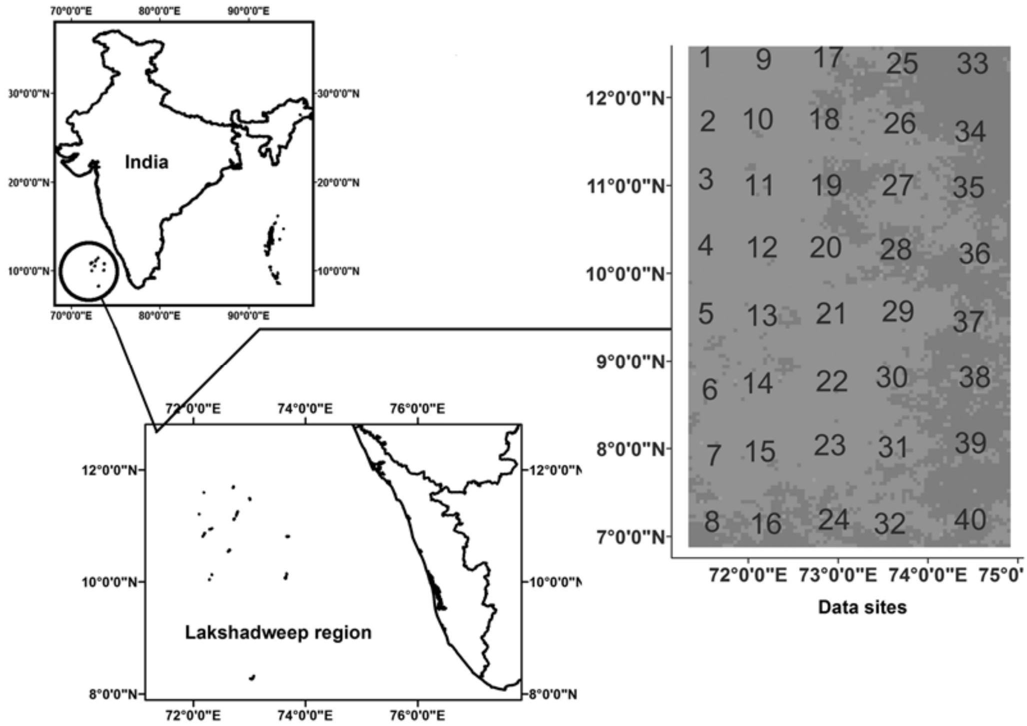

Figure 1. Map of the study area.

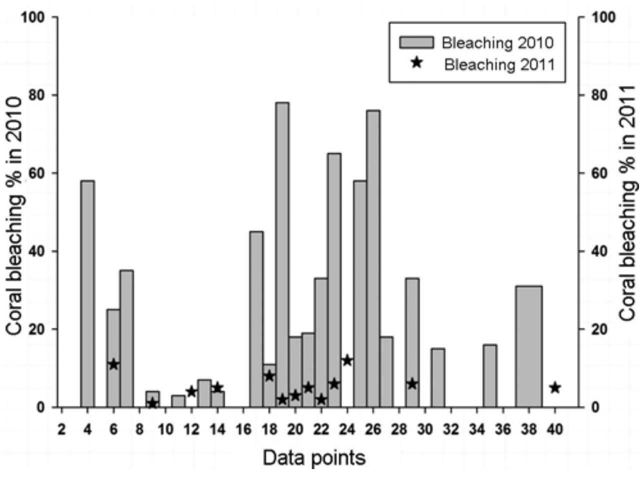

Figure 2. Bleaching scenario during 2010 and 2011.

Figure 3 is a plot of the 5-year summer season climatology of SST, PAR and CDOM for 2010 and 2011. SST was found to range between 29.5°C and 30.5°C. While about 55% of the region was registered with an average temperature of 29.5°C, 45% of the region was observed with a higher summer temperature (30.5°C). SST ranged from 30.83°C to 31.95°C and 30.78°C to 31.9°C during 2010 and 2011 respectively; it showed that both years experienced an acute summer. Five-year summer climatology showed that the summer PAR ranged between 42.92 and 46.45 E m^{-2} day^{-1} along the Lakshadweep region. The summer PAR availability observed during 2010 and 2011 showed overall similarity in intensity and spatial distribution. PAR availability observed during 2011 was recorded between 39.99 and 50.23 E m^{-2} day^{-1}, which was almost similar to the 2010 observation that ranged between 39.39 and 49.40 E m^{-2} day^{-1}. During 2010, about 27.5% of the total region registered high PAR observation of 48–49 E m^{-2} day^{-1}. But in 2011, high PAR of 48–50 E m^{-2} day^{-1} was observed at about 62.5% of the total area. Five-year CDOM index summer climatology registered an average summer distribution of 0.2–4.1 along the Lakshadweep region. In 2010, the CDOM index ranged between 0.04 and 5.78, but 2011 registered a higher CDOM index ranging between 1.04 and 9.59. While 40% of the total study area registered a high CDOM distribution in summer 2011, only 15% of the total area experienced high CDOM distribution during 2010.

Impact of various parameters on reef endurance was assessed by deriving summer month anomalies from the 5 year baseline climatology (Figure 4). An absolute positive anomaly was observed for summer SST during 2010 and 2011 at all the sites. About 23 sites in 2010 and 21 sites in 2011 were identified with high SST anomaly which ranged from 0.12°C to 0.96°C, and 0.08°C to 0.85°C respectively. It is clear from the SST anomaly observation that the trend of distribution of positive anomaly was similar for 2010 and 2011. This illustrated that the rate of impact of SST over the region during the

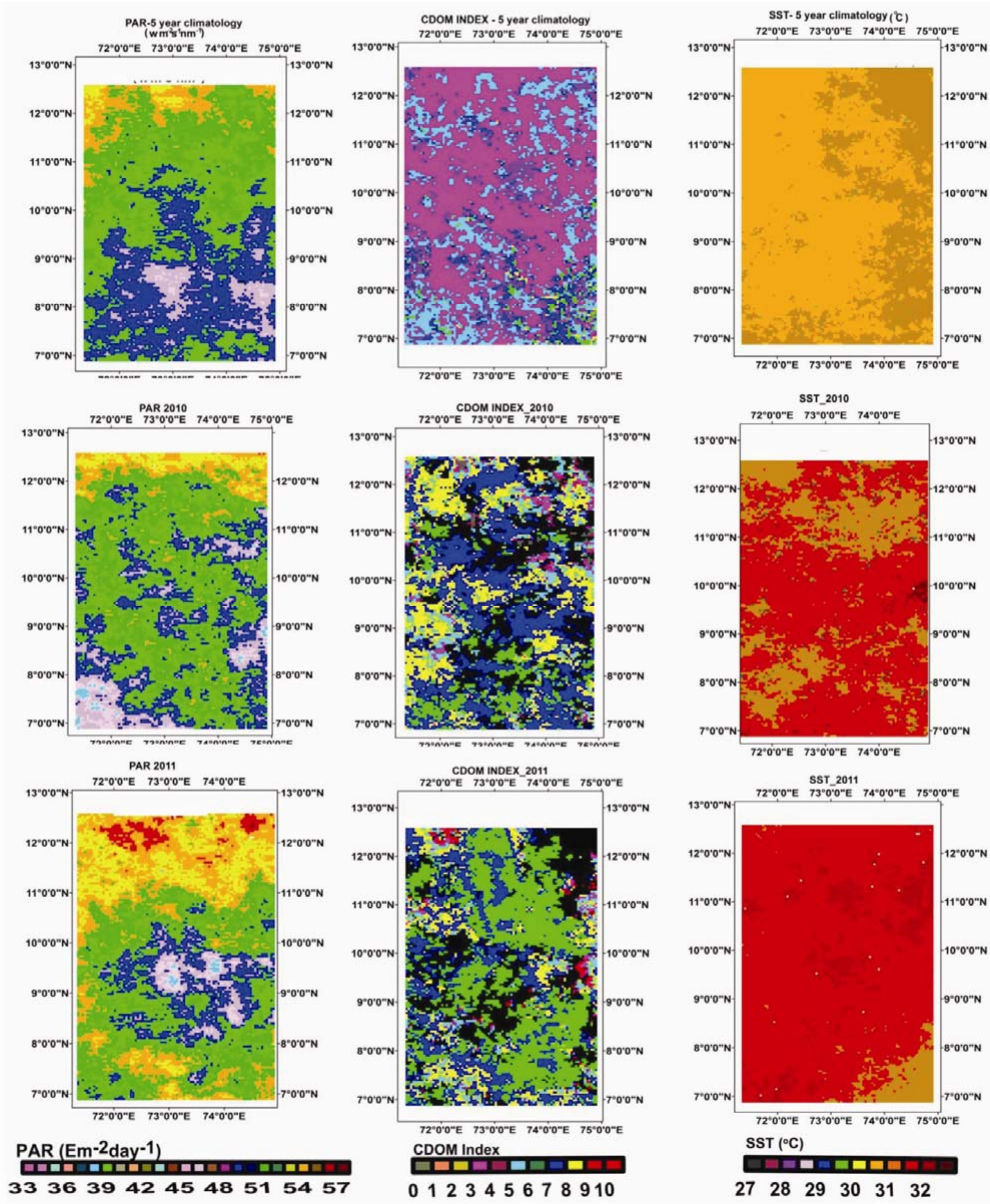

Figure 3. Five-year summer climatology and spatial distribution of major environmental parameters during 2010 and 2011.

periods was the same. The anomaly in PAR observation during 2010 and 2011 was registered between –2 and 1.93 E m^{-2} day^{-1}, and –3 and 4.33 E m^{-2} day^{-1} respectively. Spatial distribution of PAR anomaly revealed positive anomalies at 34 sites in 2011 and 19 sites in 2010. The spatial PAR availability was prominent in the Lakshaweep region during 2011 compared to 2010. Studies have shown that increase in the availability of PAR

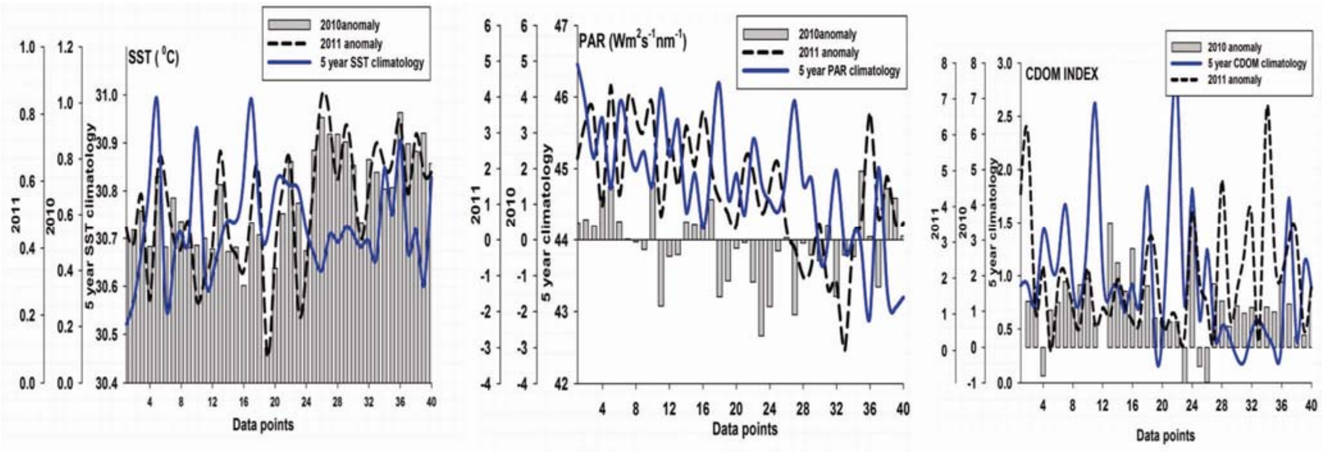

Figure 4. Anomaly in sea-surface temperature (SST), photosynthetically active radiation (PAR) and chromophoric dissolved organic matter (CDOM) index during 2010 and 2011 from 5-year climatology.

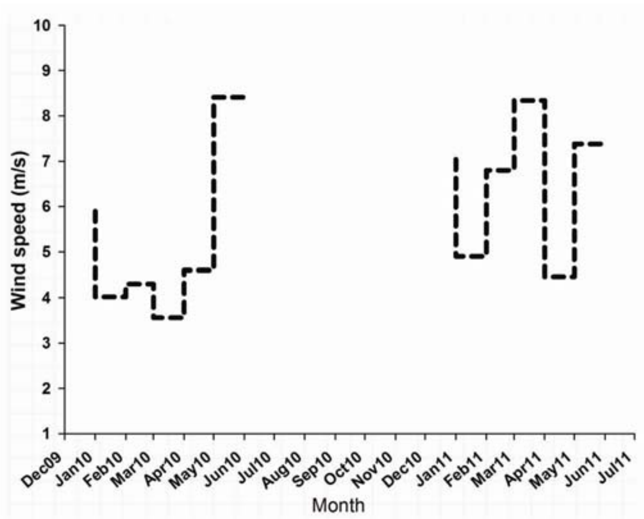

Figure 5. Wind intensity during summer 2010 and 2011.

can possibly increase the chances of coral bleaching[22]. Therefore, it can be considered that majority of sites in the Lakshadweep region were under increased stress from the high PAR availability during 2011. While 2010 was characterized with 36 positive CDOM index anomaly sites and 4 negative CDOM index anomaly zones, ranging between –0.9 and 3.95, all 40 sites during 2011 were observed with positive anomalies ranging between 0 and 6.76. This high CDOM content and spatial extend variability depicted prominently high CDOM density in the surface water of Lakshadweep region during 2011 compared to 2010. Reduced CDOM content during the summer of 2010 can be attributed to low wind mixing (Figure 5) and photodegradation of CDOM can be attributed to high PAR on the surface water[23]. Whereas during 2011, though PAR availability was recorded the highest, CDOM density was found to be persistently high in the water column. This might be due to the high rate of resuspension of settled organic material through wind mixing than the rate of photodegradation of CDOM. The CDOM degradation was compensated consistently by the resuspended organic material.

Table 1 presents the relationship of environmental parameters with observed bleaching in different study sites. Pearson correlation analysis was conducted in R to understand the relationship among SST, PAR and CDOM over the recorded bleaching events during 2010 and 2011. Figure 6 shows the correlation matrix map. Correlation analysis showed a statistically significant positive relationship between SST and bleaching events (Pearson $r = 0.432$ and P value $0.012 < 0.05$). Bleaching recorded an insignificant (P $0.945 > 0.05$) positive relationship with PAR ($r = 0.012$), whereas it recorded a significant (P $0.0012 < 0.05$) negative relationship with CDOM content ($r = -0.539$). Results derived from Table 1 as well as the correlation analysis (Figure 6) indicate the insignificance of PAR in the observed bleaching events of 2010 and 2011. CDOM and SST were observed to have significant statistical relationship with the bleaching events and hence this is discussed in detail.

It can be seen from Table 1 that all sites with elevated SST do not report bleaching events. Though the summer SST during 2011 is similar to that observed during 2010, intensity and incidence of bleaching are found to be far lesser than that observed during 2010. This illustrates that elevated SST alone is not responsible for the observed bleaching events during 2010 and 2011. The low correlation statistics derived between bleaching events and SST also corroborates this notion. Observations on CDOM content at sites recorded with bleaching events (21 sites in 2010 and 12 sites in 2011) indicate that high bleaching events are associated with lower CDOM content and the probability of bleaching reduces with increase in CDOM density. Reduced CDOM content during summer 2010

Table 1. Bleached sites and corresponding prominence of sea-surface temperature (SST), chromophoric dissolved organic matter (CDOM) and photosynthetically active radiation (PAR)

	Bleaching (%)		SST		PAR		CDOM	
Site	2010	2011	2010	2011	2010	2011	2010	2011
4	58	0	0.48	0.34	1.21	0.95	–0.80	2.33
6	25	11	0.48	0.59	0.50	1.26	1.25	1.79
7	35	0	0.66	0.43	0.02	3.85	1.33	2.10
9	4	1	0.48	0.47	–0.26	3.09	1.74	1.69
11	3	0	0.51	0.31	–1.84	0.66	0.65	0.68
12	0	4	0.47	0.61	–0.45	2.82	0.00	1.16
13	7	0	0.70	0.68	–0.41	1.50	1.48	3.24
14	4	5	0.46	0.44	0.50	3.18	2.36	1.95
17	45	0	0.57	0.52	1.13	2.04	0.71	0.84
18	11	8	0.52	0.60	–1.59	1.14	1.71	2.84
19	78	2	0.52	0.08	–1.14	0.73	0.80	2.73
20	18	3	0.40	0.38	–0.23	0.42	0.72	0.67
21	19	5	0.60	0.58	–0.06	2.21	0.69	0.88
22	33	0	0.79	0.64	–1.18	1.93	0.70	0.91
23	65	6	0.64	0.21	–2.68	0.77	–0.99	0.38
24	0	12	0.47	0.34	–1.86	1.46	3.95	3.01
25	58	0	0.83	0.61	–0.30	2.14	–0.53	1.89
26	76	0	0.94	0.85	0.06	0.32	–0.98	1.29
27	18	0	0.88	0.78	–2.09	–0.23	1.77	0.42
29	33	6	0.86	0.76	–0.41	–0.70	0.57	0.89
31	15	0	0.57	0.42	0.40	–1.40	0.94	2.67
35	16	0	0.69	0.65	1.93	0.57	0.98	2.87
38	31	0	0.82	0.73	1.43	1.76	0.28	3.17
40	0	5	0.78	0.62	0.10	0.46	1.82	1.32

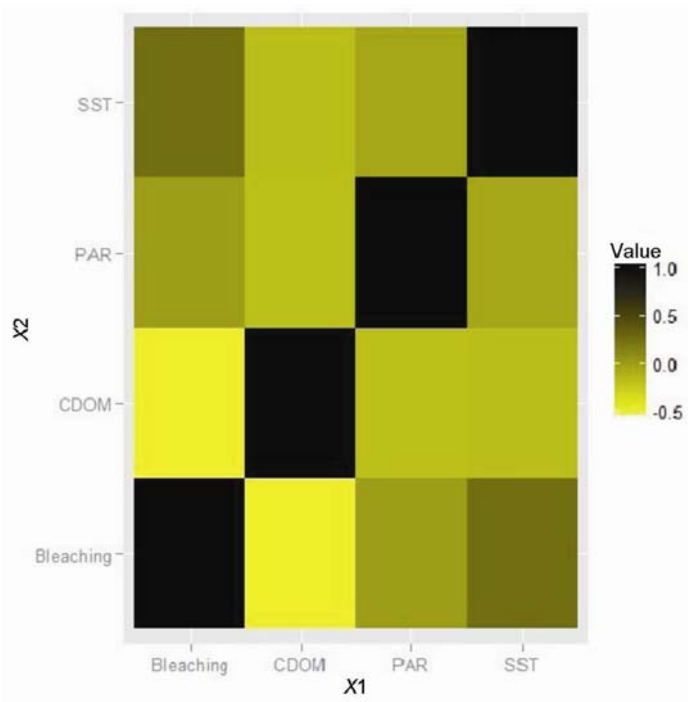

Figure 6. Correlation matrix for bleaching versus environmental parameters.

might have imparted heavy stress over reefs by keeping water column more transparent to UV radiation[24]. Increased availability of UVR when coupled with the elevated SST during the summer 2010 may have increased the amplitude of bleaching events through escalated DNA damages, photoinhibitioin of photosynthesis and increased zooxanthelle expulsion by elevated SST[13]. While in 2011, summer was characterized by intermittently high CDOM content during the entire season and persistently high CDOM content all along the study sites. This elevation of CDOM content in 2011 summer was as a result of prominent wind-induced mixing and resuspension of settled organic compounds. Chromophoric disolved organic matter-rich water during 2011 attenuated large amounts of UVR before reaching the corals[25]. Lesser UVR penetration by CDOM-rich water column evidently reduced the stress imparted on the corals, as stress imparted by SST alone is far less than of SST–UVR coupled stress. Results from the present study corroborate previous observations that mass bleaching events typically occur when sea conditions are unusually calm[26]. Hence, it can be concluded that bleaching events in Lakshadweep are potentially due to high UVR exposure coupled with elevated summer SST. This explains the contradictory bleaching events that occurred in the Lakshadweep reef system during 2010 and 2011.

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