CHAPTER I

INTRODUCTION

Coral reef bleaching is a phenomenon that has attracted a great deal of attention in recent years. Although first noted in the field as long ago as 1931 by Yonge and Nicholls, there have been three world-wide bleaching episodes over the last decade, in 1979-80, 1982-83, and 1986-88, that were well documented (e.g., Glynn, 1984; Brown, 1987; Williams and Bunkley-Williams, 1990). Nearly all of the world's major coral reef regions (Caribbean/western Atlantic, eastern Pacific, central and western Pacific, Indian Ocean, Arabian Gulf, Red Sea) experienced some degree of coral bleaching and mortality during the 1980s (Brown, 1987; Glynn, 1990, 1993; Coffroth et al., 1990; Williams and Bunkley-Williams, 1990). The pronounced increase in extent and intensity of each event has prompted concern among reef scientists.

The term "bleaching" implies loss of color which can be achieved by a reduction in the number of zooxanthellae or by loss of chloroplast pigments or a combination of both. Under normal environmental conditions the algal population in host tissues is maintained at a relatively constant level (Drew, 1972) by a regulatory mechanism which is still not clearly understood. However, the recent warrant has suggested that the population density of zooxanthellae in host tissue is dynamically maintained via the balance between mitokinesis (ie. production of new zooxanthellae during mitosis) and accommodation of density by the host of which included host growth and removal of the surplus cells by either expulsion of zooxanthellae or digestion by the host (Hoegh-Guldberg et al., 1987; Wilkerson et al., 1988). In contrary, under environmental extreme, the delicate balance among symbionts is destroyed and resulted in active expulsion of zooxanthellae. The mechanism of algal release is, however, more or less conclusive. With regard to the present knowledge (see Gates et al., 1992; Brown and Ogden, 1993), zooxanthellae could be released by any of five mechanisms. The five mechanisms are: (a) exocytosis of zooxanthellae from the host cell, resulting in the release of isolated algae; (b) apoptosis (programmed cell death) and (c) necrosis, both resulting in the release of zooxanthellae associated with remnants of the host cell; (d) pinching off of the distal portion of the host cell, resulting in the release of zooxanthellae surrounded by the vacuolar and pinched off plasma membrane and (e) detachment of endoderm cells from the host and release of these intact cells containing their complement of zooxanthellae.

A variety of environmental changes or stresses may account for coral bleaching. These include starvation or depletion of nutrient supply (Yonge and Nicholls, 1931a; Muscatine, 1971), lowered salinity due to storms (Goreau, 1964; Egana and DiSalvo, 1982), reduced irradiance (Yonge and Nicholls, 1931b; Rogers, 1979), an increase in light intensity (Coles and Jokiel, 1978; Kinzie et al., 1984; Harriot, 1985; Hoegh-Guldberg and Smith, 1989), decreased temperatures (Walker et al., 1982; Steen and Muscatine, 1987; Gates et al.,1992), and elevation in water temperatures (Yonge and Nicholls, 1931a; Jaap, 1979; Yamazato, 1981; Glynn, 1983, 1984; Glynn et al., 1988; Roberts, 1987; Williams et al., 1987; Lang et al., 1988; Cook et al., 1990; Gates, 1990; Gates et al., 1992; Hayes and Bush, 1990; Jokiel and Coles, 1990). In addition, bleaching may result from man-made disturbances such as thermal discharge (Jokiel and Coles, 1974; Coles, 1975; Neudecker, 1983), kaolin clay spill (Dollar and Grigg, 1981), fish-collecting chemicals, i.e. quinaldine and rotenone derivatives (Jaap and Wheaton, 1975), oil pollutants (Peter et al., 1981 in Brown and Howard, 1985; Knap, 1987; Guzman et al., 1991) and transplantation from deep- to shallow-water (Lang, 1973; Dustan, 1979).

Because there are several reef-dwelling taxa, e.g. foraminifera, sponge, hydrocorals, sea anemones, alcyonarians, soft corals, zoanthids and tridacnid clams, besides scleractinian corals which contain zooxanthellae or other kinds of symbiotic algae that often lose their algae during bleaching events, it is appropriate to employ the general term "coral reef bleaching" to describe this kind of disturbance (Williams and Bunkley-Williams, 1990).

While bleaching may be caused by a wide variety of environmental stimuli as pointed out earlier, it is generally believed that the major coral reef bleaching events witnessed over the last 10 years were the results of increased seawater temperatures and/or increased irradiance (Brown, 1988, 1990; Glynn, 1993). The earlier events in 1982-1983, in which widespread bleaching and significant coral mortality occurred across the Pacific from Panama to Java, were attributed to seawater warming that accompanied the 1982-1983 ENSO (El Nino-Southern Oscillation) event (Glynn 1983-85, 1988a, 1990; Glynn et al., 1988; Coffroth et al., 1990). That event was also considered as the major disturbance for community changes in coral reefs in the Indo-Pacific region (Glynn 1988a, 1990; Glynn et al., 1988; Brown and Suharsono, 1990; Warwick et al., 1990). More recently, the 1987-1988 event, bleaching of zooxanthellae cnidarians occurred intensively throughout most of the Caribbean reef provinces, and that event has also being attributed to higher seawater temperature (Roberts, 1987; Williams et al., 1987; Williams and Bunkley-Williams, 1988; Cook et al., 1990; Hayges and Bush, 1990; Szumant and Gassman, 1990).

Critical threshold temperatures for coral bleaching vary geographically, but can be expressed universally as fixed increments relative to the historical mean local summer maxima (Jokiel and Coles, 1990). Bleaching can be induced by short-term exposure (i.e. 1-2 days) at temperature elevations of 3 ^{0}C to 4 ^{0}C above normal summer ambient or by long-term exposure (i.e. several weeks) at elevations of 1 ^{0}C to 2 ^{0}C close to their lethal limits during the summer months. Observations in some geographical localities show that the annual variation in seawater temperature, which were never lethal, were responsible for dynamic seasonal phenomenon of darkening and paling coloration in corals (Gates, 1990). Temperature elevations above the summer ambient, but still below the bleaching threshold, can impair growth (Jokiel and Coles, 1977; Coles and Jokiel, 1978; Hudson, 1981; Goreau and Macfarlane, 1990), respiration (Coles and Jokiel, 1977), colony photosynthetic rate (Hoegh-Guldberg and Smith, 1989) tissue biomass and ability to reproduce (Szumant and Gassman, 1990).

Light effect was suggested as a possible cause and/or intensifier of the 1982-83 (Fisk and Done, 1985; Harriot, 1985) and the 1987-88 (Bunkley-Williams and Williams, 1987; Williams et al., 1987; Williams and Bunkley-Williams, 1988) bleaching events. Evidence for light effect was based largely on bleaching being more pronounced in more exposed areas of effected hosts. High natural light intensity accelerated bleaching at high temperature, increased mortality rate, reduced carbon fixation and lowered growth rate (Coles and Jokiel, 1978). The wavelength as well as the intensity of solar radiation can influence bleaching. Corals and their contained zooxanthellae are responsive to spectral distribution in the UV (Jokiel and York, 1982; Siebeck, 1988; Lesser et al., 1990). Spectral composition in the visible range also influences pigmentation and growth in corals (Kinzie et al., 1984). The best evidence for light-related damage to bleached hosts is the reduced pigments in zooxanthellae remaining in bleached corals. However, Hoegh-Guldberg and Smith (1989) suggested temperature increases, not light increases, cause the expulsion of zooxanthellae and that increased light reduced the number of existing zooxanthellae. The amount of chlorophyll per zooxanthellae was generally inversely related to irradiance (Dustan, 1982; Muller-Parker, 1987; Battey and Porter, 1988; Lesser et al., 1990). Therefore, temperature and light possibly interact synergistically; high light accelerates bleaching caused by elevated temperature (Oliver, 1985; Jokiel, 1988; Jokiel and Coles, 1990).

Although a variety of physical stresses have long been known to induce coral bleaching, elevated temperature appears to be the pervasive factor that resulted in the recent world-wide bleaching phenomena (Jokiel and Coles, 1990; Williams and Bunkley-Williams, 1990). Reef scientists have recently claimed that evidence from circumtropical coral reef bleaching supports the hypothesis that bleaching may be the harbinger of climatic changes (Jokiel, 1988; Jokiel and Coles, 1990). The 4 warmest years of the last 100 were all in the 1980's and 1987 was the warmest (Kerr, 1988). Projected changes of global surface temperature in the next 50 years are uncertain and not uniformly distributed around the globe ranging from 1^0 to 5 ^{0}C. The possible rise in temperature of the tropical oceans will probably be about 1 ^{0}C (Wyrtki, 1990). If global temperatures continue gradually increasing, then extensive coral reef bleaching will eventually occur during every warmwater period in much of the tropics (Williams and Bunkley-Williams, 1990). Solar radiation accelerates bleaching at high temperature (Coles and Jokiel, 1978; Hoegh-Guldburg and Smith, 1989). Possible warming trends acting synergistically with possible increasing UV levels due to thinning of the earth's protective ozone layer may aggravate coral bleaching and threaten the existence of coral reefs (Jokiel, 1988; Jokiel and Coles, 1990).

Williams and Bunkley-Williams (1990) employed the term "bleaching complex" to describe a series of time-related bleaching events. Each complex included a "preceding event" before the most extensive ("main events") bleaching began. Undoubtedly, the bleaching that occurred in 1979-80, 1982-83, and 1986-88 were bleaching complexes that included a preceding event 1 year (1979, 1982, 1986) before the main event. In addition, the 1986-88 complex possessed a "following event" (1988) before the complex was ended. Furthermore, Williams and Bunkley-Williams (1990) also formulated a model by analysis of the bleaching events in the last decade and suggested that those three bleaching complexes were a cyclical phenomenon, proposing that bleaching cycles will continue to occur on average every 3 to 4 years. Furthermore, they have predicted another bleaching complex and stated that the complex will begin with a preceding event in 1990 or 1991 and to become a major world-wide bleaching event in 1991 or 1992 which also expected the more severity and extense of the event.

Although the first noted on isolated incidences of bleaching on intertidal reef flats at Phuket Island has documented since 1979 to present and suggesting regular occurrences without causing extensive mortality (Brown, 1987), the 1991 coral reef bleaching event in the Andaman coast of Thailand appears to be the first known extensive occurrence of the phenomenon in Thai waters. On 30 May 1991, bleaching was first noticed on the intertidal reef flat at the Phuket Marine Biological Center (PMBC). White patches of strands of *Acropora* spp., *Goniastrea* spp., *Porites lutea*, etc., were clearly seen from a distance. Further observations on reef areas nearby the PMBC suggested a widespread event and brought about an extensive field survey in Phuket, Phang-nga and Krabi provinces. Conspicuous and synchronous bleaching of reefs were encountered and vast varieties of scleractinian corals and other reef cnidarians were affected and subsequently died following the event. Alteration of reef communities over the large area was, thus, suspected. The coincidence of this event with an elevation of seawater temperatures was consistent with most other bleaching phenomena over the last decade. The event provided good evidence for furthering our understanding of coral reef bleaching. The long- and short-term consequences for coral colonies and reef communities to this bleaching event remain to be fully evaluated.

Objectives

1. To describe the bleaching event in coral reefs of the Andaman coast of Thailand.
2. To quantify the degree of damage to a coral reef at the Phuket Marine Biological Center (PMBC) site, following the bleaching event.
3. To investigate the long-term consequences for the reef community at the PMBC site, resulting from bleaching.
4. To describe the process of recovery from bleaching.
5. To estimate the rate of increase in pigmentation as the coral tissues are repopulated with zooxanthellae.
6. To compare the nature and rates of the processes of recovery between different coral species.
7. To study the changes in protein quantity in bleached corals' tissues during the recovery process on the basis that coral tissue components could also be affected by the loss of zooxanthellae.

Expected Results

The design of this investigation will provide some information on the effects of bleaching on corals at both colony and community levels, which have not been documented before in the Thai waters.

Periodic sampling of bleached tissues during color changes allow an estimation of the rate of increase in pigmentation as the coral tissue is repopulated with the symbiotic zooxanthellae. Recovery process with respect to photosynthetic pigment extraction techniques and tissue composition analysis could also be described.

Tagging data and successive data derived from line transect method established during and after bleaching event at PMBC fixed station will reflect the damage and changes in coral community as a result of this bleaching event.

In circumstantial evidence, increased seawater temperatures and solar radiation (especially UV radiation), either separately or in combination, have received consideration as potential stressors causing coral reef bleaching in large scale. Furthermore, as it has been recently claimed that mass coral reef bleaching of circumtropical coral reefs may be the harbinger of climatic change, this study will provoke future interest and examination of the responses of corals and reef communities to predicted increase in seawater temperatures over the next 50 years.