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Review Paper

Coral bleaching phenomenon and the occurrence of its events in South-East and South Asia

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Abstract

Coral bleaching is a detrimental environmental phenomenon which affects the mutual association between the reefs and zooxanthellae. Consequently, this causes reversible or irreversible damage to the coral species; which negatively affects the marine ecosystem due to the dependence of many marine species on the coral reefs. This paper includes an overview of the coral bleaching events in the waters of South-East Asia (Cambodia, Indonesia, Malaysia, The Philippines, Singapore, Thailand and Vietnam) and South Asia (Bangladesh, India, Pakistan, Maldives and Sri Lanka); most of which have taken place due to the rise in sea temperature caused by El Nino or global warming. The mass bleaching events of 1997-1998, 2010 and 2015-2016 have adversely affected the coral cover in the waters of the aforementioned East Asian countries. On the other hand, in South Asia, these mass events have affected the coral coverage in the Indian water. As per the findings of this manuscript, the coral bleaching in Maldives and Sri Lanka occurred in 1998 and 2016. Whereas, the coral bleaching in Bangladesh and Pakistan was reported in 2018-2020 and 2020 respectively. As highlighted in this study, in the various regions of Southeast-Asian waters, about 5 to 100% coral reef got affected in the aforementioned bleaching events. While, about 15 to 90% coral cover was bleached in various regions of the South-Asian waters.

Keywords: Coral reefs; Climate change; Coral bleaching; El-Nino; Asia**.**

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1. Introduction

Corals are one of the well-known marine organisms, which resemble with plants; but they are actually animals (Jamal, 2020). Taxonomically, they belong to class Anthozoa and phylum Cnidaria, and they are related to jellyfish, anemones, and hydras (Putnam *et al.,* 2007). Moreover, corals appeared almost 425 million years ago. They are termed as 'foundational species', because they played pivotal role in the creation of high productivity and structural complexity of coral reef ecosystems (Benzoni *et al.,* 2012). The coral reefs are also termed as "oceanic rain forests" due to their high species diversity (Arulananthan *et al.,* 2021). The most established coral reefs discovered till now are estimated to be 5000 to 10,000 years old; and many of them are creating thin veneers over the older ones and forming thicker structures of reefs (Monagurusamy and Dhanasiri, 2001). There are almost 1500 species of corals, out of which almost 900 are scleractinian corals. Moreover, most of the coral reefs are hermatypic, which means that photosynthetic algae, belonging to family Symbiodiniaceae, in their tissues (LaJeunesse *et al.,* 2018). This symbiosis contributes in high productivity and biomass of the habitats of coral reefs (Bellwood *et al.,* 2004). Furthermore, coral reefs begin to form when 'planulae' (free-swimming coral larvae) get attached to the hard surfaces mostly rocks, either along the submerged edges of continents or along the submerged edges islands. During their expansion and growth, coral reefs tend to form fringing, barrier or atoll; which are their three major and biogeographically similar structures (Hoek and Bayoumi, 2017). About less than one percent of the surface of Earth is covered with coral reefs (Saravanan *et al.,* 2017). More specifically, 0.2% of the ocean floor is covered with coral reefs (MFF Pakistan, 2016). Moreover, most of the world's coral reefs are inhibited between the latitudes of 30° N and 30° S, which means that most of them are present in subtropical and tropical regions (Saravanan *et al.,* 2017). Even though coral reefs thrive best in the waters of warm tropical regions, they extend beyond these tropics towards the regions of higher altitude through warm currents' push (Burke *et al.,* 2002). The Philippines, Malaysia, Indonesia and Papua New Guinea are the most diverse regions in terms of having coral reefs; and each of these countries have 500 to 600 coral species (Venkataraman, 2011).

Furthermore, there are many attributes of coral reefs that make them noteworthy entities in the earth's environment. First of all, coral reefs generate high-quality climate records as climate's geochemical tracers are incorporated in them; therefore, they are also utilized in paleoclimatic studies (Cole, 2014). Moreover, one of the distinctive features of coral reefs is that they act as the habitat of many marine species, which give them noteworthy ecological value (Saravanan *et al.,* 2017). It has been found out that almost 25% of marine species live in them (MFF Pakistan, 2016). In addition, according to old estimates, almost 1 to 8 million inhibited in them or associated with them (Cortés, 1997). However, the recent estimates reveal that about 1 billion people are living within 100 km of coral reef regions (Sing *et al.,* 2022). This variety of species is very beneficial and they augment the overall value of coral reefs. For instance, the coral reefs plants and animals

are being utilized to produce medicines for the cure of various diseases including arthritis, cancer, bacterial infections and viral diseases (Hoek and Bayoumi, 2017). Coral reefs are basically host to a multitude of biodiversity; from small organisms like planktons to large organisms such as sharks (Slezak, 2016). Along with this, coral reefs have high aesthetic value, and they are means of tourists' attraction (Hoek and Bayoumi, 2017). Furthermore, they are the source of generation of about 30 billion dollars on annual basis, which add up economic benefit to their significance (Saravanan *et al.,* 2017).

Although a range of studies regarding corals have been conducted in the field of ocean/marine sciences, there is necessary to sum up bleaching events altogether to build the collective understanding of such occurrences on various regional levels. Therefore, this paper aims to build the basic understanding the cause and effects of coral bleaching and to provide an overview of the coral bleaching events that have occurred in South-East Asia and South Asia. The South-East Asian countries discussed here are Cambodia, Indonesia, Malaysia, The Philippines, Singapore, Thailand and Vietnam. Additionally, the South Asian countries discussed in this paper are Bangladesh, India, Pakistan, Maldives and Sri Lanka. Moreover, the information is gathered from different sources of literature including mainly survey reports, research papers and review papers, and it is based on the coral bleaching events that have been observed, reported and recorded in literature.

2. Review findings

2.1. The overview of coral bleaching

In simple terms, coral bleaching refers to whitening of the tissues of corals. This occurs due to expulsion of the zooxanthellae (unicellular algae) or the reduction of photosynthetic algal pigments, which makes the white aragonite skeleton visible through the transparent tissues of corals (Plass-Johnson *et al.,* 2014). For instance, in the regions of Caribbean Sea and Pacific Ocean, almost 70% of the coral reefs have been damaged due to bleaching (Hoek and Bayoumi, 2017). The bleached corals are not actually dead, and they are able to survive by trapping planktons for nutrition through their tentacles. However, they become extremely weak, and can be easily killed either by any competing seaweed or by any disease (MFF Pakistan, 2016). The bleaching of coral reefs is considered to be an effective indicator of environmental issues. Alternatively, there are various environmental phenomena that also act as the indicators of coral bleaching. In this context, Figure 1 depicts the indicators that represent the occurrence of coral bleaching (Plass-Johnson *et al.,* 2014).

The first major or mass event of coral bleaching occurred in the time period of 1997-1998, which caused mortality of 16% of corals around the globe. The main reason which triggered this bleaching was warming of sea water due to El-Nino (Hussain and Ingole, 2016). Another mass coral bleaching event in the world was reported in 2010. This bleaching was caused due to the rise in sea surface temperatures (SST) as a result of

intense La Niña event that began in early 2010 and continued till late 2010 (Tun *et al.*, 2013). However, the most detrimental and prolonged coral bleaching event has taken place between 2014 and 2017, due to the El Nino warming. During this time frame, more than 70 percent of the world's coral reefs were damaged (Albright, 2017). Specifically, the bleaching in the year 2016 is considered to be the longest mass bleaching event in the world (McDermott, 2016).

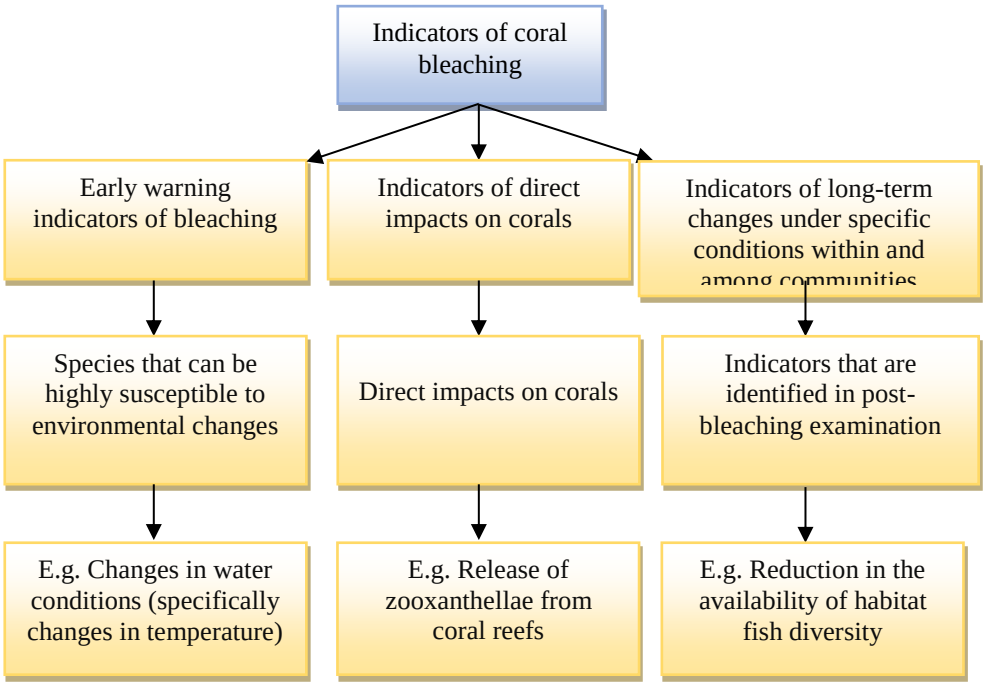


Figure 1. Indicators of coral bleaching (Data source: Plass-Johnson *et al.*, 2014)

2.2. Causes of coral bleaching

Some of the major phenomena that trigger the bleaching of corals are described below.

1. Climate change and global warming

   Contrary to eurytherms, which have the ability to tolerate wide temperature range, stenotherms lack the ability to sustain in the environment that has wide range of temperature. It means that stenothermic species are capable of tolerating only a small temperature range, and they get highly disturbed if they experience high fluctuations in the temperature of their habitats. Therefore, this stenothermic attribute of coral polyps makes them one of the most vulnerable species to climate change, and climatic fluctuations adversely impact those (Saravanan *et al.*, 2017). Whenever the sea surface temperature (SST) becomes greater than the highest maximum monthly mean (MMM) or the temperature in the warmest month, they become highly vulnerable to bleaching. In fact, rising temperature up to 1 to 2°C over the long term average maximum can cause mass bleaching (Hoegh-Guldberg, 1999).

2. El-Nino phenomenon

   ENSO (El-Nino Southern Oscillations) is one of the dominant physical drivers of climate and is a classic example of the interaction between atmosphere and oceans. It

occurs in the region of tropical Pacific (L'Heureux, 2014). El-Nino is the warm phase of these oscillations, which occurs as a result of the reduction in upwelling cold oceanic water due to the reversal of walker circulation of trade winds in the Hadley cells. Additionally, La-Nina is the cold phase of these oscillations that occurs as the result of enhanced walker circulation and strong upwelling of cold water (Trenberth and Fasullo, 2013). One of the reasons of the occurrence of coral bleaching is the increasing water temperature due to the El-Nino phenomenon (MFF Pakistan, 2016).

3. Ocean acidification

   Another significant cause of coral bleaching is the prevalence of ocean acidification. Ocean acidification has been accelerated in the 21st century along with global warming. Consequently, this decrease in the pH of oceanic water causes the degradation of the carbonate structure of the reef system (Hoegh-Guldberg *et al.*, 2007).

2.3. Impacts of coral bleaching

The direct and indirect effects of various human-induced stresses (like overfishing, pollution and harmful fishing practices) have put the marine organisms under pressure. (McClanahan *et al.,* 2002). Coral reefs are not an exception in this regard, and they are also being severely affected by several anthropogenic activities (Brandl *et al.*, 2019). It is estimated that about 27% of coral reefs have been permanently lost, and it is predicted that they will experience a further loss of about 30% the upcoming thirty years. One of the factors that make coral reefs highly vulnerable to extinction is restricted geographic ranges. Basically, the restricted-range species are present in the centers of endemism (being native to a single defined location); and the 10 richest centers of endemism of the world cover 15.8% of coral reefs, which is equivalent to 0.012% of oceans (Hoek and Bayoumi, 2017).

The biggest setback of coral bleaching is that it disturbs the mutualistic symbiosis of zooxanthellae and their host. In cases of extreme bleaching, the functioning of coral reefs can be adversely affected, because bleaching has the potential to cause systemic failures and extreme ecosystem degradation (Wild *et al.*, 2011). Moreover, many people in the world are dependent on coral reefs for their livelihoods such as people working in tourism sector (Souter *et al.,* 2021a). For instance, in Pakistan, almost 1% of the Gross Domestic Product (GDP) is dependent on the fishing sector along with the ability to provide employment to about 1% of the country's labor force. In case of extinction of coral in this country, the suitable ecosystem for fishes gets disturbed; which can eventually result in unemployment along with loss of millions of Pakistani rupees (Amin, 2020). Therefore, it is evident that bleaching of coral reefs also affect in terms of economic losses (Souter *et al.*, 2021a).

Figure 2 depicts the South-East Asian and South Asian countries included in this article in the waters of which various events of coral bleaching have occurred. This map has been created in ArcGIS software (version 10.8) to provide the location illustration of the study regions.

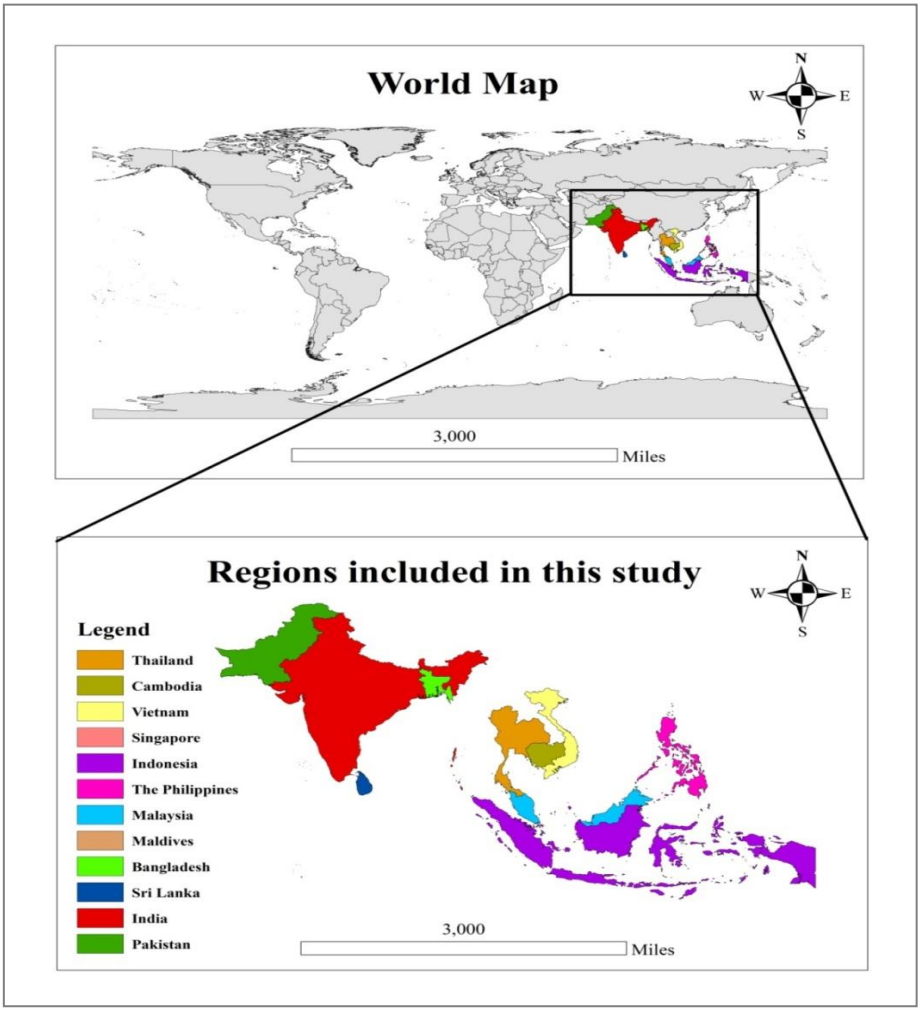
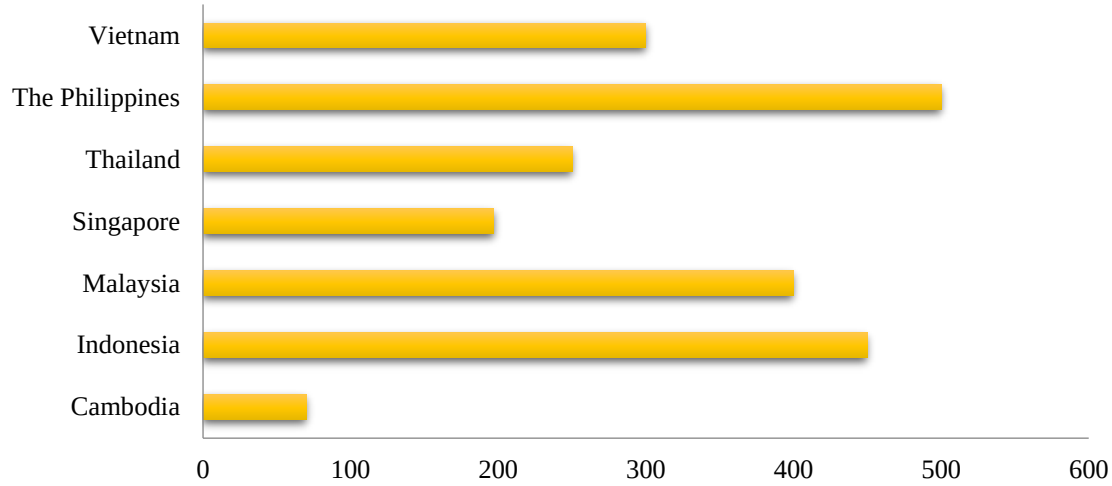


Figure 2. Location map highlighting South-East Asian and South Asian countries, study area (created in ArcGIS 10.8)

3. Coral bleaching events in the South-East Asia

It is estimated that over 3000 species on a single reef can be found in South-East Asia (Venkataraman, 2011). In terms of coral species diversity and extent, this region is considered as coral reefs' global center; and almost 34% of the total Earth's coral reefs are present in the South-East Asian seas where occupy about 2.5% of world's total sea surface (Burke *et al.,* 2002). Figure 3 depicts the number of coral species in the waters of South-East Asian countries.

The corals in the waters of the countries mentioned in Figure 3 have gone through multiple bleaching events, the overview of which is given below (Green, 2016; Roberts-Artal, 2017; Wong, 2017; Chan, 2020; Hyde, 2022).



	Cambodia	Indonesia	Malaysia	Singapore	Thailand	The Philippines	Vietnam
Coral species	٧٠	450	400	197	250	500	300

Figure 3. Number of coral species in waters of the South-East Asian countries (Green, 2016; Roberts-Artal, 2017; Wong, 2017; Chan, 2020; Hyde, 2022)

3.1. Coral bleaching in Cambodia

The Cambodian waters contain almost 70 coral species, which provide habitat to many fishes (UNEP, 2007). Most of the coral species are present on rocky bases, and only a few are present in the form of fringing reef formations. There are 52 offshore islands in Cambodia, out of which one is Koh Tang. Some surveys were conducted in this Koh Tang Island, which revealed the presence of coral species belonging from 33 genera. On the other hand, the inshore islands of Cambodia have very low coral diversity due to high turbidity of water (Burke *et al.*, 2002).

Coral bleaching that occurred between 1997 and 1998 due to ENSO, affected the Cambodian reefs as well; and 80% of corals in the region Sihanoukville were bleached during 1998 (Wilkinson, 1998). Furthermore, in May 2010, severe coral bleaching was reported at Combodian region of Koh Rong/Koh Rong Semleon, which affected 75 to 90% of hard corals. In addition, other corals (including zoanthids, soft corals and giant clams) were also affected (Tun *et al.*, 2013). Severe and moderate bleaching was not reported in the bleaching event of 2015; however, minimal bleaching was observed (more than 67% coral population minimally bleached). On the other hand, in 2016, 24% of Cambodian corals have gone through severe bleaching, 47% have gone through moderate bleaching, and 24% of the coral population has only gone through minimal bleaching (Kimura *et al.*, 2018).

3.2. Coral bleaching in Indonesia

The coral reef area in Indonesia extends to 51,020 km^2, which is almost 18% of the total coral reef area of the world. This country has patch reefs, fringing reefs, barrier reefs and

atolls. Furthermore, Indonesia has one of the richest biodiversity of coral reefs. The total number of coral species discovered in the country is 450, which belong to 70 genera. Tourism is one of the fast growing economic sectors in Indonesia, which is also supported by the diversity of coral reefs (Meinita, 2007).

Bleaching in 1998 also affected the corals in the waters of Indonesia. This event in was initiated by a warm current which flowed from the South China Sea to the Java Sea (Indonesia). Bleaching of almost 75 to 100% of the 25% coral cover was observed at Tulamben (situated in eastern Bali) and around Bali Barat National Park (situated in north-west Bali). Contrarily, areas like Nusa Penida and Nusa Lembongan have gone through lesser bleaching (Wilkinson, 1998). In addition, mass coral bleaching in 2010 has adversely affected the Indonesian corals. The regions of Indonesia in which this bleaching event has occurred included Aceh, Ambon, Bali (Ngurah Rai Reef, northeast Bali), Banyuwangi, Bangko Ƭ Bangko, Karimun Jawa, Kupang, Lombok, Padang, Sabang, Situbondo, Spermonde, Thousand Islands Jakarta,The Gilis Lombok, Tomini Bay and Wakatobi. Moreover, 100% bleaching of some vulnerable coral species were reported, and severe bleaching adversely affected even the more resistant taxa of corals (Tun *et al.,* 2013). Additionally, on the basis of the survey of Coral Bleaching Network, except one province (West Papua), all provinces went through coral bleaching event in 2016. It means that the corals of 21 provinces got bleached within the 25 to 75% range in each province. Of 145 data locations reported, is the one and only province with no reported bleaching. This bleaching mainly affected branching corals; whereas, foliose corals were less affected. Moreover, both reef slope and reef flat were affected by this coral bleaching event (Kimura *et al.,* 2018).

3.3. Coral bleaching in Malaysia

There are almost 400 coral species in Malaysia with the total coral cover of about 1687 km^2 (Meinita, 2007; Khodzori *et al.,* 2019). The majority of Malaysia's coral reefs are present along the Sulu Seat east and north coasts of Sabah (Cros *et al.,* 2014). The hard coral diversity in Peninsular Malayisa is relatively low, and is reported to be in poor condition due to the impact of sedimentation in this region. Along with this, along Straits of Malacca, the anthropogenic activities (like land clearance) also has negative impacts on this region's coral species (Khodzori *et al.,* 2019).

Like many other countries, the 1998 coral bleaching event has also affected the coral cover in Malaysian waters. Bleaching of 30 to 40 % coral cover at Pulau Gaya (Sabah) has occurred. Additionally, in Pulau Sakar and Pulau Baik, almost 30% and 5% of coral species were bleached respectively. Plus, only minor or insignificant bleaching has been reported on Mamutik Island during this bleaching event (Wilkinson, 1998). Furthermore, coral bleaching was also reported in Malaysia in 2010, which specifically occurred in Pulau Tioman; located along the eastern coast of Peninsular Malaysia (Tun *et al.,* 2013). Other Malaysian regions affected in this event were Perhetian and Redang Islands (Wouthuyzen *et al.,* 2018). It is considered to be more severe bleaching event in Malaysia as compared the one that occurred in 1998, because it ended up bleaching 50% corals till

20 m depth. That is why Department of Marine Parks has taken prompt action of closing 12 dive sites within between July 2010 and October 2010, in order to allow recovery of bleached corals (Tun *et al.,* 2013). Similarly, in 2016 between May and June, various regions of Malaysian waters (including Tioman, Redang, Sibu, Payer, Rusukan Besar islands) experienced mild to severe bleaching. This event has bleached 10-80% of coral cover (Wouthuyzen *et al.,* 2018).

3.4. Coral bleaching in Singapore

Nearly 200 species (197 to be specific) of hard corals are found in Singaporean waters. Moreover, coral reefs are mostly found skirting the southern islands of mainland Singapore, comprising patch and fringing reefs (Kimura *et al.,* 2018). Moreover, most of the coral reefs of Singapore are present in the southern islands south of the country (National Parks Agency, 2021).

The rising water temperature up to 33°C in Singapore, where normal water temperature is 28 to 30 °C, has resulted in mass bleaching event in 1998. This bleaching adversely affected all species of hard corals and soft corals. Later when temperature decreased, some of the coral species began to show recovery (Wilkinson, 1998). Additionally, in 2010, moderate to severe coral bleaching occurred in Singapore in all coral reefs across all reef zones. The monitoring data indicated that severity of bleaching was highest in inter-tidal reef flat zones. Plus, in the sub-tidal zones, bleaching of hard coral ranged from 30% to 60%. Moreover, most bleached corals retained some color, and 5% to 30% of the bleached corals turned white (completely bleached) (Tun *et al.,* 2013). Furthermore, during early May in 2014, sea surface temperature surpassed the maximum monthly mean (MMM) of 29.8°C, and reached up to 30.5°C in June. Due to this warming, Singapore's waters were also affected and the sub-tidal reefs faced mild to moderate coral bleaching with 0% to 11.8% of bleaching prevalence (Bleach Watch Singapore, 2014). Along with this, during April 2016, the sea surface temperature again surpassed the maximum monthly mean; and then peaked reached 31.4°C in the month of May which was much higher than the bleaching threshold of 30.8°C. As a result, Singapore's reefs went through moderate to severe bleaching with 42% to 66% of bleaching prevalence across the six sub-tidal sites. Preliminary assessments conducted in one of the one bleached sites revealed that the most affected genera of corals in this bleaching event were Pocillopora (89%), followed by Pachyseries (86%) and Fungia (80%) (Kimura *et al.,* 2018).

3.5. Coral bleaching in Thailand

There are almost 250 coral species in Thailand (Meinita, 2007). The coral reefs in this country extend to about 152 km^2 over 300 small islands. These reefs can be divided into four groups; which include inner Gulf of Thailand in Chonburi Province, eastern Gulf of Thailand in Chanthaburi, Rayong, and Trat Provinces, western Gulf of Thailand in Chumporn, Surratthani, Prachub Kirikhan, Nakhon Si Thammarat, Pattani, Songkhla and Narathiwat Provinces, and Andaman Sea coastline in Pukket, Pang-Nga, Raong, Krabi,

Trang and Sutan Provinces. Moreover, three kinds of reefs are found in Thailand, which include fringing reefs' early formation, developing fringing reefs and no true structures of reefs (Yeemin *et al.,* 2006).

In 1998, the temperature of water in the Gulf of Thailand exceeded the normal range of 28-29°C, and reached higher than 32°C; which eventually became prime cause of coral bleaching. The bleaching of 1998 affected coral reefs in the Gulf of Thailand from Trat province (Far East) and Narathivat province (South) to Chonburi province in the inner area of the Gulf. However, at in the Andaman Sea, no bleaching was observed during this time frame. In some places in the Gulf, bleaching was extremely severe. For instance, it has affected 100% of Acropora in the areas having shallow water (Wilkinson, 1998). Moreover, in June 2010, coral bleaching occurred in Thailand; and ended up in severe coral bleaching (more than 80%) in all reefs in every Thai province in the Andaman Sea and the Gulf of Thailand. In addition, the overall coral mortality in the Gulf of Thailand was between 5 to 50%. Moreover, in the Gulf of Thailand, this bleaching event was similar to the 1998 event in terms of extent; but with had greater severity as compared to 1998 bleaching event. However, in the Andaman Sea, the bleaching event of 2010 was greater in extent and severity both as compared to the 1998 event (Tun *et al.,* 2013).

In addition, coral bleaching was detected in 2014 in the Andaman Sea and the Gulf of Thailand. in the Andaman Sea, *Fungia fungites* was reported as the only bleached coral in 2014; and several other corals were partially bleached (including Acropora divaricata, Goniastrea edwardsi, Platygyra pini etc) (Kimura *et al.,* 2018). On the other hand, various surveys conducted at four sites in Trat Province placed in the Eastern Gulf of Thailand. In the month of March, 2014, revealed two types of symptoms occurred; partially bleached colonies and pale colonies. However, most of the bleached colonies were recovered after a few months (Ruangthong *et al.,* 2014).

As a whole, the 2014 event of coral bleaching in Thailand was milder than that of 2010 event (Yeemin *et al.,* 2014). Later on, in 2016, mass coral bleaching event was witnessed in the Andaman Sea and the Gulf of Thailand. Severe coral bleaching of 50% was reported at 20 different stations in the Andaman Sea; whereas, and severe coral bleaching of 27.42% was reported at 17 different stations in the Gulf of Thailand. However, due to the seawater temperature's decrease as a result of monsoon in 2016, the mortality of corals in 2016 bleaching event was lower than that of 2010 event (Kimura *et al.,* 2018).

3.6. Coral bleaching in the Philippines

The Philippine archipelago is situated between 4º25' North and 21º7' North. The Philippines has one of the world's largest group of islands (having 7,597 islands), and extends from north to south till 1,880 km (ADB, 2014). More than 500 species of corals are found in the waters of the Philippines, which mean that it has a very large coral cover and has a large variety of coral species (California Academy of Sciences, n.d.). The Philippines' coral reefs are considered to be most vibrant reefs around the globe (Warne, 2022).

In 1998, from June to November, intense coral bleaching was witnessed throughout the Philippines. Various studies indicated that the live coral cover has gone through a decline of more than 46%, and the dead coral cover was increased up to 49% as a result of this bleaching event. Moreover, El-Nino along with anthropogenic activities was the contributing factor in this particular bleaching event in the Philippines (Arceo *et al.,* 2001). Another coral bleaching event in the Philippines was observed in late May 2010; due to which the corals in eight areas of the country were severely affected. These areas include Bauan, Calapan in Oriental Mindoro, Pagbilao in Quezon, Nasugbu, Lian, Mabini, and Lobo and Calatagan in Batangas (Tun *et al.,* 2013). Furthermore, the mass coral bleaching of 2016 has also affected the coral cover in the Philippine. For instance, a survey conducted to examine the effects of 2016 bleaching event was conducted in Bolinao-Anda Reef Complex or BARC (situated at northwestern Philippines). It was found that 25% of colonies were bleached as a result of the thermal stress of that triggered this bleaching event (Quimpo *et al.,* 2020).

3.7. Coral bleaching in Vietnam

More than 300 scleractinian coral species are present in the coastal waters of Vietnam. Among them, 277 coral species (from 72 genera) are present in Southern region, while 165 coral species (from 52 genera) are present in the Northern region of the country (Vo, 2001). Moreover, the Northern coral species are found in the form of fringing reefs; whereas, the Southern coral species are also found in the form of platform reefs (Vo, 2001).

Extensive bleaching of corals in Vietnam began in mid-July 1998. As a result of this bleaching event, the regions off of Nha Trang; situated in south-central Vietnam, have gone through moderate levels of coral mortality. On the other hand, major bleaching was observed in Con Dao National Park, where 70% of corals were affected. On the whole, the 1998 event in Vietnam resulted in coral losses of 70 to 80% in the coral cover of shallow water (1-2 m deep) (Wilkinson, 1998). Additionally, in deeper water, coral mortality reached the level of 90% (Wilkinson, 1998). Furthermore, coral bleaching in Vietnam in 2010 was found in depths of 8 to 10m. This event affected hard corals, soft corals along with sea anemones (Tun *et al.,* 2013). In 2015 and 2016, during the months of May and July, the coral bleaching events of different impacts' levels occurred in the coastal waters of Vietnam. In 2015, this bleaching was observed and found in the shallow waters of 2 to 7 m depth at some areas with a very low ratio and a very low mean cover of slightly bleached corals recorded in Van Phong Bay, Cam Ranh Bay, and Nha Trang Bay. Moreover, in 2016, bleaching caused much more serious impact to Vietnamese coral reefs in Phu Quoc at the depth of 10m; with mean cover of 20.2 ± 16.6% and ratio of 28.2 ± 12.2% bleached corals (Kimura *et al.,* 2018). This mean cover and ratio were much higher than that of other regions in the south-central Vietnam, like Van Phong Bay, Nha Trang Bay, Ninh Hai coast, and etc (Kimura *et al.,* 2018).

As shown in Table 1, it briefly represents the time, causes and impact of coral bleaching events in the waters of aforementioned countries.

Table 1. Coral bleaching events in the waters of South-East Asia n countries

Country	Time of occurrence	Causes of coral bleaching	Severity/ impact	References
Cambodia	1998	SST increase due to ENSO	80% of corals in the region Sihanoukville	Wilkinson, 1998
	2010	SST increase due to La Niña	75 to 90% of hard corals in Koh Rong Semleon	Tun *et al.*, 2013
	2015	Warming caused by El Nino	More than 67% coral population minimally bleached	Kimura *et al.*, 2018
	2016	Warming caused by El Nino	24% of Cambodian corals have gone through severe bleaching	Kimura *et al.*, 2018
Indonesia	1998	SST increase due to ENSO	Bleaching of 75 to 100% of the 25% coral cover at Tulamben	Wilkinson, 1998
	2010	SST increase due to La Niña	100% bleaching of some vulnerable coral	Tun *et al.*, 2013
	2016	Warming caused by El Nino	25 to 75% range in each of the 21 provinces	Kimura *et al.*, 2018
Malaysia	1998	SST increase due to ENSO	Bleaching of 40 % coral cover at Pulau Gaya (Sabah), 30 % in Pulau Sakar and 5 % Pulau Baik Insignificant bleaching on Mamutik Island	Wilkinson, 1998
	2010	SST increase due to La Niña	50% corals bleached till 20 m depth	Tun *et al.*, 2013
	2016	Warming caused by El Nino	10-80% of coral cover bleached	Wouthuyzen *et al.*, 2018

Singapore	1998	SST increase due to ENSO	Bleaching adversely affected all species of hard corals and soft corals.	Wilkinson, 1998
	2010	SST increase due to La Niña	Moderate to severe coral bleaching (most bleached corals retained some color, and 5% to 30% of the bleached corals turned white)	Tun *et al.*, 2013
	2014	Warming caused by El Nino	Mild to moderate coral bleaching of 0% to 11.8%	Bleach Watch Singapore, 2016
	2016	Warming caused by El Nino	Moderate to severe bleaching of 42% to 66%	Kimura *et al.*, 2018
Thailand	1998	SST increase due to ENSO	Severe bleaching in Gulf of Thailand (but no bleaching in Andaman Sea)	Wilkinson, 1998
	2010	SST increase due to La Niña	Severe coral bleaching (more than 80%) in the Andaman Sea and the Gulf of Thailand	Tun *et al.*, 2013
	2014	Warming caused by El Nino	Milder than 2010 event	Yeemin *et al.*, 2014
	2016	Warming caused by El Nino	Severe coral bleaching of 50% in the Andaman Sea; and severe coral bleaching of 27.42% in the Gulf of Thailand	Kimura *et al.*, 2018
The Philippines	1998	SST increase due to ENSO	Live coral cover has gone through a decline of more than 46%	Arceo *et al.*, 2001
	2014	SST increase due to La Niña	Severely affected corals in eight areas of the country	Tun *et al.*, 2013
	2016	Warming caused by El Nino	25% of colonies were bleached	Quimpo *et al.*, 2020
Vietnam	1998	SST increase due to ENSO	Coral mortality of 70 to 80% in shallow water and of 90% in deep water	Wilkinson, 1998
	2010	SST increase due to La Niña	Coral bleaching in depths of 8 to 10m	Tun *et al.*, 2013
	2015	Warming caused by El Nino	Slight bleaching in 2 to 7 m depth of water	Kimura *et al.*, 2018
	2016	Warming caused by El Nino	Serious coral bleaching in Phu Quoc (at the depth of 10m)	Kimura *et al.*, 2018

4. Coral bleaching events in the South Asia

The South Asia region has 4.2 % (10,949 km^2) of global area of coral reefs (Souter *et al.*, 2021b). About 51 million people in the South Asia are dependent on coral reefs for food or their livelihood; and the tourist expenditure associated with coral reefs is estimated to be $ 1.4 billion on annual basis. It means that coral reefs have very high significance in this region (Souter *et al.*, 2021b). The number of coral species in the waters of South Asian countries is shown in Figure 4, and the corals in the waters of these regions have been the victim of detrimental bleaching events (Dasgupta, 2016; Slezak, 2016; Narin, 2017; Mandhro, 2020).

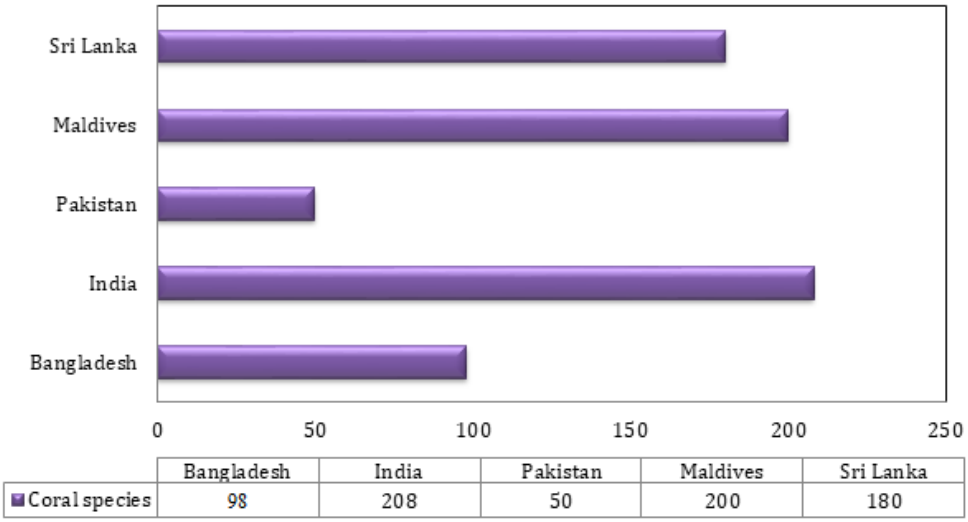


Figure 4. Number of coral species in the waters of South Asian countries (Monagurusamy and Dhanasiri, 2001; Slezak, 2016; De *et al*., 2020, Ali *et al*., 2020; Habib and Islam, 2021)

4.1. Coral bleaching in Bangladesh

Till now, 98 species of hard corals (belonging to 18 families and 37 genera) have been reported in Bangladesh's waters (Habib and Islam, 2021). Due to enriched marine environment and diversified ecosystem, St. Martin Island (also known as Coconut Island) is such an island in Bangladesh that is an ideal habitat for the coral species (Sakib, 2021). This small sedimentary island situated in northeast of Bay of Bengal is surrounded by rocky reefs, and it is the only island of Bangladesh where coral communities are present (Tomascik *et al.*, 2021; Habib and Islam, 2021).

This region of the aforementioned St. Martin Island has gone through coral bleaching from the time span of 2018 to 2021, which affected many coral species. The main cause of this bleaching event is considered be anthropogenic influence of unplanned tourism, as this island is a very popular tourist destination (Sakib, 2021). However, most of the bleached corals got naturally regenerated as a result of changing environmental variables during the pre-monsoon and winter seasons (Mahmood *et al.*, 2022). By keeping in view this bleaching event, 1743 km^2 area surrounding St. Martin Island have been recently declared as Marine Protected Area (MPA) (BBC, 2022).

4.2. Coral bleaching in India

The Indian Ocean is highly rich in terms of having a huge variety of coral species. All of the major types of coral reefs, including barrier, fringing and atoll, are present in India. The Gulf of Kutch in the northwest, and Palk Bay and Gulf of Mannar in the southeast of India's mainland coast are the regions that contain coral reefs. Additionally, some other regions of India contain the patches of reefs (e.g: Malvan at West Coast) (Venkataraman, 2011). On the whole, the previous studies showed that there were up to 208 coral species in India (Krishnamoorthy, 2011). However, now India has 585 coral species including 108 genera and 23 families (De *et al.,* 2020).

The coral reefs in the Indian waters were highly impacted by the El-Nino event of 1998, which caused 50 to 60% mortality of the region's corals. Moreover, the climate records of India depict that from 1951 to 2015, the temperature of sea surface in the tropical Indian Ocean have increased by almost 1 degree ºC (Nandi, 2021). Specifically, the regions of Andaman and Nicobar experienced coral bleaching in 1997-1998, 2002 and 2005. Along with this, temperature rise resulted due to El-Nino resulted in the bleaching in the region of Lakshadweep Island (in 2010 and 2015). Moreover, coral bleaching in India also occurred in Pal Bay and Gulf of Mannar (in 1997-1998, 2002 and 2010-2015). The causes of the occurrence of these events were increase in temperature, sedimentation and delayed monsoon. The rise in temperature resulted in bleaching event in Gulf of Kutch, Malvan and Grande Island as well; in the period of 1997-1998 and 2010-2015, 2014, and 2015 respectively. The Malvan bleaching incident resulted in 15% bleaching; whereas, the Grande Island vent resulted in 41.5% bleaching of the coral reefs **(**Hussain and Ingole, 2016).

4.3. Coral bleaching in Pakistan

Coral patches are present in a few restricted locations in Pakistan, which are mainly found along the Balochistan coast. This country has almost 50 live coral species. Plus, Churna Island is very rich in terms of coral species (Ali *et al.,* 2020). However, there is no true coral reef ecosystem in Pakistan, still "proto-reef" is found in the region of Astola Island. Proto-reef is basically a reef in its initial stages of formation. (MFF Pakistan, 2016) The hard corals are abundant in the Astola Island, where several coral species like *Porites nodifera, Coscinaraea monile* and *Favites complanata* are present. On the other hand, soft corals are abundant in the regions of Jiwani, Ormara, Goth Abdul Rehman and Astola Island (Ali *et al.,* 2014).

In October, 2020, the first coral bleaching in the history of Pakistan has been observed in the region of Churna Island (Jamal, 2020; Mujeebullah, 2020). This Churna Island is Pakistan situated along Balochistan coast at west of Hub River, and is almost 9 km away from this river. This island is about 8m deep and 1.2 km long (Jamal, 2020). According to WWF Pakistan, the core reason of this coral bleaching was the increasing temperature of seawater that was mainly caused by the industrial activities (thermal power plant, oil

refinery etc) going on near the Churna Island. (Jamal, 2020). According the experts of related fields, underwater temperature has reached the range of 25 to 27 ºC; and if it reaches to the level of 28 ºC, then it would be extremely harmful for the coral reefs (Mujeebullah, 2020). On the other hand, another view was that this bleaching was a result of tourism activities, according the survey conducted by Balochistan Environmental Protection Agency (Khan, 2021).

4.4. Coral bleaching in Maldives

Maldives is enriched with a huge variety of coral species. Up to 200 species that representing more than 60 genera, are present in Maldivian marine water. Due to the huge reliance on fisheries and tourism, corals play very important role in the livelihoods of the people of Maldives (Slezak, 2016).

Maldives has experienced two events of severe coral bleaching; one in 1998 (Naseer, A. 1997) and the other in 2016 (Montefalcone *et al.,* 2020). Coral bleaching was also observed in 2010 in Maldives, but it was much milder than that of 1998 and 2016. This 2010 event is considered to be mild because it has not caused prominent mass morality of corals (Morri *et al.,* 2015; Montefalcone *et al.,* 2020). On the other hand, the bleaching event of 1998 resulted in the morality of more than 90% corals, and only 6.8 ± 0.3% corals survived. The coral mortality of 2016 bleaching event was lower than that of 1998 event, and this low morality can be associated to the "Adaptive Bleaching Hypothesis (ABH)" in shallow reefs of Maldives. In addition, the atolls (ring-shaped coral islands) having different levels of human pressure did not depict any significant difference in coral mortality. In contrast, atolls with more human pressure depicted greater coral mortality in the 2016 heat rise and coral bleaching event (Montefalcone *et al.,* 2020).

4.5. Coral bleaching in Sri Lanka

The number of coral species in Sri Lankan waters is estimated to be up to 180.The coral reefs in Sri Lanka include three types, that are barrier (Silavathurai and Vakalai), Fringing (Hikkaduwa). In Sri Lanka, majority of the coral reefs are of sandstone and rock. There is limited extent of true coral reefs, and fringing coral reefs are present in only 2% of the coastline. These fringing coral reefs are mainly present along southern, southwestern, and eastern coasts of Sri Lanka. However, off-shore patch reefs are more extensive (Monagurusamy and Dhanasiri, 2001). Moreover, during some baseline surveys conducted in 2017 and 2018 in Jaffna Peninsula (Northern Sri Lanka), 113 species of scleractinian hard corals (16 families and 39 genera) along with 7 soft coral genera were recorded. Out of these 36 scleractinian coral species, were recorded for the first time in Sri Lanka (Arulananthan *et al.,* 2021).

In April, 1998, in Hikkaduwa Nature Reserve in Sri Lanka, an event of mass coral bleaching took place. It was later estimated that the coral morality was nearly 90% (Jinendradasa and Ekaratne, 2000). The reason of this coral bleaching event was the increase of approximately 4 to 5°C in temperature as compared to the seasonal norm.

There was also reduction in the coral settlement till about a couple of years after this bleaching (Jinendradasa and Ekaratne, 2000). Furthermore, in 2016, bleaching of coral reefs was again observed in Sri Lanka. Specifically, it was observed in the south and south-western coast along with Jaffna and Bar Reef in Kalpitiya. All the signs of this bleaching were similar to the signs of 1998 bleaching event. Experts have identified the rise in temperature as the cause of the 2016 coral bleaching event as well (Economynext, 2016).

Table 2 depicts the location, time and causes of coral bleaching events in the waters of aforementioned South Asian countries.

Table 2. Coral bleaching events in the waters of South Asian countries

Country	Coral bleaching location	Time of occurrence	Causes of coral bleaching	References
Bangladesh	St. Martin Island	2018-2021	Anthropogenic influence due to unplanned tourism	Sakib, 2021
India	Andaman and Nicobar	1997-1998 2002 2005	Multiple causes	Hussain and Ingole, 2016
	Lakshadweep Island	2010	El-Nino that led to increase in temperature	
		2015	South-West monsoon failure	
	Gulf of Mannar and Palk Bay	1997-1998	Increase in temperature	
		2002	Sedimentation	
		2010-2015	Delayed monsoon	
	Gulf of Kutch	1997-1998 2010-2015	Increase in temperature	
	Malvan	2014	Increase in temperature	
	Grande Island	2015	Increase in temperature	
Pakistan	Churna Island in Arabia Sea	2020	Increasing temperature of seawater caused by industrial activities Tourism activities	Jamal, 2020
Maldives	*Not specified*	1998	El-Nino that led to increase in temperature	Montefalcone *et al.*, 2020
		2010	---	Morri *et al.*, 2015
		2016	Increase in temperature	Montefalcone *et al.*, 2020
Sri Lanka	Hikkaduwa Nature Reserve in Sri Lanka in South and south-western coast along with Jaffna and Bar Reef in Kalpitiya	1998	El-Nino that led to increase in temperature	Arulananthan *et al.*, 2021
		2016	Increase in temperature	Economynext, 2016

Conclusion

This paper involves the discussion of the events of coral bleaching that have affected the coral cover in South-East Asia; including Cambodia, Indonesia, Malaysia, The Philippines, Singapore, Thailand and Vietnam, and South Asia; Bangladesh, India, Pakistan, Maldives and Sri Lanka. By going through the literature related to the aforementioned subjects, it has been analyzed that most of the events of coral bleaching that occurred in these regions have been caused by the rise in sea temperature due to El Nino or global warming. Secondly, the number of species and the coral bleaching events in the waters of these areas are based on the species and the events reported till now. There is possibility that there may be more coral species in these areas which are still undiscovered, and some more events of coral bleaching may have occurred in the waters of these countries. In the light of the findings, the wildlife conservation and marine protection departments in all aforementioned countries should tackle the issue of coral bleaching on priority basis. Along with this, in order to become able to observe and report bleaching on time, frequent and effective monitoring or surveys of the coral reefs is needed be ensured. In addition, the regions where coral reefs have been affected or are at risk of bleaching, should be converted into protect areas in order to stop their further deterioration or to prevent them from getting damaged.

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