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Survival of high latitude fringing corals in extreme temperatures: Red Sea oceanography

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ABSTRACT

This multi-year study set out to establish a comprehensive knowledgebase for a fringing coral reef in the Gulf of Suez, while also investigating the link between coral reef survivability and the extreme environmental conditions present in the region. The Gulf of Suez is a narrow branch of the northern Red Sea for which all forms of environmental and scientific data are severely lacking. Monitoring oceanographic and meteorological data provides evidence of both seasonal variability and interannual variability in this region, and may reveal correlations between reef health and prevailing climate conditions. Specifically, this research sought to document the environmental conditions under which Zaki's Reef, a small fringing coral reef (29.5°N and 32.4°E) that lies at the northernmost limit of tropical reefs worldwide, is able to survive, in order to determine how extreme the conditions are. Results of observed seawater temperature revealed that coral species at Zaki's Reef regularly experience 2–4 °C and 10–15 °C daily and seasonal temperature variations, respectively. Seawater temperature monthly means reached a minimum of 14 °C in February and a maximum of 33 °C in August. Monthly mean sea surface temperature climatology obtained from satellite measurements was comparable to observed seawater temperatures, while annual air and seawater temperature means were identical at 22 °C. Observed seawater temperatures exceeded established coral bleaching thresholds for extended periods of time, suggesting that coral species at this location may have developed a mechanism to cope with such extreme temperatures. Further scrutiny of these species and the mechanisms by which they are able to thrive is recommended.

1. Introduction

Zaki's Reef is a small fringing coral reef located in the northern Red Sea, near Ain Sokhna (29° 55′N and 32° 22′E). The reef extends approximately 1 km parallel to shore and a half kilometer offshore, beginning approximately 50 m from the beach (Fig. 1). Located in the shallow Gulf of Suez (~50–80 m deep), Zaki's Reef lies adjacent to an extremely arid desert where rainfall is minimal, evaporation rates are high, and freshwater inputs are nearly non-existent. The persistent trade winds and extreme air temperatures result in high salinity (43–45 psu) and large daily and seasonal temperature fluctuations. High seawater temperatures and salinity reduce oxygen solubility, which can stress many species of reef dwelling organisms, so the organisms that live here must be able to tolerate these environmental extremes.

Red Sea coral reefs are cited as the most diverse in the world (Loya, 1972). Yet, of the estimated 335 species of corals found in the Red Sea, only 35–40 species have been identified in the Gulf of Suez (Mustafa, 2000). Of those species, just six dominated approximately 94% of Zaki's Reef (Moustafa et al., 2008a). The Gulf of Suez's subtropical location means that it is warm enough to harbor a wealth of tropical biota however, its high-latitude results in significant seasonal temperature variations, particularly in the summer and winter seasons (Moustafa et al., 2008b). These extreme seasonal temperature variations not only may exceed known coral bleaching temperature but also may lead to more frequent coral exposures to bleaching conditions due to its high latitude location.

Water temperature is considered the primary determining factor for reef distribution worldwide (Rowan, 2004; Bairdet et al., 2009; Brown and Cossins, 2011), with optimum temperatures for coral growth ranging from 26 to 27 °C (Edmunds, 1994; Glynn et al., 2001). Coral reef distributions have been reported to be aligned with a monthly minimum seawater temperature of 18 °C (Baria et al., 2012; Krishnan et al., 2011). Cold seawater temperature also causes coral bleaching and mortality (Lirman et al., 2011). Coral bleaching commonly occurs when water temperatures get too high, but life-threatening stress and bleaching also occur when water temperatures drop too low.

In 2004 we performed a baseline characterization of this newly discovered fringing coral reef (Zaki's Reef), located in a northernmost region of the Red Sea. Annual surveys then sought to primarily monitor the health and survival of this initially pristine reef. After we realized the reef community's ability to continue to thrive despite the pressure of a number of anthropogenic and manmade stressors, we sought to investigate its salinity and temperature regime. Furthermore, we

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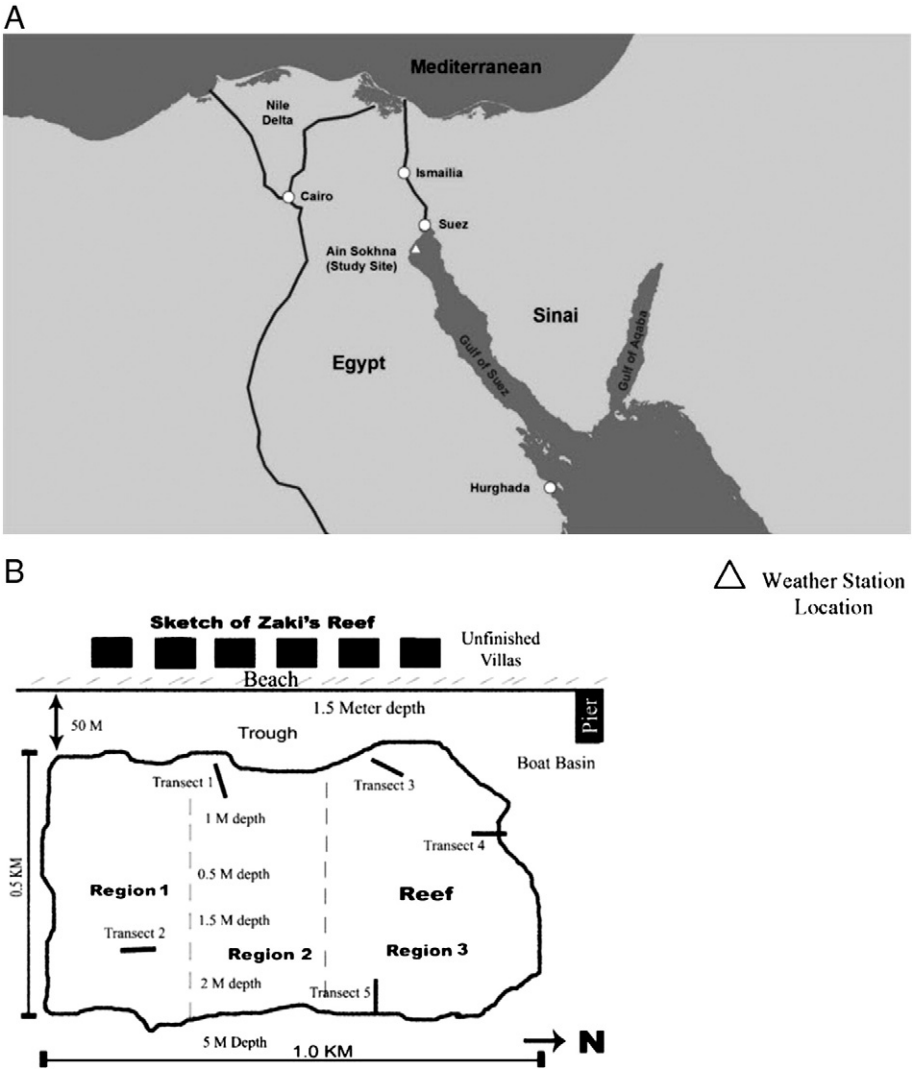

Fig. 1. Location of Zaki's Reef in the Red Seas Gulf of Suez, approximate 80 km south of the highly trafficked Suez Canal. Panel A, general location of the study area. Zaki's Reef is located approximately 60 km from Suez City. Panel B: Location of air and water monitoring stations at Zaki's Reef.

found that long-term in situ seawater and air temperature data were nonexistent for this region of the Gulf of Suez. Therefore, the overarching goal of this multi-year study was to establish a knowledge base for fringing coral reefs in the Gulf of Suez and provide basic information for current and future reef management. Specific objectives of this research were:

1. Establish regional long-term seawater temperature ranges and trends and investigate their impact on the coral reef ecosystem,
2. Determine the cyclic nature of measured seawater temperature and how it relates to measured air temperature,
3. Compare our measured time series temperatures with climatology from observed satellite sea surface temperatures to utilize existing coral bleaching warming tools (i.e., NOAA's Coral Reef Watch Satellite Bleaching Alert system), and
4. Based on this data, examine how and why Zaki's Reef is able to survive the extreme and variable conditions found near the northernmost limits for subtropical reefs.

In situ air and water temperature time series data were collected from the study site, primarily to complement the overarching goal of establishing a consistent multi-year database for this region. We used time series and statistical analysis to analyze the gathered temperature data and compared our findings to other studies to reach our conclusions.

2. Theory/calculation

2.1. Data collection

In situ seawater temperature data were collected at five locations (stations) across the reef to sample every 30 min (Fig. 1). Temperature sensors were deployed for 14 and 11 months between June 2006 and August 2007 and between August 2007 and June of 2008, respectively. At least one sensor (Optic Stow Away — TEMP$^{(C)}$ ONSET Computer Corporation) was deployed at each transect (Fig. 1). Air temperature data were collected for two years between August 20, 2007 and September 16, 2009 (ONSET, http://www.onsetcomp.com/images/graphs/U23RHGraph.gif).

Daily means from 48 observations per day (sampled every 30 min) were calculated to develop the database used for all statistical analyses presented. All monthly and annual means are based on daily data, unless otherwise stated. Annual means and correlation coefficients were calculated from the start date where both air and seawater temperatures were available (i.e., August 21, 2007).

2.2. Satellite-based sea surface temperature (SST)

Sea surface temperature is globally provided by NOAA and the US Navy, for an average ocean-skin temperature on a 0.5° and a 1/8° grid,