

Resilient reefs in crisis: A 25-year synthesis of coral reef change, stressors, and conservation in Egyptian Red Sea coasts

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Abstract

The Red Sea's exceptional geological, climatic, and biological characteristics constitute one of the world's most distinctive marine ecosystems. However, despite their global reputation for diversity and resilience, these coral reefs face mounting pressure from human activity, pollution, and climate change. To identify geographic research trends, prominent stressors, species distribution, and conservation priorities, this study synthesized 67 coral reef studies conducted along the Egyptian Red Sea coast between 2000 and 2025. Data were aggregated from official environmental agencies and scientific databases to visualize temporal and spatial patterns. Analysis reveals a significant geographical bias: 44% of research focused on the northern Red Sea and Gulf regions, while only 8% focused on the southern areas. Anthropogenic impacts, pollution, and coral bleaching were the most frequently investigated stressors, accounting for approximately 60% of reviewed studies. Taxonomically, the families Acroporidae and Merulinidae represent 45% of known species, with hard corals accounting for nearly 80% of all records. While the highest species richness was observed in both the northern and southern regions, it was *Acropora*. Significant knowledge gaps remain regarding coral diseases, resilience mechanisms, and recovery dynamics. Consequently, these findings underscore the urgent need for resilience-based management, integrated monitoring, and conservation policies addressing both natural and anthropogenic stressors to safeguard Red Sea biodiversity.

Keywords: Coral reefs, Resilience, anthropogenic impact, bleaching, climate change, biodiversity, Red Sea, Egypt.

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1. Introduction

The Red Sea is distinct from all other areas, including its tectonic background, environmental characteristics, and biological features. The basin is a relatively young oceanic feature that has been transitioning or is transitioning along its entire length from a continental rift to a true oceanic seafloor spreading system, the specifics of which are still subject to considerable debate (Rasul *et al.*, 2015). It is a partially enclosed, elongated warm water body measuring approximately 2,000 km in length, with a maximum width of 355 km, covering a surface area of approximately 458,620 km² and holding a volume of approximately 250,000 km³ (Head, 1987). Most countries near the Red Sea are characterized by hot and arid climates. This led to the unique characteristics of the Red Sea: its water temperatures fluctuated between 20°C in spring and 35°C in summer, and its salinity level ranged from 36.5‰ at the southern entry to more than 41‰ in the summer in the northern Gulf of Aqaba (Berumen *et al.*, 2013; Ormond and Edwards, 1987). These conditions are considered most suitable for organisms, especially coral reef communities (Hawkins and Roberts, 1994). The Red Sea is one of the most important regions, boasting spectacular coral ecosystems (Berumen *et al.*, 2013; Mohammed, 2012). The Egyptian marine environment is characterized by unique habitats, one of which is coral reefs, which are

considered one of the most important communities in the Red Sea but are also threatened (NCS, 2009; Samy *et al.*, 2011). Habib and Thiemann (2022) reported that the Red Sea has narrowed protected areas that are affected by pollutants such as microplastics and mercury, which affect coral reef communities. In addition, the Red Sea provides a suitable model for studying how reefs are affected by anticipated global climate change scenarios. Repeated heat stress exposure in the North Red Sea has been proposed to enhance plant tolerance (Barshis *et al.*, 2013; Brown *et al.*, 2002; Van Woesik *et al.*, 2012). The Red Sea contains some of the first coral reef fauna collections and examinations, but as research in other well-known coral seas has expanded, published studies on coral reefs are limited to three hot spots located near research institutions in very wealthy countries. However, the direction of more comprehensive reef research in the basin has clearly changed (Cochran *et al.*, 2024). The Egyptian marine environment can be distinguished by its unique habitats and endangered species, including coral reefs, mangrove trees (2 species), seagrass (10 species), marine mammals (17 species), marine tortoises (5 species), sharks (more than 20 species), sea cucumbers, bivalves, and numerous birds (including White-eyed gulls, Sooty falcons, and Ospreys) (NCS, 2007; 2009). The results showed that different thermal stresses were experienced by the Arabian Gulf and the

Red Sea, as shown by the total positive SST anomaly and events occurring in different trends (Said *et al.*, 2024). The dynamics and temperatures of the sea surface are constantly influenced by climate change, particularly along the Red Sea shoreline where continual expansion continues (Osman *et al.*, 2024). In tropical and subtropical regions of the world's oceans, Coral reefs are the most diverse underwater ecosystems in the tropical and subtropical regions of the world's oceans. It occupies approximately 25% of all marine life and comprises only 0.1% of the ocean floor. Coral reefs support more species than any other environment and serve as habitats for a variety of fish, shellfish, and other invertebrates that are targeted for fishing. Coral reef fisheries play vital ecological roles in coral reefs, such as herbivory, in addition to providing food, revenue, recreation, and considerable cultural and spiritual significance. Several studies have explored the environmental status of these natural resources, including pollution monitoring, coral reef bleaching, fish population dynamics, stock assessments, fish growth characteristics, and recording of new species recording, and so on (Mahdy *et al.*, 2022). Previous studies have illustrated that coral reefs occupy an area of approximately 284,300 km² to approximately 920,000 km² (Bruckner, 2011; Costanza *et al.*, 1997; Gladstone *et al.*, 2006; Spalding *et al.*, 2001). The area of coral reefs over the Red Sea covers 8,890 km², which is relatively close to the Caribbean reefs

10,530 Km² and smaller than the great barrier reefs (GBR), which represents approximately 17,400 km². However, the Red Sea (approximately 2,000 km) and GBR (approximately 2,300 km) are almost similar in length (Berumen *et al.*, 2013). The coral reef habitats of the Egyptian Red Sea are characterized by the occurrence of over 350 species of hard and soft corals and thousands of different invertebrate species (DiBattista *et al.*, 2015; Khaled and Abdelsalam, 2025). In the last 20 years, the Egyptian Red Sea coastline has increased its tourism activity, which affects the coral inside the shore, and human activity has caused many issues, such as sedimentation and damage to coral reefs by boat anchors that have crushed it (Dar *et al.*, 2012). Human activities cause stressors both on land and in water, which erode the natural ability of reefs to recover, which maintains their predominantly coral composition; factors such as coastal development, loss of nursery habitats, oil contamination, and other pollutants, as well as climate change and the natural degradation of the reef caused by predators, all contribute to the rapid decline of the Red Sea's reef fish, similar to many other reef fish worldwide (Brown and Cossins, 2011; Feary *et al.*, 2007). Resilience based management (RBM) was developed in response to the difficulties in fostering ecosystem resilience, and the durability of coral reefs is characterized by their capacity to withstand harm, bounce back from it, and persist in offering benefits

and services to the ecosystem (Bestelmeyer and Briske, 2012; Mumby *et al.*, 2007). Managing ecosystems using resilience theory and tools aims to optimize future resilience based outcomes. Resilience based management of coral reefs may include identifying spatial variations in resilience, which have received significant support from prominent conservation organizations and experts in coral reef ecology (Anthony *et al.*, 2015; Chapin *et al.*, 2009; Graham *et al.*, 2013; McClanahan *et al.*, 2012). Coral reefs are exposed to many direct and indirect factors that affect their health and growth, such as high water temperatures that cause bleaching, damage caused by anchors, threats to their colonies by *Acanthaster planci*, sedimentation onto the reef, and an increase in water turbidity, which reduces the quantity of light that reaches the corals and may result in bleaching (Brown and Ogden, 1993; Linton and Warner, 2003; Tribollet *et al.*, 2002). Indirect factors, such as human activity, affect reef resources, such as fish and shellfish, and overfishing of parrotfish species is a primary contributor to the degradation of coral reefs through coral bleaching, illness, mortality, erosion, and reef destruction (Downs *et al.*, 2005; Mumby *et al.*, 2004; Wilkinson, 2004). Climate change affects coral reefs, and at narrow temperatures, some species can tolerate and survive; however, the majority can lose their zooxanthellae, and some tissue pigments lead to bleaching. Research has indicated that global

warming is responsible for coral bleaching. Over the past 20 years, there has been a correlation between elevated sea surface temperatures (SSTs) and most large scale coral bleaching events. Photosynthesis by zooxanthellae accounts for the majority of coral's carbon budget; as a result, bleached corals adapt to prolonged and severe temperature stressors (Sammarco, 1996; Sotka and Thacker, 2005; Wilkinson, 2004.). According to Rosenberg and Ben-Haim (2002), coral tissue is affected by high water temperatures of 29°C, resulting in complete tissue destruction; the coral animal becomes less healthy overall because of thermal stress; its tissues are likely deprived of nutrients and ultimately perish because of reduced translocation of photo assimilates, which is in turn triggered by a decrease in photosynthesis by its algal symbiotic (Fine *et al.*, 2002). Coral reefs are exposed to a lot of pollutant material that may be ingested by the corals. Hankins *et al.* (2018) showed that the excretion of two species of *Scleractinia corals* contains microplastics and that the skeletal growth of *Lophelia pertusa* is also disturbed by microplastics, which affects growth and feeding and reflects polyp activity and prey catch rate (Chapron *et al.*, 2018). Pandolfi and Jackson (2001) suggested that overfishing is characterized by excessive resource depletion, leading to ecological damage. Negative fishing practices are not only considered one of the most significant threats to coral reefs but also affect the population size of non-

target species collected by fishing methods (Erdmann *et al.*, 2000). Quantitative data on the role of herbivores in this region are lacking, except for a few recent studies that have measured and quantified the variance in the importance of parrotfish in the Red Sea reefs (Afeworki *et al.*, 2011; Alwany *et al.*, 2009). Parrotfish play an important role in the erosion of coral reefs through their burrowing behavior on the surface of the coral, and when they obtain food, they secrete a special material by their jaws to break it down. They turn the residual into the coral surface, which may affect the living organism called a polyp. Numerous reef fish that feed on plants do not comprise a single ecologically cohesive population (Bellwood, 1995; Bellwood and Choat, 1990; Bellwood and Wainwright, 2002; Choat, 1991). *Acanthaster planci* and *Drupella gastropods* have caused significant damage to multiple reefs, and damage caused by bleaching episodes and the expansion of Crown of Thorns (COTS) is caused by higher larval survival, which feeds on phytoplankton (Fabricius *et al.*, 2005; Veron, 2002). Coral illness can cause bleaching, which refers to the phenomenon where certain living coral tissues are ill due to disease, and disease outbreaks can cause a reduction in coral diversity rather than a decrease in coral density (Kuta and Richardson, 2002; Nugues and Roberts, 2003; Westmacot, 2000). Coral reef bleaching mortality has risen dramatically since the first major episodes in the 1980s, implying that we

may be close to a mass extinction event of coral reefs caused by extremely high temperatures; researchers documented a mass bleaching event along the Saudi Arabian coast of the Red Sea during 2015-2016 and discovered changes in the composition and structure of reef benthic communities, resulting in environmental changes surrounding coral reefs (Gonzalez *et al.*, 2024; Malanoski *et al.*, 2024). Consequently, a significant research gap exists in literature; although some geographic regions and environmental impacts have been sufficiently studied, other crucial areas remain largely unexplored, resulting in insufficient data and inconclusive results for comprehensive ecosystem management. Therefore, the objectives of this study were to analyze resilience indicators at specific coral reef locations along the Red Sea coast of Egypt, provide an adaptable framework for ecological assessments, and investigate the health, variety, and abundance of coral.

2. Materials and methods

In this study, we collected metadata from a wide range of reputable scientific platforms and research databases to identify and analyze manuscripts focused on Coral Reefs along the Egyptian Red Sea coast. Online databases and research engines; including Scopus, Google Scholar, ScienceDirect, Ecosia, Reports from the Egyptian Environmental Affairs Agency (EEAA), and the Egyptian Journal of Aquatic Research were screened for

relevant publications from 2000 to 2025. To verify species identities and conservation status, we used the IUCN Red List and the World Register of Marine Species (WoRMS). All extracted metadata and source details were organized and documented using Microsoft Excel throughout the literature review. Publications addressing coral reef ecology, biodiversity, and environmental stressors were systematically screened, and all extracted metadata and source information were organized in Microsoft Excel throughout the review process. Conservation status and taxonomic updates were

verified using global biodiversity and species-assessment resources to ensure accuracy in species identification. For spatial organization, the Egyptian Red Sea was divided into three main regions: the Gulf Region (including both the Gulf of Aqaba and the Gulf of Suez), the Northern Red Sea (from Ras Ghareb to Marsa Alam), and the Southern Red Sea (from Marsa Alam to Halayeb sector). Across all studies, threats to coral reefs were categorized into major themes, including anthropogenic impacts, pollution, coral bleaching, coral growth and resilience, coral diseases, and climate change.

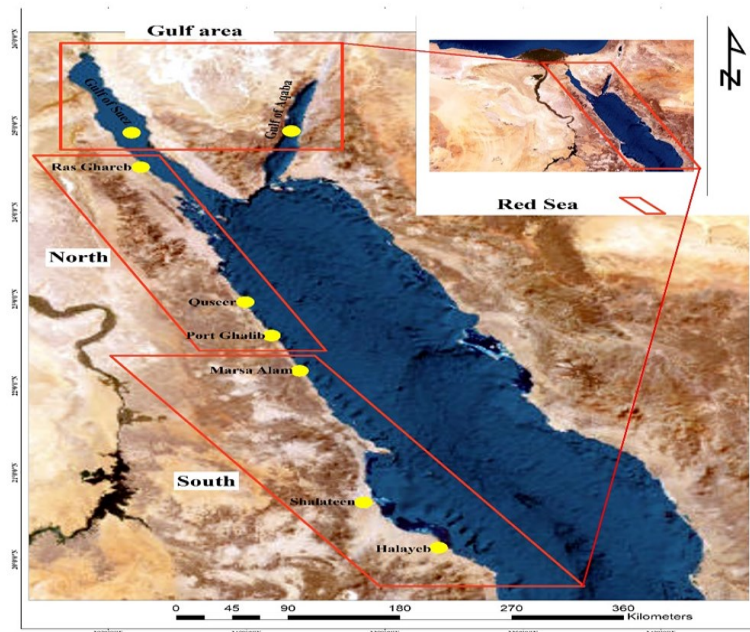


Figure (1): Study area across the Egyptian Red Sea coasts (Gulf Region, North and South).

3. Results

The analysis revealed that 67 documented research that focused on coral reefs along the Egyptian Red Sea coast between 2000 and 2025. Early foundational studies began with Frihy *et al.* (1996), who investigated the anthropogenic impacts on coral reef

ecosystems, followed by Riegl and Piller (1999). Research activity continued steadily through the early 2000s and began to increase significantly after 2006, reaching its highest level by 2024 (Figure 2). This upward trend reflects growing scientific interest and concern regarding the health and sustainability of coral reef systems in the region.

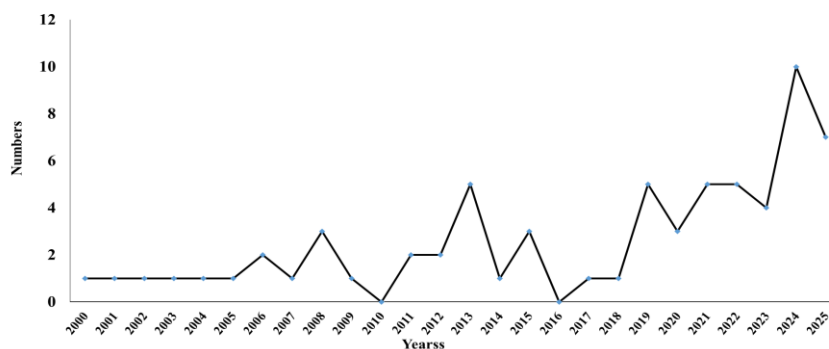


Figure (2): Total numbers of coral reef studies in the Egyptian Red Sea coast from 2000 to 2025.

Sixty-seven studies on Coral Reefs in the Red Sea have been conducted. These studies were separated into three regions: 22 studies were conducted in the Gulf region, which includes the Gulf of Aqaba and the Gulf of Suez; 22 studies were

conducted in the northern Red Sea; and only eight studies were conducted in the southern Red Sea, while different studies focused on the whole of the Red Sea (General) were covered by 15 studies (Figure 3).

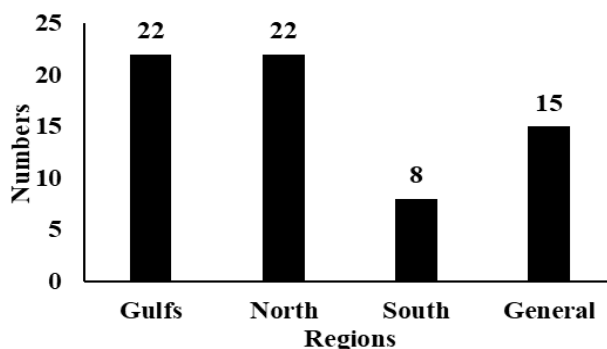


Figure (3): Number of Coral Reef studies by region.

Hard corals dominated the datasets with approximately 182 records (80%), while soft corals accounted for 47 records (20%), making hard coral records 3.77 times higher than soft coral (Figure 4). Regionally, the North holds the largest

share studies with 134 records, followed by the South with 111; together, these areas represent most observations, while other regions show a sharp decline, with GOA contributing 42 records and GOS contributing only 19 (Figure 5).

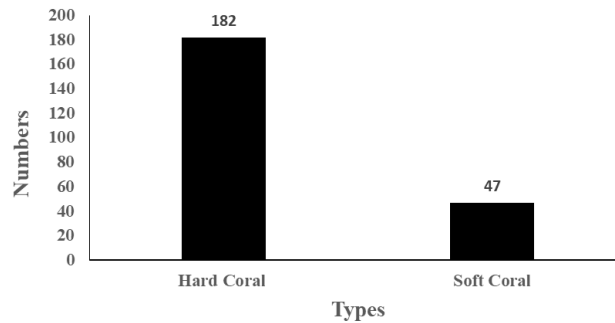


Figure (4): Hard and Soft Coral records in the study area.

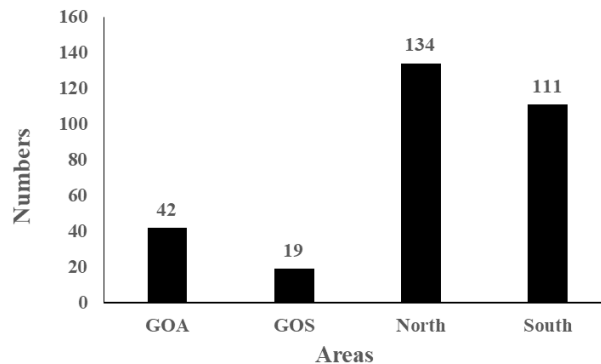


Figure (5): Composition and regional distribution of coral records in the compiled datasets.

The current study found that the northern region of the Red Sea had the most researched reef types, totaling 120, including 113 hard species and 7 soft species. The southern region ranked second, with 83 coral reef species (79

hard and four soft). The Gulf region contains approximately 43 reef species (40 hard and three soft) (Figure 6). These values reflect the research using presence-based records rather than standardized abundance estimates.

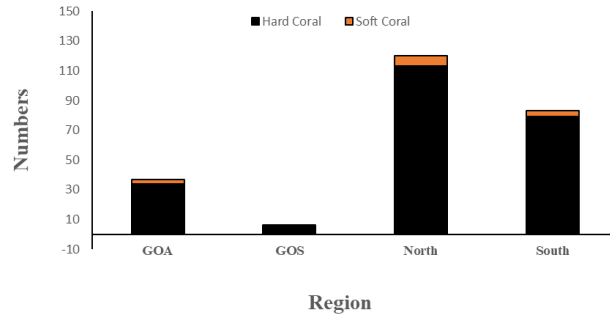


Figure (6): Coral reef species rich by region and growth form (North, South, GOA, and GOS), illustrating spatial and morphological variation across study areas.

The current study revealed the distribution of coral reef studies in scientific research according to their condition, which is classified by the Red List of endangered species as follows: the least concern has the largest share, with nearly 68 records,

while the endangered is close behind with 56 records. In contrast, all other cases have significantly lower numbers: weak accounts have only 7 records, records with no data have 3, and threatened closing records have only 1 (Figure 7).

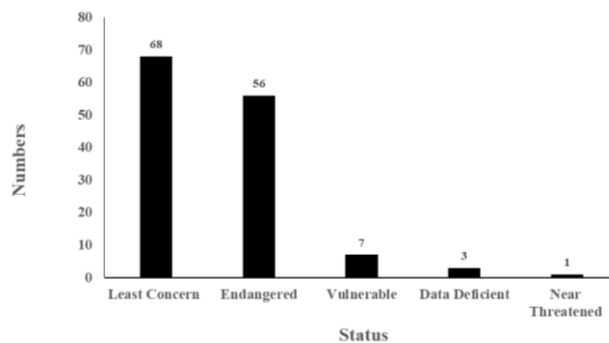


Figure (7): Distribution of coral reef IUCN Red List categories in the compiled datasets.

Research focusing on coral stressors is highly skewed toward human and climate related impacts. The top three categories were anthropogenic impacts (21 mentions), bleaching/thermal stress (13), and pollution (11), which collectively

accounted for nearly 59% of all mentions (45 of 76), indicating an overwhelming emphasis on external stress drivers (Figure 8). The following analysis included the most common and diverse hard coral species by family: The

Acroporidae family is the most widespread, with approximately 54 species, followed by the Merulinidae family, which has 28 species. The

Alcyonidae family is the most abundant and widely distributed group of soft corals, comprising approximately nine species (Figure 9).

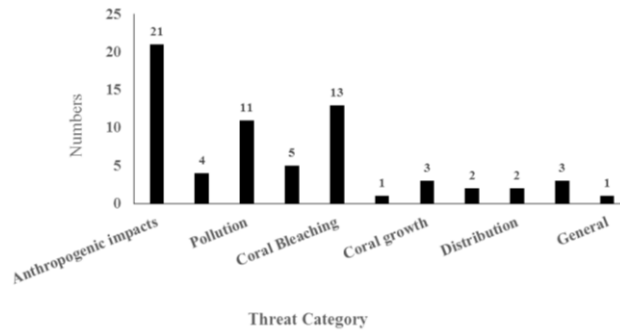


Figure (8): Distribution of stressors categories referenced across Coral Reef studies.

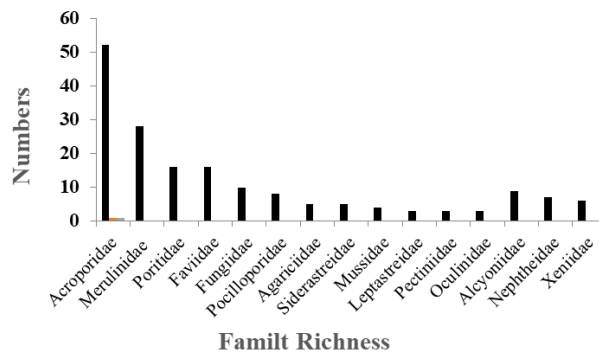


Figure (9): Family-level species richness of coral taxa in the datasets.

The current study reviewed studies on coral distribution based on the genus. *Acropora* was the most abundant, with 41 species, and the least abundant and widely distributed genera were *Leptosterea*, *Platygera*, *Pocillopora*, and *Galaxia* (Figure 10). A similar trend can be seen

among soft coral genera, with *Sarcophyton* receiving the most mention, followed by *Sinularia* and *Dendronephthya* (Figure 11). *Xenia*, *Lobophytum*, and *Heteroxenia* have fewer observed abundances in the literature.

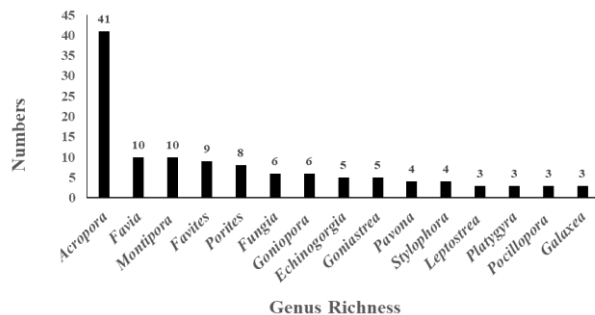


Figure (10): Distribution of species richness across dominant coral genera.

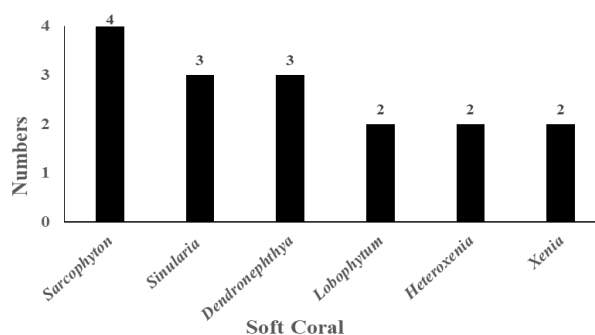


Figure (11): Highly abundant mentions for soft Coral in the data set.

This analysis confirmed the existence of a research gap in the study of the presence of various coral reef species between 2000 and 2025. Studies have shown its presence in some years and

scarcity in others, with the highest rate of studying species occurring during 2005 and 2014, with 60 species. Affluence remained low after 2014, with slight increases in 2023 and 2025 (Figure 12).



Figure (12): Annual Coral species presence per year (2000–2025).

4. Discussion

This study offers a comprehensive assessment of Red Sea coral species from 2000 to 2025 by examining their species distribution, conservation status, stressors, and dominant families. The findings revealed an ecosystem under severe stress, dominated by hard corals, with endangered species forming the largest conservation category. Combined pressures from bleaching and anthropogenic impacts pose the greatest threat to the reef structure and long term survival. Protecting biodiversity within key reef building families is critical to maintaining ecosystem resilience and safeguarding this unique marine environment. Egyptian coral reefs, which span the entire Red Sea, play a vital role in regional marine biodiversity. While several studies have focused on these reefs, most have concentrated on the Northern Red Sea, particularly between Marsa Alam and Hurghada, and the Gulfs region, leaving other areas less explored. Several studies have examined the impact of human activities on coral reefs in the Red Sea. Ammar and Mahmoud (2006), Attalla *et al.* (2015), Hussein *et al.* (2023), and Pastorino (2024) focused on anthropogenic pressures, particularly in the Marsa Alam. Kotb *et al.* (2015) and Nassar *et al.* (2021) conducted research on coral resilience in the southern Red Sea. Ammar and Mahmoud (2006) highlighted how physical factors and human activities influence coral

distribution in Sharm El Loly and Tobia Kebir. Activities such as diving, swimming, boat anchoring, and fish feeding were identified as major stressors at Tobia Kebir, whereas fishing boats had the greatest impact at Sharm El Loly. Lower sedimentation and higher water transparency were linked to greater coral cover in Sharm El Loly. Species composition also varied; massive corals, particularly *Porites* spp., were more abundant at Tobia Kebir, whereas the hydrocoral *Millepora dichotoma* dominated Sharm El Loly. Research across 29 reef sites between Marsa Umm El-Grifate, Marsa Shuna (north of Marsa Alam), and Abu Dabab examined the influence of tourism related activities on coral cover. Resorts, diving, snorkeling, beach picnicking, and boat mooring were found to reduce living coral cover, particularly in sheltered areas, which showed lower cover than exposed, less impacted sites. However, overall coral cover across all sites was not significantly affected by human activities, such as coastal development, diving, and fishing (Attallah *et al.*, 2015; Mostafa, 2003). More recent work by Pastorino (2024) highlighted emerging threats, including sunscreen use and microplastic pollution in Marsa Alam and Hamata (southern Red Sea Riviera). Hussein *et al.* (2023) further demonstrated that urban development in Marsa Alam negatively affects coral reef distribution, in contrast to sites protected from urbanization. The main coastal cities in Egypt include Sharm El Sheikh, Ras Ghareb, Hurghada,

Safaga, Quseir, and Marsa Alam. These regions are influenced by human activities and have documented a growing number of tourists visiting marine protected zones, which still maintain relatively high biodiversity and coral health. However, the rapid increase in tourism in Marsa Alam's southern sector without adequate environmental management measures poses a serious risk to the area's integrity, as has already been observed in Sharm El Sheikh's tourist attractions (Gallegati *et al.*, 2025). Studies on coral reef resilience in the southern Red Sea have focused on the areas between the House Reef Fantazia Resort and the House Reef of Shams Alam Resort, extending to Wadi El-Gemal National Park. The findings indicate that branching corals dominate most surveyed sites, particularly exposed locations, while massive corals are more common in sheltered areas, which also show lower resilience than exposed and unimpacted sites. Recruitment colonies were more abundant in the exposed and unimpacted sites than in the sheltered and impacted sites. Total coral cover and recruitment were negatively associated with algal cover, whereas fish abundance was positively correlated with live coral cover but inversely correlated with total coral cover. Herbivorous fish abundance showed a positive relationship with coral cover and recruitment and a negative one with algal cover. Conversely, planktivorous fish are negatively linked to both coral cover and recruitment (Attallah *et al.*, 2021; Kotb *et al.*, 2015). Surveys have

documented significant coral diversity along the coast of the Egyptian Red Sea. Kora *et al.* (2014) identified 61 Scleractinia species from 25 genera and 10 families, whereas an earlier study recorded 13 species from the coastal plain. Ghallab *et al.* (2024) assessed the reef status at eight northern Red Sea islands in the Gulf of Suez and four offshore sites near Hurghada and found that southern reefs were generally healthier than northern ones. High percentages of dead corals were observed across all sites, largely attributed to stressors such as recreational activities, urban development, illegal fishing, petroleum operations in northern areas, and occasional oil spills. Human impacts were also evident at Hurghada and Marsa Alam, where sedimentation from beach activities and damage from diving and boat anchoring affected the reef health. Mohammed (2005) recorded 63 species of hermatypic corals from 25 genera and 15 families in these impacted areas. Similar pressures have been reported at Ain Al-Sukhna and Sharm El-Sheikh, where bioerosion by sea urchins, macro-algal overgrowth, and competitive displacement of corals were identified as the major causes of reef degradation (Ali and Hamed, 2006). Genevier *et al.* (2019) linked extreme heat events to coral bleaching across the Red Sea using remote sensing data, revealing a steady warming gradient from south to north. The northern sites (Hurghada, Safaga, Quseir, and Port Ghaleb) showed reduced heat stress when bleaching thresholds were raised to 32°C, unlike the central

and southern regions, indicating that northern corals are nearing their thermal limits (Eladawy *et al.*, 2022). This pattern aligns with the historical bleaching records. Symbiodiniaceae density analysis further supports these findings: samples from Hurghada had the highest average density, followed by Port Ghaleb, Safaga, and Quseir, whereas corals in Marsa Alam exhibited a marked decline in symbiotic content (Desoky, 2021). Mahmoud *et al.* (2019) investigated coral reef recruitment by transplanting 180 specimens of eight robust species belonging to two families (Pocilloporidae and Acroporidae). New recruits were observed for *Stylophora pistillata*, *Pocillopora verrucosa*, *P. damicornis*, and *Acropora degitefera*, whereas recovery was recorded only for *S. pistillata*. Environmental stressors also included natural radioactivity and radiological hazards, which were assessed at three sites: the Quseir Harbour, Marsa Alam marine area, and near the Quseir desalination plant outlet. Marsa Alam exhibited the highest specific activity levels, linked to sediment input from the Al-Alam Valley and heavy minerals introduced by desalination discharge. Brine and pollutants from these plants pose significant risks to marine ecosystems, as documented in Dahab in the Gulf of Aqaba (Nassar *et al.*, 2025; Shabib *et al.*, 2021). Coral bleaching events have further impacted reefs along the Red Sea. Desoky (2021) reported bleaching in both inshore and offshore reefs from Hurghada to the

Wadi El-Gemal National Park, confirming widespread vulnerability. Distance from the shore had little influence on coral resistance, but several genera (*Millepora*, *Montipora*, *Pocillopora*, *Acropora*, and *Porites*) showed high bleaching coverage and intensity, indicating greater vulnerability to heat stress. Darmaraki *et al.* (2025) linked marine heatwaves to widespread bleaching along the Red Sea from northern sites, such as Sharm El Sheikh, Hurghada, and Al Wajh, to the central and southern regions. Their analysis revealed that atmospheric forcing drives heat waves in the northeast and southwest, while horizontal advection plays a dominant role along the southeast and northwest coasts. Although regional factors shape heatwave dynamics, extreme warming caused by horizontal advection tends to persist longer than atmospheric heat fluxes, which act as the primary cooling mechanisms in most areas. In the Northern Red Sea, 24 studies have documented the impact of human activities on coral reefs in the Northern Red Sea. The earliest work by Firthy *et al.* (1996) examined tourism and residential recreational activities in Hurghada that led to reef damage and erosion. Zaid and Kotb (2000) reported outbreaks of *Acanthaster planci*, a natural stressor whose effects were amplified by human impacts between Hurghada and Safaga. Dar (2002) highlighted that landfilling altered coastal physical parameters, increased heavy metal concentrations, and affected marine fauna, with northern

Hurghada being more impacted than the south due to reduced reef protection. Coastal development also increases sedimentation rates, reduces zooxanthellae density, and increases mucus secretion (Selim, 2007). Construction activities further threaten reef ecosystems through disturbances, hydrodynamic changes, dust deposition, and turbidity (Sherif *et al.*, 2024). Al-Hammady (2011) assessed bleaching and fertility patterns across sites from Hurghada to Quseir and found the highest bleaching and mortality at Ras El-Behar (oil pollution and fishing) and the lowest at Kalawy Bay. The highest proportions of severely bleached colonies (4.76%) and dead colonies (11.1%) were recorded at Site 1, whereas Site 4 showed the lowest values (0.47% and 2.19%, respectively). Hanafy (2012) examined the effects of tourism and scuba diving on three bays between Quseir and Marsa Alam and revealed significant negative impacts on coral reef ecosystems. Tourist activities caused physical damage to coral colonies, and increased sedimentation limited coral recruitment, reducing hard coral cover and favoring sediment-tolerant species. These findings highlight the need for effective tourism management to protect fragile reef environments. Additionally, heavy metal contamination in Hurghada and Safaga indicated significant pollution in both regions. Research on heavy metal concentrations in sediments and seawater has revealed that Safaga is more polluted than Hurghada, negatively affecting local flora and fauna and underscoring the

need for stronger environmental management (Hussein, 2012). High levels of heavy metals were also detected in the Hamrawein Harbor sediments, whereas coral species were recorded in Wadi El-Gemal. In Quseir, the concentrations of heavy metals, rare earth elements, and other hazardous elements were within tolerable ranges compared to those in previous studies (Madkour, 2013; Mohsen *et al.*, 2022). Another research direction explored the use of artificial reefs as a conservation strategy. Kotb (2013) demonstrated the successful colonization of corals and fish on artificial structures, supporting their use as an effective tool to mitigate the impacts of tourism on natural reefs. At Marsa Alam, human activities such as coastal development, diving, and fishing showed minimal influence on total living cover, with unimpacted sites averaging 83% and impacted sites averaging 81%. Generally, sheltered sites were more affected than exposed ones, yet the overall living cover remained stable. Corals exhibit remarkable adaptability to surrounding waves and current conditions. In areas exposed to strong water movement, branching coral forms tend to dominate, whereas in more sheltered environments, corymbose and massive forms are more prevalent (Sharaka, 2015). Marine diseases, especially those affecting corals, are a serious environmental concern. El-Morsy *et al.* (2017) conducted a study investigating the presence of fungi in various marine organisms, including hard corals, sea

cucumbers, gastropods, and sediments. We identified 12 fungal species from 9 different hard coral species. Notably, fungi from the genus *Aspergillus* were found in coral colonies regardless of their condition (healthy, bleached, or dead). The study highlighted that *Aspergillus fumigatus* and *A. terreus* were more common in dead coral colonies, whereas *A. niger* and *A. parasiticus* were more prevalent in bleached colonies. These findings suggest a possible connection between certain fungal species and deterioration of coral health. A recent study has emphasized the importance of remote sensing technologies for monitoring coastal and underwater ecosystems. These tools are vital for detecting environmental changes and assessing their impact on marine habitats. To improve their effectiveness, researchers have stressed the need for accurate classification, monitoring, and evaluation of coastal activities. They also advocated further research to develop a spectral library tailored to the benthic environments of the Red Sea. This would enhance the use of remote sensing in ecological studies, particularly for identifying coral species and assessing coral biodiversity and health using hyperspectral data. In the Gemsa coastline of the Egyptian Red Sea, remote sensing has been successfully applied to detect coral bleaching and evaluate reef conditions. The study produced bathymetric models, ecological maps, and documented bleaching events during a marine heat wave. A key finding

was that satellite-based remote sensing offers a cost-effective alternative to traditional marine geophysical surveys (MGS), enabling large-scale environmental monitoring (Abo Elenin *et al.*, 2020; Khaled *et al.*, 2025). In addition, coral reefs face numerous threats that contribute to disease outbreaks. Disease screening conducted at three patch reefs off the coast of Hurghada in the northern Red Sea revealed five common coral diseases: black band disease (BBD), white syndrome (WS), growth anomalies (GA), pink line syndrome (PLS), and skeletal eroding band (SEB). Research has shown that infected corals host a significantly higher abundance of microbes than healthy ones (Mohamed *et al.*, 2023). In a related study, 200 fungal strains, mostly from the phylum Ascomycota, were isolated from the common Red Sea scleractinian coral, *Stylophora pistillata*. These findings highlight the diverse and sometimes contrasting roles of fungal symbionts in coral health (Granit *et al.*, 2025). The Foraminifera in Reef Assessment and Monitoring (FORAM) Index has emerged as one of the most systematic and standardized biomonitoring tools in recent years. It uses benthic foraminifera as an indicator to assess coral reef health, offering valuable insights for ongoing ecological studies (Makled and El Atiek, 2024). The thermal stress on coral reefs has also been the focus of recent research. By analyzing three key parameters (Maximum Sea Surface Temperature (SST max), Degree Heating

Weeks (DHW), and Marine Heatwaves (MHW)) scientists have found that southern Red Sea reefs may be more vulnerable to even slight increases in temperature beyond their usual thermal limits. In contrast, although the northern reefs are warming rapidly, they may not yet have reached critical stress levels (Hanafy *et al.*, 2024). Extensive research on coral reefs in the Gulf region was conducted between 2001 and 2025. One notable study by Kotb (2001) investigated the growth rates of three dominant scleractinian coral species, *Stylophora pistillata*, *Pocillopora damicornis*, and *Acropora granulosa* in Na'ama Bay near Sharm El-Sheikh, Egypt. These findings suggest that light and temperature simultaneously influence coral linear extension growth, and other factors, such as reproduction, may also play a role. Interestingly, high light intensity and elevated temperature may inhibit coral growth. To preserve coral reefs as a valuable economic resource, particularly through tourism, stronger enforcement and sustainable tourism development are essential (Kotb *et al.* 2004). Monitoring efforts in South Sinai have revealed a decline in coral cover with increasing depth, which is consistent with previous Red Sea studies. Shallow reef areas have been significantly impacted by snorkelers and local fishermen, and visible damage, such as coral breakage and partial mortality, has been observed. These findings highlight the urgent need for management interventions, especially

given the public's strong interest in nature conservation (Hannak, 2008; Kompatscher, 2009; Tilot *et al.*, 2008). Despite these challenges, Kotb (2004; 2008) reported that the overall health of coral reefs in the Red Sea and Gulf of Aden remains relatively favorable, with coral cover typically ranging between 20 percent and 50 percent. However, this type of coverage is vulnerable to various environmental and human-induced threats. One significant factor affecting coral reefs is the presence of the Crown-of-Thorns Starfish (COTS) *Acanthaster planci*, a major coral predator. Despite these and other challenges, live coral cover in areas such as the Gulf of Suez and the Gulf of Aqaba is still generally recorded between 30 percent and 50 percent. However, many factors continue to influence the long term health and stability of the coral reefs in this region. Researchers have identified two distinct threats to coral reefs in the Northern Red Sea, particularly in the Gulf of Aqaba. First, global warming directly affects these ecosystems. High thermal stress leads to coral bleaching and significantly reduces the natural resilience of the reefs. Local human-induced pressures further intensify the effects of rising seawater temperatures and require immediate mitigation. Across various regions of the Red Sea, other reefs have also experienced significant bleaching, highlighting a widespread ecological crisis. This is particularly evident in Dahab, where 18 sites were surveyed between November 2019 and February 2020 (Darwees, 2021;

Fine *et al.*, 2013; Kleinhaus *et al.*, 2020). Second, the impact of artificial light pollution is studied. Studies have shown that it negatively affects the photosynthetic processes of coral species collected from the same region (Ayalon *et al.*, 2019). These findings emphasize the dual pressures of climate change and local human activity in this sensitive marine environment. In response to these challenges, Hasan (2019) examined the effectiveness of introducing new hard substrates to promote coral growth and succession. Over a ten-year monitoring period (2007: 2017), the addition of these substrates led to the successful establishment and growth of nine hard coral species. Specifically, five branched and four massive coral species were recorded, thereby demonstrating the potential of substrate modification as a reef restoration strategy to increase coral cover and support community development. Ghallab *et al.* (2020) investigated the coral reef diversity across the northernmost islands of the Red Sea. Their research revealed a high diversity of coral species in the area, with *Acropora* and *Stylophora* being the most abundant species. Importantly, the study found that these dominant species were negatively affected by human activities, specifically tourism and oil drilling, near the study sites. This highlights the vulnerability of the most diverse coral communities in the Red Sea to local anthropogenic pressure. Bashar *et al.* (2023) conducted further research into coral resilience. They assessed the health

of three coral species (*Acropora humilis*, *Pocillopora damicornis*, and *Stylophora pistillata*) in Taba and Dahab by measuring their growth rates. These Assessments are crucial because growth rates serve as direct indicators of coral recovery potential in the face of climate change. At Sharm El-Sheikh, marine ecology is also affected by rising temperatures due to climate change and human activities such as diving, snorkeling, and other marine recreation (Gerges *et al.*, 2024 and Feldman, 2025). Although Red Sea coral reefs have historically experienced fewer mass bleaching events than other global marine regions, this trend may be changing. Griffin (2024) explored the relationship between bleaching and multiple environmental factors, including water temperature, acidification, pH, wind speed, salinity, and chlorophyll concentration. The results are alarming: all indicators indicate a dramatic increase in bleaching risk by 2050, 2070, and 2100, with a projected three-fold increase by the end of the century. Diseases are also emerging as a major contributor to coral reef decline. Khalil *et al.* (2024) studied hard coral diseases in the Gulf of Aqaba and revealed that infected corals showed clear signs of physical distress, including tissue loss and degenerative changes. Notably, microbial pathogens of human origin, such as *Rothia kristinae* and *Cupriavidus pauculus*, are frequently detected in these diseased corals. This strongly suggests that the environmental pollution caused by human activity facilitates

the spread of diseases and compromises coral health. Despite these challenges, promising rehabilitation efforts are still required. Al-Horani and Langdon (2024) demonstrated the success of transplanting corals onto dead coral rocks, achieving a 100 percent survival rate for the fragments. To fully evaluate the effectiveness of this method, long term monitoring is required to determine how long it takes for living coral tissue to completely cover the rehabilitated rock surfaces.

5. Conclusion

This study highlights the complex interactions between natural variability, anthropogenic stressors, and coral reef resilience in the Egyptian Red Sea. An analysis of two decades of research from 2000 to 2025 revealed that most studies have focused on the northern Red Sea, where coral reefs are increasingly affected by coastal development, pollution, and tourism. Despite these pressures, dominant genera such as *Acropora* and *Porites* show notable adaptability, reflecting the exceptional thermal tolerance and ecological uniqueness of the Red Sea. However, continued exposure to cumulative stressors threatens resilience in the future. Addressing the existing gaps in coral disease research, recovery mechanisms, and spatial monitoring is essential to ensure the long term sustainability and conservation of these vital marine ecosystems. To maintain

coral reef health along the Egyptian Red Sea, future efforts should prioritize the establishment of standardized monitoring frameworks and expand research coverage to the southern and offshore regions. Strengthening national databases, enforcing strict regulations on coastal development, and reducing pollution from tourism and industrial activities are urgent measures. Collaboration among scientific institutions, local communities, and policymakers is crucial for designing adaptive management strategies that integrate ecological, social, and economic dimensions. Finally, investing in coral restoration projects, climate resilience studies, and public awareness initiatives will enhance both scientific understanding and community engagement in preserving Egypt's most valuable marine ecosystems.

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