Ministry Environment

Egyptian Environmental Affairs Agency

Nature Conservation Sector

Red Sea Protectorates

Scientific Review for the Coral Reef Bleaching Event (2023) along the Egyptian Coast of The Red Sea

BY

Tamer Monir Attalla Sharaka (PH.D)

Environmental Research – Red Sea Protectorates

REVIEW BY

Dr Mohamed Salem Abed El Naiem

Head of the Natural Conservation Sector

February2024

Acknowledgment

The Red Sea Protectorates is deeply appreciation Hurghada Environmental Protection and Conservation Association **(HEPCA)** for their repaid response to the early alert for coral bleaching in Red Sea and their efforts to conduct the detailed survey along the Egyptian coast of the Red Sea to evaluated the statues of the coral reef bleaching during 2023.

We wish to express our sincere appreciation to **Prof. Dr. Mahmoud Hassan Hanafy**, Professor of Marine Ecology, Marine Science Department, Faculty of Science, Suez Canal University, and The Scientific consultant for Red Sea Governor and HEPCA and **Dr Muhammad Yousef Dosoky**, Lecture of Marine Ecology, Department of Marine Science, Faculty of Science, Port Said University, for their great effort to prepare the SCIENTIFIC NEWS REPORT "**Coral Bleaching Event of 2023**": Exploring distribution, sensitivity, and recovery potential on the Egyptian coast of the Red Sea.

Scientific Review for the Coral Reef Bleaching Event (2023) along the Egyptian Coast of The Red Sea

Corals have a symbiotic relationship with microscopic algae called zooxanthellae that live in their tissues. These algae are the coral's primary food source and give them their color. Zooxanthellae provide coral with nutrients through photosynthesis. In exchange, coral supplies carbon dioxide and ammonium to zooxanthellae. This relationship, where both organisms benefit, is known as a symbiotic relationship (*Glynn, 1996; Hughes et al., 2018; Leggat et al., 2019; Sully et al., 2019*).

When corals are stressed by prolonged exposure to elevated temperatures and/or extreme short-term increases in temperature or changes in environmental conditions such as light, or nutrients, it can disrupt the symbiotic relationship between corals and zooxanthellae, they expel the symbiotic algae living in their tissues, causing them to turn completely white. This is called coral bleaching, (*Lesser , 2011*) . When a coral's environment becomes abnormally warm, these algae begin to misbehave. They essentially go into overdrive and instead of producing food they produce detrimental molecules called reactive oxygen species (ROS). These molecules cause havoc inside the coral cells (*Fridovich, 1998*). The coral has no choice but to expel the algae before these molecules ultimately kill the coral, leaving behind their transparent tissue and stark white skeletons (*Lesser, 2011*). When a coral bleaches, it is not dead. Corals can survive a bleaching event, but they are under more stress and are subject to mortality (*Marshall and Schuttenberg, 2006)*.

1- Causes of Coral Bleaching

Although some are more common than others, coral bleaching can have a number of causes which are summarized by (*Brown, 1997a, b; Lesser, 2011; Wooldridge, 2013*):

Temperature

The most common cause of coral bleaching, and the biggest concern among the environmental protection community, is rises in seawater temperature as a result of global warming. Changes in water heat affect zooxanthellae photosynthesis, forcing it out of coral polyps and depriving coral of essential resources.

Solar Irradiance

During summer months, coral bleaching can occur due to solar radiation. Both photosynthetically active radiation and UV radiation have been associated with bleaching.

Subaerial Exposure

Low tides, sea level drops and tectonic uplift can result in sudden exposure of coral to the atmosphere. Whether due to exposure to high/low temperature, increased solar radiation or desiccation, subaerial exposure often results in bleaching and consequent coral death due to sudden changes in atmospheric conditions.

Sedimentation

Though uncommon, coral bleaching can sometimes be linked to sediment. Activities such as land clearing and coastal construction can result in high rates of erosion, increasing sediment content in water and disrupting the natural process of photosynthesis.

Fresh Water Dilution

Following intense storms or heavy rainfall, increased freshwater precipitation can cause rapid dilution, increasing water salinity. Such events, though considerably rare, can cause bleaching in small, nearshore areas.

Inorganic Nutrients

Increases in inorganic nutrients such as ammonia and nitrate do not deplete coral of zooxanthellae, but rather cause it to multiply, increasing its content by 2-3 times. Though this does not directly cause bleaching, secondary adverse effects such as lower coral resistance and increased disease susceptibility can occur.

Xenobiotics

Exposure of coral to chemical contaminants such as copper, herbicides and oils can cause zooxanthellae loss. Such loss is often highly localized, only occurring where xenobiotics (foreign substances) come into contact with coral.

Epizootics

Epizootics are diseases that are temporarily prevalent, often becoming widespread through animal populations. Pathogen-induced bleaching commonly results in sporadic or whole-colony death amongst coral populations, leaving behind a white skeleton. (Not to be mistaken for bleaching.)

2-Mechanisms of Coral Bleaching

Coral bleaching is primarily induced by two factors: photoinibition and oxidative stress. A clear indicator for coral bleaching is that the coral's zooxanthellae are experiencing either one or both of these stressors. Photoinhibition is the process in which a constantly high absorption of excitation energy and a decrease in photosynthetic electron transport combine to cause damage to the photosystem II reaction center of photosynthetic organisms (*Hoogenboom et al. 2012*). Photoinhibition can be caused by exposure to thermal stress and increased ultraviolet radiation (UVR). It leads to a reduced yield from photosynthesis and energy expenditure on the repair of damaged tissues (*Long et al. 1994*). Oxidative stress occurs within an organism when the production and accumulation of Reactive Oxygen Species (ROS) exceed the organism's capacity to control their levels (*Fridovich 1998*). ROS are a group of compounds (superoxide radicals, hydrogen peroxide, hydroxyl radicals, and ions) that, when they accumulate in the cells, can damage lipids, DNA, and proteins. They are normally controlled by anti-oxidants produced by the organism. ROS production can increase rapidly in photosynthetic organisms such as zooxanthellae when they are exposed to increased temperature and UVR (*Suggett et al. 2008; Lesser and Farrell 2004*). As these two factors increase, the production of ROS overwhelms the antioxidant defenses and causes extensive damage (*Martindale and Holbrook 2002*). Besides being transferred to the host from the zooxanthellae (*Suggett et al. 2008*), ROS are also produced by the cnidarian hosts as a response to thermal stress (*Dykens et al. 1992*). A build-up of ROS in coral tissues might be monitored as an indicator for a potential future bleaching event. As the host cells are exposed to, and damaged by, the built up ROS, there are several ways in which the symbiosis can be uncoupled. In apoptosis, a programmed cell death pathway is initiated due to exposure to ROS or extensive damage to the DNA or other cell components. In necrosis, the cell's functioning is disrupted to a degree where it disintegrates without a controlling pathway (*Martindale and Holbrook 2002*). Additionally, zooxanthellae can be expelled from the host tissue by exocytosis into the gastrovascular cavity, or the cell can be detached from the endoderm as a whole (*Gates et al. 1992*). Not all zooxanthellae get out from the coral polyp but some of them still inside it, (*Gates et al. 1992).*

Photosynthesis by zooxanthellae can provide the coral host with a significant proportion of its energy demand (*Tremblay et al., 2012*). A loss of this contribution due to bleaching severely impacts coral fitness, reducing reproductive output and growth (*Manzello, 2010; Cantin, et al. 2010; Brown, 2012*). Calcification can be "light enhanced" during the day (*Gattuso et al. 1999; Schutter et al. 2012*), and although the precise physiological mechanism behind this process is still under debate, a loss of zooxanthellae has a clear adverse effect on calcification *(Moya et al. 2008)*. Coral bleaching can also increase the occurrence of growth anomalies, disturbing the normal development of coral colonies (*McClanahan et al,. 2009*). The reproductive capability of the coral is influenced in the period following a bleaching event, with a reduced number of gametes being produced by bleached coral tissue (*Armoza-Zvuloni et al. 2011*). Coral reproduction is further impacted by increased water temperatures through reduced fertilization success *(Albright and Mason 2013)*, and reduced larvae survivorship and settlement *(Randall and Szmant 2009a, b)*.

3- Variations in Bleaching Susceptibility

Corals vary in their susceptibility to bleaching. Consistent patterns of susceptibility can be seen among coral species, with a general trend of higher susceptibility in more intricate, branching forms and lower susceptibility in massive species, especially those with fleshy polyps. Corals can also acquire a greater tolerance to bleaching stresses if they are constantly exposed to higher temperatures or greater irradiance. Corals on reef flats, for example, will often be able to tolerate much higher water temperatures than colonies of the same species inhabiting reef slopes, (*Marshall and Schuttenberg, 2006).*

The type of zooxanthellae can also influence bleaching susceptibility. There are at least nine groups (called clades) of zooxanthellae currently recognized, and there may be many species within these groups. Zooxanthellae clades vary in their ability to tolerate elevated temperatures, and some corals have heat-resistant clades, and are therefore, more resistant to bleaching. However, corals with heat-resistant clades tend to grow more slowly, creating evolutionary trade-offs in the symbiotic relationship that maintains a diversity of clade-coral relationships, (*Marshall and Schuttenberg, 2006).*

Many field studies had shown that the heat stress can lead to different bleaching patterns between regions, reefs, depths, or coral species *(Muir et al., 2017; Monroe et al., 2018; McClanahan et al., 2020)*. This difference is mostly related to factors such as coral genetics, morphology, or endosymbiont genotype *(McClanahan, 2004; Sampayo et al., 2008; Thomas et al., 2018; Manzello et al., 2019; Qin et al., 2019; Mies et al., 2020, Dosoky et al., 2021).* This may explain why some reefs have thermal tolerance despite receiving heat stress above the bleaching thresholds of others.

Shlesinger &van Woesik,(2023), examined the overall bleaching responses of corals in the Atlantic, Indian, and Pacific Oceans, using both a spatially explicit Bayesian mixed-effects model and a deep-learning neural-network model. They used a 40-year global dataset encompassing 23,288 coral-reef surveys at 11,058 sites in 88 countries, from 1980 to 2020. They found that, there are several potential reasons for the overall differences in the bleaching responses of corals among the three oceans, including being conditional on historical events, geographical circumstances, and contemporary thermal regimes. On the one hand, historical seawater temperatures may create certain evolutionary legacies, influencing contemporary coral distributions and thermal tolerances *(Fine et al., 2013; Howells et al., 2013; McClanahan et al., 2020; Smith et al., 2022; Thompson and van Woesik, 2009; Voolstra et al., 2021).* On the other hand, more recent temperature fluctuations may predispose contemporary corals to increased thermal tolerance through rapid acclimatization, epigenetic modifications, or adaptation *(Barshis et al., 2013; Brown et al., 2002; Guest et al., 2012; Hackerott et al., 2021; Matz et al., 2020; Maynard et al., 2008; Oliver and Palumbi, 2011; Schoepf et al., 2022; Thomas et al., 2022)*.

Another plausible explanation for the oceanic differences in the bleaching responses of corals might be related to the species composition. Reefs with high coral coverage and diversity are less sensitive to bleaching, as they includes coral species naturally differ in both their short- and long-term thermal tolerances with their genotypic diversity, and adaptive capacity to the different environmental conditions, *(Burgess et al., 2021; Grottoli et al., 2014; Loya et al., 2001; van Woesik et al., 2011; Voolstra et al., 2020, Shlesinger &van Woesik,2023).*

<u>4- Recovery from Bleaching</u>

Post-bleaching trajectories of coral communities differed among reef locations and regions (*Baker et al. 2008*), with some reefs recovering to pre-bleaching coral coverage and composition (*van Woesik et al. 2011; Gilmour et al. 2013*), while others failed to recover and/or become dominated by algae or other benthic organisms (*Stobart et al. 2005; Graham et al. 2015*). Thus there were two type of coral recovery from bleaching, long term recovery and rapid recovery.

The long term recovery involve of regrowth of bleached colonies and settlements of new recruitments from the surrounding reefs. In the past, many coral communities have taken a decade or more to recover after severe bleaching events *(Adjeroud et al. 2009; van Woesik et al. 2011; Gilmour et al. 2013; McClanahan 2014; Graham et al. 2015)*, but for some, recovery was more rapid (e.g., 7 years in *Palau, Golbuu et al. 2007*; 3 years at lagoonal reefs in the Seychelles, *Koester et al. 2020*). In some severely devastated coral communities, regrowth of remnant colonies and new recruits supplied by neighboring reefs were the main drivers of recovery (*Golbuu et al. 2007; van Woesik et al. 2011; Graham et al. 2015*). In contrast, due to limited connectivity with other reefs, recovery of isolated coral communities in Western Australia was primarily driven by regrowth of coral remnants (*Gilmour et al. 2013*).

Following severe thermal stress and coral bleaching, reefs can undergo drastic changes in coral community composition (*Graham et al. 2015; Hughes et al. 2017, 2018b*), e.g., through the steady replacement of thermally sensitive corals by weedy and stress-tolerant corals (*Darling et al. 2013; Edmunds et al. 2014; McClanahan et al. 2014, 2020; Palumbi et al. 2014*). For instance, in many reefs, thermally sensitive *Acropora* species have declined in number and/or coverage following thermal stress events, while massive, stress-tolerant Porites were unaffected (*Loya et al. 2001; Adjeroud et al. 2009; McClanahan 2014; Head et al. 2019*).

Marshall and Schuttenberg, (2006), stated the processes of rapid coral recovery after bleaching. Without the zooxanthellae to support their metabolic processes, corals begin to starve. Should water temperatures return to normal conditions soon enough, corals can survive a bleaching event. Where bleaching is not too severe, the zooxanthellae can repopulate from the small numbers remaining in the coral's tissue, returning the coral to normal color over a period of weeks to months. Some corals, like many branching corals, cannot survive for more than 10 days without zooxanthellae. Others, such as some massive corals, are capable heterotrophs and can survive for weeks or even months in a bleached state by feeding on plankton. Even corals that survive are likely to experience reduced growth rates, decreased reproductive capacity, and increased susceptibility to diseases. *Cox (2007)* found no change in reproductive parameters after a bleaching in *Montipora capitata* and hypothesized that this was due to the coral's capacity to increase its heterotrophic feeding. Along with carbon fixation by the zooxanthellae, heterotrophic feeding is an important source of energy for corals, and *Grottoli et al. (2006)* found that some corals are able to meet 100 % of their daily metabolic requirements through heterotrophic feeding. Corals of the species *M. capitata* were able to replenish their energy reserves within 6 weeks after a bleaching event when exposed to naturally available zooplankton. Plasticity in heterotrophic feeding has been found to help corals in both resistance to thermal stress *(Borell et al. 2008)* and recovery from bleaching events *(Connolly et al. 2012).*

If a coral reef is exposed to stressful conditions that are known to cause bleaching, its fate is influenced by three key ecological attributes:

- Extent to which corals can withstand elevated stress without bleaching (resistance)

- Ability of corals to survive bleaching (tolerance)
- Ability of coral communities to be replenished (recovery) should significant coral mortality occur

5- The properties of Red Sea and past bleaching events

The Red Sea is 2,270km long from 30°N in the Gulf of Suez to 13°N at Bab el-Mandab where it joins the Gulf of Aden. It has a maximum of 350km wide and 2,920m deep and surrounded by extremely arid coastlines. The southern entrance at the Straits of Perim is only 130m deep, which restricts water exchange between the Red Sea and the Gulf of Aden (*Edwards and Head, 1987*).

The land surrounding the Red Sea is hot and dry with minimal fresh water inflows, and high rates of evaporation, the Red Sea is characterized by warm water temperatures, ranging from 21ºC-30ºC for its mostly northerly latitudes. The input of surface waters from the Gulf of Aden must compensate for evaporation losses. As a result the salinity varies along the Red Sea from 36.5ppt at the southern entrance, to more than 41ppt in the northern Gulf of Aqaba in summer. Water temperatures and nutrient concentrations decrease in surface waters towards the northern end, where the water is generally clearer (*Hawkins and Roberts, 1994*).

Reefs occur on most of the length of the Red Sea, on both coasts, but tend to be at their best in the central and northern Red Sea, on the coasts of Sudan, Saudi Arabia and Egypt, and it is there that the greatest variety of reef types can be found (*Fishelson 1980; Bemert and Ormond, 1981*). The coral reef area within the Red Sea (c. 8,890 km2) is broadly comparable to that of the Caribbean (c. 10,530 km2). Although the reef area is only approximately half that of the Great Barrier Reef (c. 17,400 km2), these two reef systems are of similar length (Red Sea: c. 2,000 km; GBR: c. 2,300 km), making the Red Sea one of the longest coral reef systems in the world (*Berumen et al., 2013*).

At the Red Sea, however, corals are thriving in extreme summer conditions of high temperature, nutrients deficiency, and high salinity while they maintain thermal tolerance and growth performance at optimum levels that make them extraordinarily ‘super-corals’ (*Krueger et al., 2017; Ellis et al., 2019*). Yet, it has been noted that the warming rate of seawater increases beyond the global thresholds from the south to the north by 0.3 °C/decade (*Chaidez et al., 2017; Genevier et al., 2019*). As such, Red Sea corals may encounter challenging conditions of +3 °C above the contemporary thermal limits by 2100 (IPCC-RCP8.5 scenario) (*Genevier et al., 2019*). Given that they can thrive under temperature exceeds the global limits, it had been proposed that northern Red Sea (NRS) coral reefs are the last to decline and are on the head candidates for worldwide reef restoration (*Fine et al., 2019; Kleinhaus et al., 2020*).

The Egyptian coast of the Red Sea extends northwestward for about 1,800 km (between 22° N and 30° N) and occupies the major proportion of the NRS at the western side. Coral reefs at this upper geographic range cover approximately 3,800 km2 (1.34% of the total coral cover on the earth) by which they are ranked fifteenth among 80 top countries that have considerable reefs (*Spalding et al., 2001*). In terms of ecological and economic values, the Egyptian coral reefs accommodate more than 200 reef-building coral species (*Wilkinson, 2000*) and each square kilometer is estimated to have a value of more than 908,000 US$ (*Fine et al., 2019*). Moreover, corals in the surface water of the Egyptian Red Sea coast are particularly thriving at an annual SST of 26.06±2.42 °C and seasonal thermal variability of approximately 3-8 °C (*Osman et al., 2018; Shaltout, 2019*). This wide thermal seasonality that may occasionally reach 11 °C in the Egyptian Red Sea proper and Gulf of Aqaba or 13 °C in the Gulf of Suez had conferred thermotolerant traits to the northern Red Sea corals and gave them the potency to adapt with a wide range of thermal dynamics (*Osman et al., 2018*).

A recent study by *Genevier et al. (2019)* showed that most of the recorded bleaching events over 31 years (between 1985 and 2015) were concentrated on the eastern coast of the Red Sea whereas the western reefs, particularly at the NRS, experienced little incidence of these events [in total three events had been reviewed by *Osman et al. (2018)]*. According to *van Hooidonk et al. (2016)*, it is expected that the bleaching episodes will affect most of the coral reefs, including reefs of the Red Sea at the Egyptian coast. Indeed, bleaching episodes or at least their consequences had already reached the Egyptian coast during 1998 (*Hassan et al., 2002*), 2007 (*Kotb et al., 2008*), 2012 (*Hanafy et al., 2012*), and more recently in 2020, (*Dosoky et al., 2021*). Comparing between all previous detailed studies for coral bleaching along the Egyptian coast of the Red Sea (*Hanafy et al., 2012*), and (*Dosoky et al., 2021*) had the almost the same finding were:

- The bleaching severity was mostly restricted to 1-10% and 11-50% categories while complete colony bleaching or mortality due to the thermal stress were rare at the Egyptian coast.
- Low occurrence of coral bleaching in the northernmost parts of the Red Sea proper at the Egyptian coast and the bleaching pattern that extended along the southern Egyptian coast of the Red Sea (up to Al-Quseir) to southern of Wadi El Gemal.

- No difference in the bleaching intensity between inshore and offshore sites, and as well as the depth.
- The particularly affected *Montipora*, *Porites*, *Stylophora*, *Pocillopora*, *Acropora* and *Millepora*.

6- Discussion of important results in SCIENTIFIC NEWS REPORT "Coral Bleaching Event of 2023": Exploring distribution, sensitivity, and recovery potential on the Egyptian coast of the Red Sea by (*Hanafy & Dosoky, 2023*)

In June, HEPCA received a bleaching warning from the National Oceanic and Atmospheric Administration (NOAA). The Bleach Watch Egypt network, fueled by member notifications on coral bleaching, was activated, with bleach watch forms distributed to all diving centers along the southern coast of the Egyptian Red Sea. A preliminary survey, guided by notifications received from Bleach Watch members, covered the Gulfs of Suez and Aqaba, as well as the Egyptian coast of the Red Sea. Following multiple notifications in August 2023, a comprehensive survey was initiated, encompassing the entire coasts of the Egyptian Red Sea, Gulf of Suez, and Gulf of Aqaba. The primary objective of this survey was to identify instances of coral bleaching, with detailed assessments conducted in affected areas. Various parameters were examined during the survey, including spatial distribution, depths (specifically 2-5m on the reef edge and 8-10m on the reef slope), offshore versus inshore reefs, coral species and genera, and sheltering conditions. The degree of bleaching severity was measured against different variables.

During the survey, over 280 tagged bleached colonies representing the most affected species or genera were identified to estimate the rate of recovery. These colonies were strategically selected to encompass the diverse range of species and genera and were influenced by variables such as geographical range, depths, offshore vs. inshore locations, and sheltering conditions. Approximately 45 days post-bleaching event, the selected colonies were resurveyed, allowing for the estimation of recovery rates, survival rates, and mortality rates across the different variables.

The discussion of the key study outcome:

According to the pervious review about the coral bleaching and its causes, the processes of coral bleaching and recovery, the properties of the Red Sea and the available data about the Red Sea, in this part we will discuss the key study outcome in (*Hanafy & Dosoky*, *2023*).

1- Geographical Range:

During the current study, the southern stretch of the Red Sea consistently exhibited heightened coral bleaching, while the northern regions—encompassing the Gulf of Suez, Gulf of Aqaba, and areas north of Quasier City—displayed only minimal indications of complete bleaching. A discernible gradient in bleaching occurrence emerged from the south of Quasier City, reaching its zenith south of Marsa Alam. The Wadi El-Gimal and Lahmi Bay regions stood out with the highest incidence of bleaching, accentuating the spatial heterogeneity in bleaching severity. The findings underscore a highly significant correlation, reminiscent of patterns observed in the 2012 and 2020 bleaching events. North of Quasier City, the bleaching spectrum ranged from unbleached to mild (26-50% of the colony was bleached), contrasting with the escalated severity witnessed southward. The Wadi El-Gimal and Lahmi Bay areas, situated south of Marsa Alam, recorded the highest percentage of mildly to completely bleached coral colonies (100%) in some, in comparison to the northern sector of the Red Sea.

According to the previous review, the most common cause of coral bleaching was rising in SST (1-2 C°) above the normal SST at the same time of the year. We reviewing the available SST data estimated by NOAA (https://coralreefwatch.noaa.gov/product/vs/data.php) from the virtual stations at the Northern Red Sea (Gulf of Aqaba and Gulf of Suez) and southern Red Sea (See Map 1), and comparing the average of SST on daily base during June, July, August and September in the past two decades (2000-2023), as these four months represented the highest SST at each year. We Found that at the southern Red Sea the average SST during June (2000-2022) was 27.66± 0.79 C°, while during June 2023 the average SST was 28.78± 0.40 C° with 1.12 C° above the normal SST over the last two decade. This sudden increasing in SST over the average SST at this time of the year (June) causes the mass bleaching to some coral species in southern Red Sea. At July 2023 it was expected that the SST continue its increasing by 1-2 C° over the normally SST at that time of the year, but what happens was non-expected decreasing in difference between average normal SST during July 2000-2022 and average SST during July 2023 (29.35± 0.65 C° and 30.04± 0.78 C°, respectively) to 0.68 C°, (See Table 1 & 2 and Figure 1).In August & September 2023, the increasing in average SST above the normal ones did not exceed 1 C° (0.81 C° & 0.73 C°)

Map (1) the location of the station estimated SST in Red Sea By NOAA

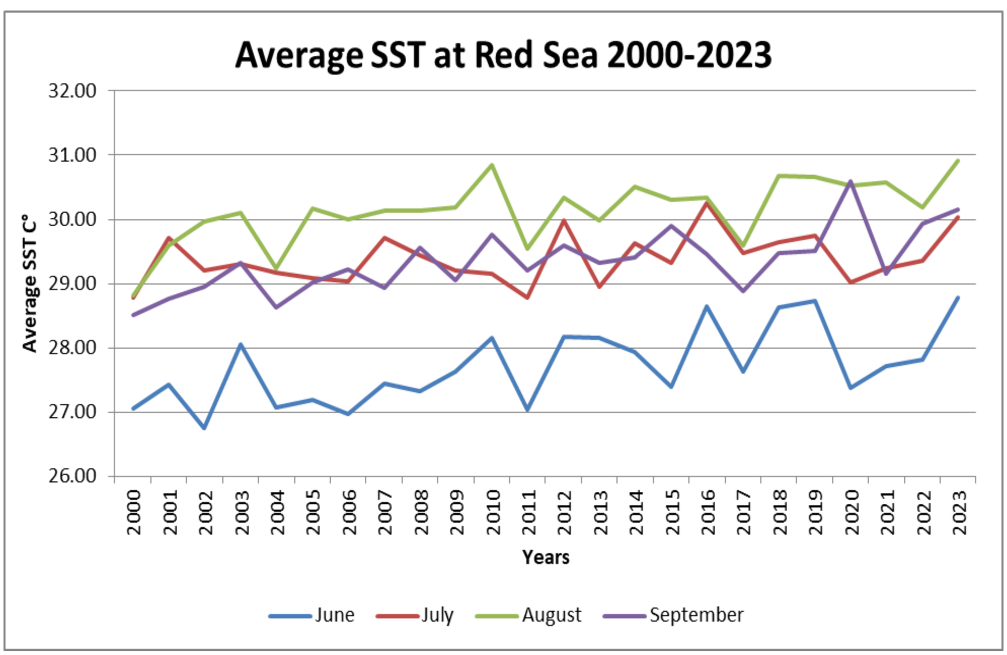

Figure (1) Average SST at Red Sea during June, July, August, and September 2000-2023

Table (1) Average SST at Red Sea during June, July, August, and September 2000-2023

Date	June	July	August	September
2000	27.05	28.77	28.81	28.51
2001	27.42	29.71	29.60	28.76
2002	26.75	29.20	29.97	28.96
2003	28.05	29.31	30.10	29.32
2004	27.07	29.17	29.24	28.63
2005	27.19	29.08	30.17	29.02
2006	26.97	29.04	30.00	29.21
2007	27.43	29.71	30.13	28.94
2008	27.32	29.44	30.13	29.57
2009	27.63	29.20	30.19	29.04
2010	28.15	29.14	30.85	29.76
2011	27.04	28.78	29.54	29.21
2012	28.17	29.97	30.34	29.59
2013	28.15	28.95	29.99	29.33
2014	27.94	29.62	30.51	29.41
2015	27.39	29.31	30.30	29.91
2016	28.65	30.26	30.33	29.45
2017	27.63	29.48	29.60	28.88
2018	28.62	29.64	30.68	29.47
2019	28.72	29.74	30.66	29.52
2020	27.38	29.01	30.53	30.59
2021	27.71	29.24	30.57	29.15
2022	27.81	29.35	30.19	29.93
2023	28.78	30.04	30.92	30.14

Table (2) Comparing between the average SST (2000-2022) and 2023 at Red Sea

	2000-2022				2023			
	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
Min	25.66	27.43	28.39	27.76	28.03	28.97	30.23	29.54
Max	29.81	31.11	31.39	30.90	29.23	31.45	31.44	30.79
Average	27.66	29.35	30.11	29.31	28.78	30.04	30.92	30.14
STDEV	0.79	0.65	0.56	0.59	0.40	0.78	0.30	0.43

On the other side, at the Northern Red Sea in Gulf of Aqaba and Gulf of Suez the increasing in average of SST during 2023 above the normal average of SST (2000-2022) during the four months, does not exceed 1 C°, ranged between 0.7 C° in Gulf of Aqaba and 0.5 C° in Gulf of Suez, as show in Table 3 & 4 and Figure 2 for Gulf of Aqaba and Table 5&6 and Figure 3 for Gulf of Suez. This slightly increase in average SST above the normally SST in that time of the year can be tolerated by lots of coral species, and this explains why the coral bleaching at the northern Red Sea was very rare comparing to southern Red Sea.

Another factor that may explain the spatial pattern of the bleaching along the Egyptian coast is the difference in the intensity of UV irradiance between the north and south. Generally, the exposure of corals to incident UV increases from the north to the south along the Red Sea (*Overmans and Agustí, 2020*). Despite the local data is critically required in this context, Overmans and Agustí (2020) had indicated that coral reefs in the central Saudi Arabian coast of the Red Sea are receiving 24% higher maximum daily UV irradiance during summer compared to those located at the north in the Gulf of Aqaba. All the previous findings consequently propose that Red Sea corals can potentially tolerate thermal stress unless the UV irradiance was not stressful.

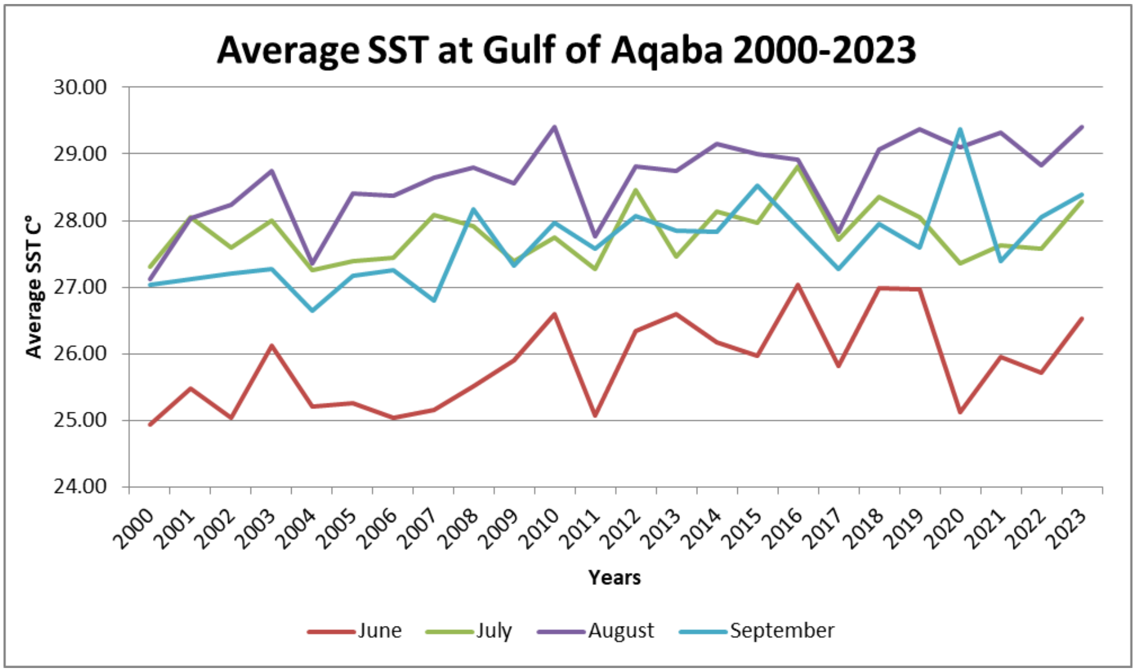

Figure (2) Average SST at Gulf of Aqaba during June, July, August, and September 2000-2023

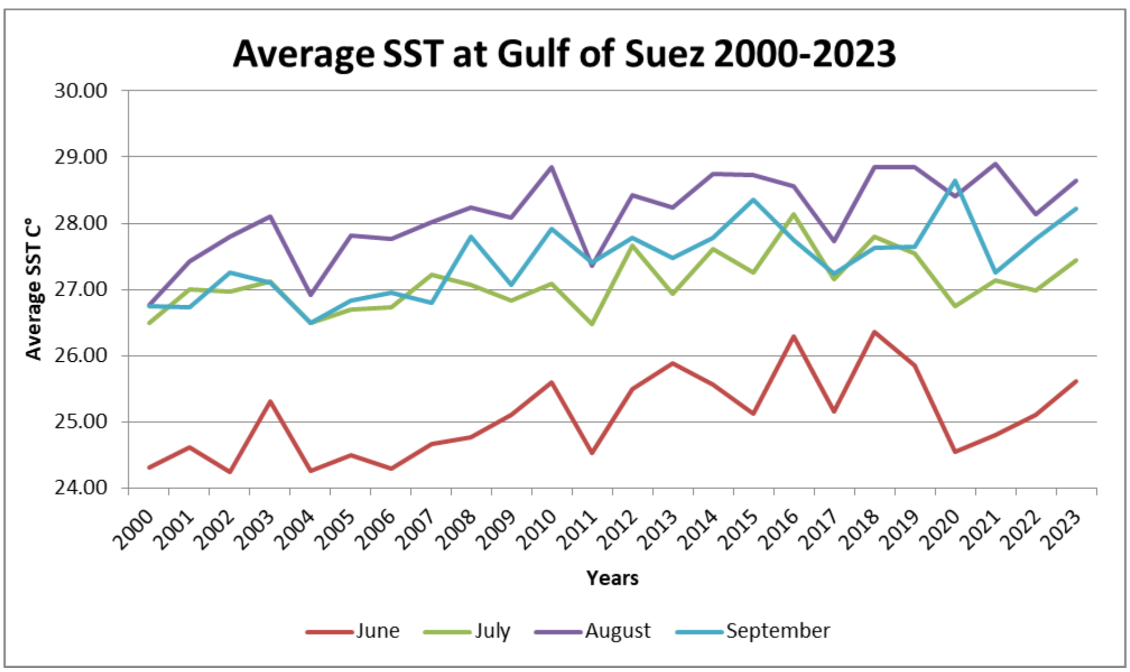

Figure (3) Average SST at Gulf of Suez during June, July, August, and September 2000-2023

Table (3) Average SST at Gulf of Aqaba during June, July, August, and September 2000-2023

Date	June	July	August	September
2000	24.94	27.30	27.12	27.04
2001	25.47	28.05	28.03	27.11
2002	25.04	27.60	28.24	27.21
2003	26.12	27.99	28.74	27.27
2004	25.20	27.25	27.35	26.64
2005	25.26	27.39	28.40	27.17
2006	25.03	27.44	28.38	27.26
2007	25.15	28.08	28.64	26.80
2008	25.51	27.91	28.79	28.16
2009	25.90	27.38	28.56	27.32
2010	26.59	27.75	29.41	27.97
2011	25.07	27.28	27.77	27.58
2012	26.34	28.46	28.82	28.06
2013	26.59	27.45	28.74	27.84
2014	26.17	28.13	29.15	27.83
2015	25.96	27.97	29.00	28.53
2016	27.03	28.82	28.91	27.91
2017	25.81	27.71	27.84	27.27
2018	26.98	28.36	29.07	27.94
2019	26.96	28.05	29.38	27.59
2020	25.13	27.36	29.10	29.38
2021	25.96	27.62	29.32	27.39
2022	25.72	27.58	28.83	28.05
2023	26.53	28.29	29.41	28.40

Table (4) Comparing between the average SST (2000-2022) and 2023 at Gulf of Aqaba

	2000-2022				2023			
	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
Min	23.86	25.53	26.19	25.59	25.56	26.53	28.12	27.64
Max	28.72	29.64	30.30	30.05	27.35	30.13	30.25	28.92
Average	25.82	27.78	28.59	27.62	26.53	28.29	29.41	28.40
STDEV	0.94	0.74	0.70	0.75	0.53	1.13	0.69	0.32

Table (5) Average SST at Gulf of Suez during June, July, August, and September 2000-2023

Date	June	July	August	September
2000	24.30	26.49	26.77	26.74
2001	24.61	27.00	27.43	26.72
2002	24.24	26.97	27.80	27.26
2003	25.30	27.11	28.11	27.10
2004	24.26	26.50	26.91	26.49
2005	24.49	26.69	27.81	26.83
2006	24.30	26.73	27.77	26.96
2007	24.65	27.23	28.02	26.79
2008	24.76	27.07	28.23	27.79
2009	25.11	26.82	28.09	27.07
2010	25.59	27.09	28.85	27.91
2011	24.52	26.48	27.36	27.41
2012	25.50	27.66	28.42	27.78
2013	25.88	26.93	28.23	27.47
2014	25.55	27.61	28.75	27.78
2015	25.12	27.26	28.73	28.36
2016	26.29	28.13	28.56	27.75
2017	25.16	27.15	27.73	27.23
2018	26.36	27.79	28.85	27.63
2019	25.85	27.54	28.85	27.64
2020	24.55	26.75	28.41	28.64
2021	24.80	27.14	28.90	27.26
2022	25.11	26.99	28.14	27.76
2023	25.61	27.44	28.64	28.22

Table (6) Comparing between the average SST (2000-2022) and 2023 at Gulf of Suez

	2000-2022				2023			
	Jun	Jul	Aug	Sep	Jun	Jul	Aug	Sep
Min	23.25	25.17	26.18	25.38	24.43	26.04	27.87	27.73
Max	27.87	28.90	29.61	29.18	26.42	28.94	29.23	28.96
Average	25.06	27.09	28.12	27.41	25.61	27.44	28.64	28.22
STDEV	0.93	0.74	0.68	0.66	0.60	0.95	0.43	0.33

2- Species Sensitivity to Heat Stress

According to the Current Study, the most sensitive Species to the bleaching were *Millepora, Montipora, Porites, Acropora, Pocillipora, and Stylophora*. Among these, a non-scleractinian coral *Millepora* followed by *Stylophora, Montipora*, and *Porites* emerged as the most affected genera, exhibiting the highest levels of severity in bleaching.

This finding is totally agreed with previous bleaching events, which had indicated that the impact of the heat stress was more influential on some specific coral species (*Furby et al., 2013; Monroe et al., 2018*). In 2012, for example, the bleaching pattern that extended along the southern Egyptian coast of the Red Sea (up to Al-Quseir), had particularly affected *Montipora, Porites, Stylophora, Pocillopora, and Millepora* (*Hanafy et al., 2012*). In additional *Dosoky el al*., (2021) stated the same genera had demonstrated similar susceptibility during 2020 heat stress period.

There were strong evidence that some keystone genera are highly thermosensitive and others none. This pattern of bleaching severities between coral genera is most likely related to the differences in the composition of Symbiodiniaceae assemblages that directly outline the thermal tolerance of the host (*Ziegler et al., 2019*). Zooxanthellae clades vary in their ability to tolerate elevated temperatures, and some corals have heat-resistant clades, and are therefore, more resistant to bleaching. However, corals with heat-resistant clades tend to grow more slowly, creating evolutionary trade-offs in the symbiotic relationship that maintains a diversity of clade-coral relationships, (*Marshall and Schuttenberg, 2006).*

3- Comparison between Inshore and Offshore Reefs

The Current study stated that, inshore and offshore reefs revealed no discernible differences, particularly in coral colonies exhibiting moderate, severe, and complete bleaching. And this also agreed with the *Dosoky et al., (2021)*.

That because the surveyed reefs in the current study are located in no more than 20km from the shore, one possible explanation for this pattern is that the offshore reefs were not far enough away from the coastal southward heatwaves and both reef systems may be vulnerable to the same heat stress conditions.

4- Comparison between Depths

The current survey delved into the impact of depth on bleaching potential, examining two specific depths: 2-5m (reef edge) and 8-10m (reef slope). The findings illuminated a higher prevalence of affected coral colonies on the reef slope compared to the reef edge. Furthermore, the severity of impact was more pronounced in the deeper studied depth (reef slope) than in the shallower depth (reef edge).

According to the previous studies Corals can also acquire a greater tolerance to bleaching stresses if they are constantly exposed to higher temperatures or greater irradiance. Corals on reef flats, for example, will often be able to tolerate much higher water temperatures than colonies of the same species inhabiting reef slopes, (*Marshall and Schuttenberg, 2006).* Also the coral colonies at the reef edge subjected to difference in tidal level effect more than at reef slope and this makes it subjected to rapid changes in water temperature than at the reef slope, and this temperature fluctuations may predispose contemporary corals to increased thermal tolerance through rapid acclimatization, epigenetic modifications, or adaptation *(Barshis et al., 2013; Brown et al., 2002; Guest et al., 2012; Hackerott et al., 2021; Matz et al., 2020; Maynard et al., 2008; Oliver and Palumbi, 2011; Schoepf et al., 2022; Thomas et al., 2022)*

5-Recovery in Bleached Colonies

During the current study, approximately 72.2% of these colonies exhibited signs of recovery, whether it is total (50.3%) or partial (21.9%) recuperation from the bleaching event. In stark contrast, only 27.8% of the total tagged colonies were deemed completely deceased after an observation period of nearly 45 days post-bleaching. A compelling correlation emerged between the sensitivity of coral species/genera to heat stress and their potential for recovery. Notably, *Porites*, a genus known for its resilience, demonstrated an impressive recovery rate. Approximately 80% of the tagged bleached *Porites* colonies fully recovered, with an additional 8-9% experiencing partial recovery. Intriguingly, even among the partially recovered colonies, it was observed that large colonies, spanning centuries in age, achieved complete recovery through the horizontal growth of polyps. This underscores the high recovery potential of large *Porites* colonies, attributed to their resilience and expected horizontal growth of polyps. In contrast, coral genera such as *Millepora, Montipora*, and *Pocillopora*, which exhibited high sensitivity to heat stress (indicated by severe bleaching, i.e moderately, severely and completely bleached colonies), surpassed expectations with recovery rates exceeding 70% for both partial and complete recuperation.

As we stated before in the previous review that during the bleaching process the zooxanthellae can be expelled from the host tissue by exocytosis into the gastrovascular cavity, or the cell can be detached from the endoderm as a whole (*Gates et al. 1992*). Not all zooxanthellae get out from the coral polyp but some of them still inside it, (*Gates et al. 1992).*

Marshall and Schuttenberg, (2006), stated the processes of rapid coral recovery after bleaching. Without the zooxanthellae to support their metabolic processes, corals begin to starve. Should water temperatures return to normal conditions soon enough, corals can survive a bleaching event. Where bleaching is not too severe, the zooxanthellae can repopulate from the small numbers remaining in the coral's tissue, returning the coral to normal color over a period of weeks to months (as *Porites & Montipora*, in current study). Some corals, like many branching corals, cannot survive for more than 10 days without zooxanthellae (like *Acropora* and *Stylophora* in current study).

On the other hands ,others, such as some massive corals, are capable heterotrophs and can survive for weeks or even months in a bleached state by feeding on plankton (like *Porites* in current study). Even corals that survive are likely to experience reduced growth rates, decreased reproductive capacity, and increased susceptibility to diseases. Along with carbon fixation by the zooxanthellae, heterotrophic feeding is an important source of energy for corals, and *Grottoli et al. (2006)* found that some corals are able to meet 100 % of their daily metabolic requirements through heterotrophic feeding (this explain the high recovery percentage in massive coral in current study). Corals of the species *Montipora capitata* were able to replenish their energy reserves within 6 weeks after a bleaching event when exposed to naturally available zooplankton. Plasticity in heterotrophic feeding has been found to help corals in both resistances to thermal stress *(Borell et al. 2008)* and recovery from bleaching events *(Connolly et al. 2012).*

Another explanation to the high recovery during the current study is the rising in SST was not high (1.12 C° as we mention before) also there was decline in increasing of SST above the normal temperature in that time of the year to 0.69 C° in next month (July 2023), this help in reduction of the stress on the bleached colonies rather that complete of increasing the SST to more than 1.12C°. Also this slightly increasing in water temperature helps corals to not expel all zooxanthellae and keep it to be used in the recovery process.

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