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Mass bleaching of soft coral, *Sarcophyton* spp. in Thailand and the role of temperature and salinity stress

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From June to October 2006 and 2007, mass bleaching of the soft coral, *Sarcophyton* spp., occurred for the first time in the upper Gulf of Thailand. Approximately 90% of the populations experienced extensive bleaching, and almost 95% of colonies were affected. Field observations also revealed that fragmentation of *Sarcophyton* spp. set in 1 month after the onset of bleaching. Some colonies started to recover to some extent by the end of July, with 95% of the population of *Sarcophyton* spp. recovering by October. Both acute and chronic trials were conducted to determine whether temperature and/or salinity triggered bleaching. In the acute tests, *Sarcophyton* spp. at 40°C and salinity 20 psu were completely bleached, and death occurred after 57 and 204 h, respectively. However, the colonies at 40 psu could survive through the experimental trial. In the chronic tests, *Sarcophyton* spp. died when exposed to 34°C, whereas complete bleaching and mortality of *Sarcophyton* spp. occurred at salinities of 10 and 49 psu. We conclude that elevated temperatures had a greater effect on the bleaching of *Sarcophyton* spp. than did salinity.

Keywords: bleaching, environmental stress, fragmentation, Gulf of Thailand, salinity, *Sarcophyton*, temperature.

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Introduction

Over the past two decades, mass bleaching of corals has frequently been observed in different parts of the world's oceans (Hoegh-Guldberg, 1999; Celliers and Schleyer, 2002; Wilkinson, 2004; Shenkar *et al.*, 2005; Whelan *et al.*, 2007). Coral bleaching results from physiological, algal, and host-related stress and involves the breakdown of the symbiosis between invertebrates like corals and the vital dinoflagellate algae of the genus *Symbiodinium* (Fitt *et al.*, 2001). Environmental stresses, such as temperature, salinity, and solar radiation, are also major contributing factors to bleaching of corals (Hoegh-Guldberg and Smith, 1989; Brown, 1997). Different species differ in their sensitivity to bleaching, depending on their shape, size of the colony, range of stress tolerance, resilience, and the ability to regenerate after disturbance, and on which *Symbiodinium* clades are involved (Buddemeier and Fautin, 1993; Fabricius *et al.*, 2004, Obura, 2005; Bellwood *et al.*, 2006). Corals with clade D zooxanthellae have been found to be the most heat-resistant (Baker *et al.*, 2004; Fabricius *et al.*, 2004), although recent work tends to dispute this (Abrego *et al.*, 2008). Corals that bleach become more susceptible to coral disease and death (Whelan *et al.*, 2007). Whelan *et al.* (2007) found that most *Colpophyllia natans* colonies died from white-plague disease type II after partly recovering from bleaching. Temperature and salinity are major factors that trigger bleaching of corals, not only by contributing to bleaching, but also by the histopathological changes that they trigger (van Woesik *et al.*, 1995).

Mass bleaching of soft corals has been reported in Australia (Fabricius, 1999), and that author reported that after soft corals had lost their dinoflagellate symbionts (zooxanthellae), the colonies died and completely disintegrated. However, information regarding the bleaching of *Sarcophyton* spp. is limited. From the Great Barrier Reef, Marshall and Baird (2000) reported that *Sarcophyton* spp. were bleached at water temperatures >31°C. Strychar *et al.* (2005) demonstrated that *Sarcophyton ehrenbergi* released greater numbers of symbiont cells than *Sinularia* spp. and *Xenia* spp., and that it can survive at 34°C. Off South Africa, Floros *et al.* (2004) found that *Sarcophyton* spp. was highly susceptible to bleaching. Mass bleaching of soft corals was observed in Thailand for the first time in 2006. However, little is known about factors that may give rise to this phenomenon and about the recovery of soft corals after bleaching. The purpose of this study was to investigate the recovery of the soft coral, *Sarcophyton* spp. after bleaching, as well as to explore the role of acute and chronic changes in salinity and temperature in the bleaching process.

Methods

Mass bleaching of *Sarcophyton* spp. was observed for the first time in June of 2006 and 2007 in the upper Gulf of Thailand, at the

Phramahachedsadharajchao Camp of the Royal Thai Marine Corps, Sattahip, Chonburi Province, where we estimated the percentage of bleaching of soft and hard corals. During the 2007 bleaching, five 50-m transect lines were laid parallel with the shoreline and surveys were carried out of the number of colonies of each species being bleached. To investigate the recovery of *Sarcophyton* spp., ten bleached colonies were tagged and observed every month. A fixed frame (20 cm × 20 cm) with 25 fixed-point intercepts was used to estimate the percentage of bleaching in each colony. During the periods of bleaching, the highest water temperature in the area was 33.7°C and the highest salinity was 33 psu. Under normal conditions, the temperature and salinity in the area are ~28°C and 30–31 psu, respectively.

A reciprocal transplant experiment was also conducted. Five bleached colonies of *Sarcophyton* spp. were collected at the Royal Thai Marine Corps site, and five non-bleached colonies were collected at Samae San Island, located ~1 km southwest from the bleached area. A number of unbleached colonies was transplanted to the Royal Thai Marine Corps site and bleached colonies were transplanted to Samae San Island, in ~2 m water depth. The change in the colour of transplanted colonies was monitored using the fixed frame technique described above.

During the bleaching periods, there were extremely low tides during the day and unusually high rainfall was recorded in the upper Gulf of Thailand. The lowest tide during June 2007 was 0.43 m, and the highest tide was 3.12 m. To determine whether salinity and temperature influenced bleaching, acute and chronic salinity and temperature experiments were conducted. In all, 40 pieces (10 cm in diameter) of *Sarcophyton* spp. were prepared and acclimatized in a tank at ambient salinity of 30–31 psu and an ambient temperature of ~28°C for 2 weeks before the experiments began.

In the experiments for acute salinity change, 15 pieces of *Sarcophyton* spp. were transferred into three tanks containing seawater at different salinities (20, 30, and 40 psu), with five pieces placed in each tank. The 30-psu ambient salinity tank served as a control. To quantify the level of coral bleaching, a colorimetric analysis of digital photographs of corals using the ENVI programme (ITT Visual Information Solutions) was conducted. Levels of bleaching were measured as the difference between the colour of a particular coral colony at the beginning and end of the experiment. Each photo quadrat was 10 cm × 10 cm. Data were collected every 15 min during the first hour, then at 2, 3, 6, 9, 12, 18, 24 h, and thereafter every 12 h. In the experiments for chronic salinity change, salinity was increased or decreased by 3 psu every 24 h relative to ambient salinity (31 psu) until all pieces of *Sarcophyton* spp. were dead, except at salinities of 19 and 43 psu, which were maintained for 4 d before continuing to decrease or increase salinity. The data and the times of data collection were the same as for the acute salinity test.

In addition, ten pieces of *Sarcophyton* spp. were transferred into two separate tanks with water temperatures of 28°C and 40°C, respectively, to assess the response to acute temperature changes. There were five pieces of *Sarcophyton* spp. in each treatment. The colour changes of the soft corals were observed every hour for the first 3 h and every 3 h thereafter. In the chronic temperature change experiment, five pieces of *Sarcophyton* spp. were placed in tanks of water at 28°C, and the temperature was increased by 3°C every 24 h until the soft coral was dead. The data and the times of data collection were the same as for the acute temperature test.

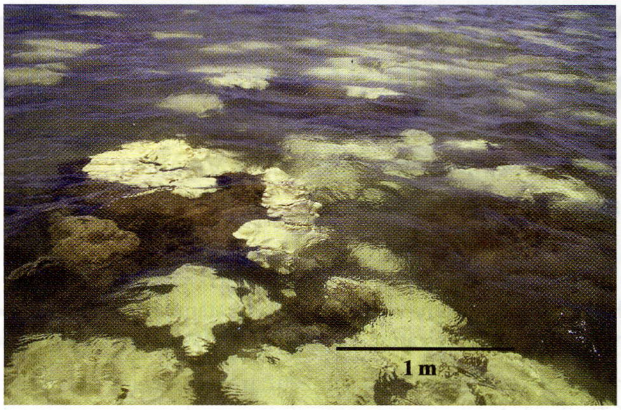

Figure 1. Mass bleaching of *Sarcophyton* spp. colonies.

Results

In 2007, 93% of the observed soft coral population in the study area (30 000 m^2) experienced extensive bleaching, with affected colonies being completely bleached (Figure 1). Soft corals bleached at depths of 1–2 m below mean sea level. One month after the onset of bleaching, in both 2006 and 2007, we noted fragmentation of *Sarcophyton* spp. (Figure 2). By the end of July, some colonies revealed partial recovery from bleaching, and by October, 95% of the bleached population of *Sarcophyton* spp. had recovered and survived. Some hard coral species in the area, such as *Favites halicora*, *Porites lutea*, *Hydnophora microconos*, *Goniastrea retiformis*, *Platygyra daedalea*, and *Turbinaria frondens*, were also bleached, but less dramatically than *Sarcophyton* spp., with 10% of the population of these species being affected.

The reciprocal transplant experiment demonstrated that the transplanted bleached colonies of *Sarcophyton* spp. had fully recovered within 7 d of relocation to Samae San Island. However, the transplanted non-bleached colonies that were moved to the Royal Thai Marine Corps site became bleached within 7 d, and remained in that state until October 2007.

Acute and chronic salinity changes

The results from the acute salinity experiment revealed that *Sarcophyton* spp. at 20 psu became completely bleached and that all died within 204 h (Figure 3). However, at 40 psu, the colonies

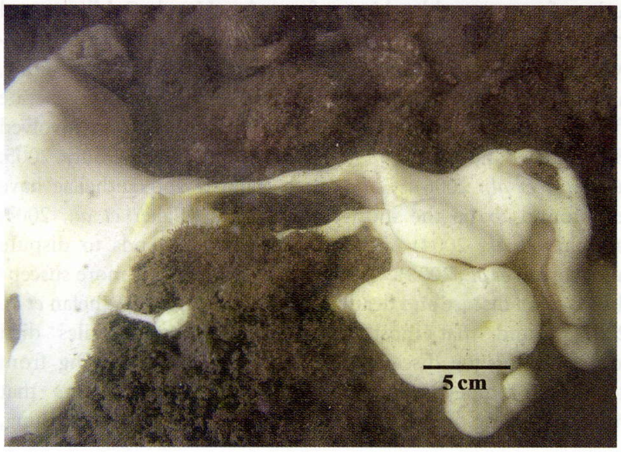

Figure 2. Fragmentation of *Sarcophyton* spp. after one month of bleaching.

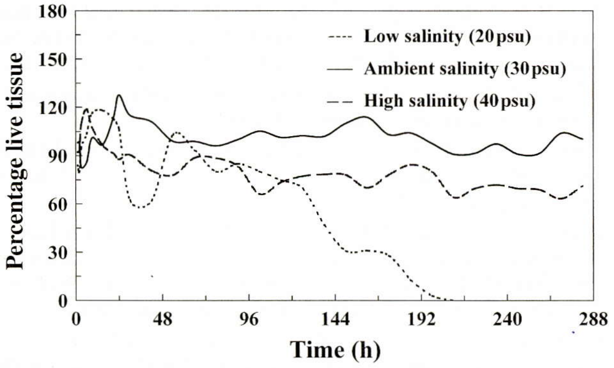

Figure 3. Percentage of non-bleached tissues (live tissues) of *Sarcophyton* spp. in the acute tests at three different salinities.

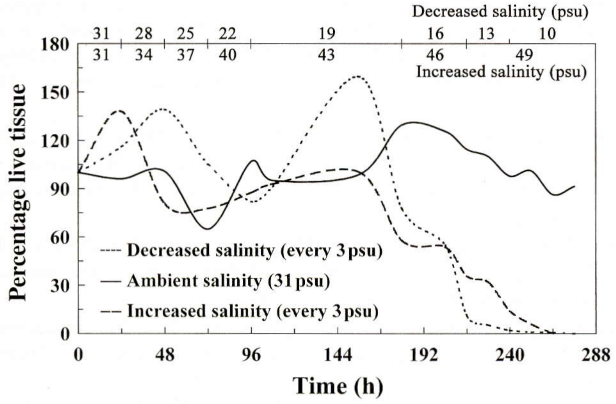

Figure 4. Percentage of non-bleached tissues (live tissues) of *Sarcophyton* spp. in the chronic tests, when salinity was increased and decreased by 3 psu every 24 h.

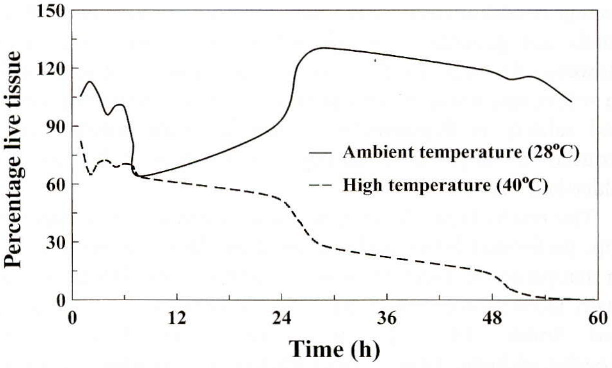

Figure 5. Percentage of non-bleached tissues (live tissues) of *Sarcophyton* spp. in the acute tests at three different temperatures.

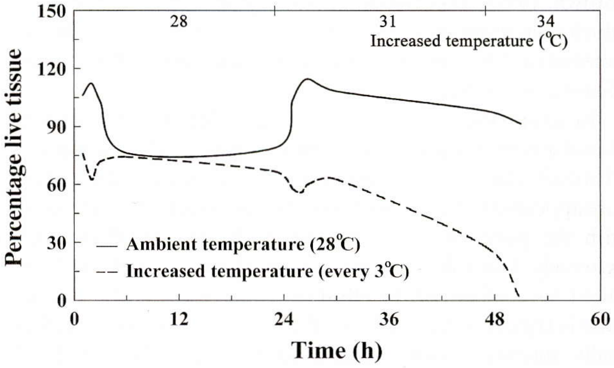

Figure 6. Percentage of non-bleached tissues (live tissues) of *Sarcophyton* spp. in the chronic tests when temperature was increased by 3°C every 24 h.

survived the experiment (Figure 3). In the chronic trial, the percentage of live tissue decreased significantly at 16 and 46 psu, and all colonies died when the salinity dropped to 10 psu (276 h after the start of the experiment), and when it reached 49 psu (264 h after the start of the experiment; Figure 4).

Acute and chronic temperature changes

In the acute temperature test, *Sarcophyton* spp. placed in 40°C water became completely bleached and all died after 57 h (Figure 5). However, in the chronic test, the gradual increase in temperature resulted in complete mortality of *Sarcophyton* spp. at 34°C (51 h after the start of the experiment; Figure 6).

Discussion

This is the first report of mass bleaching of the soft coral, *Sarcophyton* sp. from the upper Gulf of Thailand. Bleaching affected *Sarcophyton* spp. substantially during a 4-month period in both 2006 and 2007. Unexpectedly, mortality of *Sarcophyton* spp. was negligible during both incidents of bleaching. During the same period, several species of reef-building corals (Scleractinia) also became bleached, although only 10% of the total populations of these corals was affected. The sensitivity of corals to bleaching varies among species and genera (Loya *et al.*, 2001; Kayanne *et al.*, 2002), with species characterized by high rates of recruitment and rapid growth being more sensitive to thermal stress and bleaching (Jokiel and Coles, 1990; Buddemeier and Fautin, 1993). Fabricius (1995), however, demonstrated that the Alcyonaceans *Sinularia* spp. and *Lobophytum* spp. were susceptible to bleaching, although they had slow growth rates and low levels of recruitment. In the present study, the soft corals were much more susceptible to bleaching than hard coral species in the same area. In addition, the transplant experiment demonstrated that *Sarcophyton* spp. could recover within a week in a suitable habitat. Corals in habitats more exposed to variable stressors, such as temperature and salinity, tend to suffer greater levels of bleaching than those found in more stable environments (Celliers and Schleyer, 2002).

Changes in heat, light, and salinity are among the main factors responsible for coral bleaching (Brown, 1997; Fabricius, 1999; Ferrier-Pages *et al.*, 1999; Strychar *et al.*, 2005). Typically, changes in salinity also cause tissue damage (van Woesik *et al.*, 1995). In addition, elevated or reduced salinity can reduce photosynthetic and respiratory rates, which in turn reduce organic carbon and energy levels (Moberg *et al.*, 1997; Ferrier-Pages *et al.*, 1999).

Our acute salinity experiments revealed that *Sarcophyton* spp. could survive a salinity of 40 psu and was able to recover from bleaching (Figure 3). Changes in salinity over short periods may result in less damage and quicker recovery rates (Nakano *et al.*, 1997). *Sarcophyton* spp. also appeared quite able to exist at salinities between 16 and 46 psu (Figure 4). The upper and lower tolerance range of *Sarcophyton* spp. was 15 psu above and below the average conditions at the study site. According to Kinsman (1964), corals are generally less tolerant of hypersaline conditions. However, this was not the outcome in our study of soft corals. In soft corals, a strategy of adaptation to changes in temperature and salinity is fragmentation, through which colony size is reduced to cope with environmental stress (Fabricius and Alderslade, 2001).

The results from the present study revealed that *Sarcophyton* spp. performed better under acute than under chronic changes in temperature. Elevated seawater temperature is one of the main factors contributing to coral bleaching (Hoegh-Guldberg and Smith, 1989; Brown *et al.*, 1996; Brown, 1997; Hoegh-Guldberg, 1999). Mass bleaching occurs when sea temperatures exceed the thermal threshold of a species (Jokiel and Coles, 1990; Buddemeier and Fautin, 1993; Brown, 1997). Mass bleaching occurred among Thai corals in 1991 and 1995, when temperatures exceeded the long-term seasonal maximum (Brown, 1997). Thermal stress causes photosynthetic dysfunction, which then results in the loss of *Symbiodinium* spp. cells, through a number of different mechanisms, including host cell detachment (Gates *et al.*, 1992).

In summary, it appears that both salinity and temperature played a role in the mass bleaching of soft coral communities in Thailand. This study, however, confirmed that elevated temperature appeared to be a more powerful causative factor than salinity, with the possibility that exposure to heavy rainfall during the extremely low tides of this period (June of 2006 and 2007) might have enhanced the effect of temperature. Heavy rainfall in June is typical of the upper Gulf of Thailand, where rainfall normally intensifies from August to October. These and other factors will form the focus of future studies aimed at gaining an understanding of the patterns of stress among coral reef organisms.

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