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CHAPTER 1

INTRODUCTION

The structures and features of both modern and ancient reefs are the net results of reef construction and erosion, affected by the inter-relationships of biological, physical and chemical agents. Trudgill (1983) reported that biological agents are the most effective ones in the coral reef ecosystem.

Bioerosion can be divided into two main categories; the surface erosion at the dead part of coral by grazing organisms and the subsurface erosion by boring organisms. The latter process has a significant effect in removing calcium carbonate ($CaCO_3$) from the coral interior. Such processes facilitate the physical destruction of coral reef by increasing porosity and decreasing the attachment strength of massive corals (Highsmith, 1981). Moreover, they also increase the surface area exposed for physical and chemical dissolution. According to the experiment of Crooke and Kepkay (1980), it was found that aragonite could be dissolved directly in sea water. Hutching (1983) proposed two erosion mechanisms which were mechanical abrasion and chemical dissolution. Soliman (1969) found that the

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influence of Lithophaga spp. were mostly due to the abrasive action of their shells. It was found that the initial bioerosion agents were polychaetes of which primarily polydroids (Spionidae) and fabrinoids (Sabellidae) have short lives, the Hypsicomus spp. and the eunicids which have longer lives (Davies and Hutchings, 1983; Hutchings and Bamber, 1985).

The effect of boring organisms in reef destruction had been discussed by various authors Otter (1937); Hien and Risk (1975); McGeachy and Stearn (1976); Highsmith (1981) and Highsmith et al (1983). They concluded that the important macroborers in coral reefs were sponges, bivalves, polychaetes and sipunculids. Tsuchiya, et al. (1986) found that the boring bivalves, polychaetes and sipunculids were the dominant groups in Porites lutea which is the reef builder species of coral reef in the Gulf of Thailand. Thus it investigated further study on the role of these in dynamic process of coral reefs in the Gulf of Thailand.

Objectives

The main objects of this study are as follows :

1. To determine and compare the species composition of some borers which play the important roles in bioerosion of Porites lutea in shallow and deep subtidal zones.

2. To estimate and compare the bioerosional rate by some boring animals in natural coral heads and in mounted coral substrates at shallow and deep subtidal zones.

3. To study some environmental factors which might facilitate the bioerosion due to boring organisms.

4. To investigate the succession of borers on coral substrates.

Expected advantage

It is hope that the results of these studies will provide the information on

1. Species or group composition and quantity of infaunal animals in living and dead coral substrates at different habitats.

2. Major bioerosional agents on reef building corals.

3. Relationship between coral substrates and infaunal animals.

4. Some essential environmental factors which facilitate the borer survival and abundance.

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Literature review

Biological and geological studies on coral reefs have provided qualitative and quantitative assessments of major constructive and destructive processes and their net products within coral reefs. The inter-relationships of these two processes from their agents particularly the biological agents are not only forming of the basis constructive processes but also the most important processes of destruction in coral reef ecosystem (Trudgill, 1983).

The biological destruction or bioerosion in coral reefs is disintegration of coral and other carbonate substrates by both boring and grazing processes. These two processes are the major processes on coral reefs which produce or induce the lost or retention of carbonate sediments in coral reefs. Therefore, each process was described as follows.

1. Bioerosion by grazing process

This process is caused by the grazing organisms feeding on filamentous algae which cover the surface of coral exoskeleton. They also remove the living tissues and underlying superficial skeletal elements. Though various organisms were reported to have grazing activities on coral surface but the major groups are as follows.

1.1 Fishes

The parrot fish (Scaridae) is an important grazer. They are able to graze on all of the filamentous algae, coral tissues and superficial skeleton. In Bermuda, the parrot fishes caused the reef that the bioerosion erosion at the rate of 210 gm /m^{-2} /$yr.^{-1}$ (Gygi, 1975 as refered by Davies, 1983) By using a different erosive estimation method, Hudson (1977) found that the bioerosion rate at Florida was 0.67 cm/yr. Frydl and Stearn (1978) found that <u>Sparisoma</u> <u>viride</u> was the only species which caused significant bioerosion and new sediment production while the other parrot fish recycled old sediments.

1.2 Echinoids

Echinoids have become the major eroders on coral reefs and in some instances, they act as an coral growth limiting factor (Glynn et al, 1979). At the density of 23 individuals/m^2, <u>Diadema</u> <u>antillarum</u> at a Barbados fringing reef caused the erosion rate of about 9.7 kg $CaCO_3/m^2/yr$ which was equivalented to the vertical erosion rate of 6 mm/yr (Hunter, 1977; Stearn and Scoffin, 1977).

The grazing activities of both parrot fishes and echinoids do not only produce carbonate sediment, but also remove living tissue as well as the underlying superficial skeleton. Therefore, if the corals do not regenerate in certain period, the same surface will prone area is not to

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colonization by excavating organisms (Bak and Steward Van Es., 1980).

2. Bioerosion by boring process

Boring process on the carbonate substrates by various borers can be divided into two main categories which depend upon the borer mechanisms to penetrate into the carbonate substrate both on macro and micro scales.

2.1 Algae and fungi

Otter (1937) reported that green algae (Chlorophyceae), blue - green algae (Cyanophyceae) and red algae (Rhodophyceae) including some fungi were burrowing plants which played important roles in coral reef destruction. Most of them could be visible as a green coloration on the live corals deeper parts. Highsmith (1981) reported that the green bands in Porites lutea skeleton was produced by an endolithic algae in the genus Ostreobium spp. The boring method of these algae are caused by chemical means of the carbondioxide produced from respiration. Kobluk and Risk (1977) study the infestation rate and they found that these boring algae could infest the carbonate substrates.

These boring algae are the pioneer to facilitate the long - lasting colonization of the boring animals. Hutching and Bamber (1985) found that all pioneer boring animals on coral substrates were the short life polychaete groups, namely, polydroids and fabricinids. These polychaete groups may feed on algae (McGeachy and Stearn, 1976). Thus, other borers could effectively penetrate into the coral substrates.

2.2 Porifera

Sponges have also played the important role in coral reef ecosystem. Vacelet (1984) reported that the sponges were the essential animal for nutrients balancing in coral reefs since they were often found living symbiotically with Cyanobacteria and Zooxanthellae. In fossil reefs sponges were part of coral reef formation. However, Some sponges are one of the most important biodestructive agents in modern coral reefs. Wilkinson (1983) reported that a limited number of siliceous sponges were known to bore into coral substrate. The most effective ones are Cliona. Rützler (1974) found that the boring sponges at Burmuda were Cliona caribbaea, C.flavifoding sp., C.paucispian sp., C. vermifera, C. diorysea , C. amplicavata sp., C. lampa. The next important genera are Spheciospongia, Anthosigmella and Siphonodictyon (Hudson, 1977). Since these sponges use similar mechanisms to erode calcium carbonate as other bioerosional organisms. A number of mechanisms have been proposed to describe the sponge bioerosion including chemical dissolution, mechanical abrasion, muscle - like excavation and the combinations of these methods. The following borings sponge descriptions are summarized from Rutzler and Rieger (1973) and Pomponi (1979). The etching cells of both newly settled larvae and mature sponges flatten one end against the substrate, and then, the complex mechanism of etching cells can cut out a hemispherical chip of coral substrates. According to Pomponi (1979), the substrate is dissolved by the combined action of a lysosomal enzyme system which dissolves organic matter, and carbonic anhydrase which requlate acid secretion at the periphery of the filopodial sheet. When the process is complete, both the chip of coral substrate and the spent etching cell are transported through the sponge and expelled. Boring sponges can produce large chamber in coral substrate, total depth varies between 0.5 mm. and 80.0 mm. but usually does not exceed 20 mm. The depth and rate of penetration depend on the porosity of the substrate, with porous corals usually being more readily bored (Neumann, 1966 and Mac Geachy, 1977).

Boring sponges are proposed to be the most important bioeroding organisms on coral reefs in highly productive areas (Highsmith 1980). In terms of bioerosion rate of coral substrate, Fütterer (1974) found that the <u>Cliona</u> spp. could produce carbonate sediment of 15 to 100 micron in size, 2 - 3 % of all sediments which consist of sponge chips and as much as 30 % of the fine sediment in the Persian gulf, lagoon of Fanning Island is sponge chip. Rutzler (1975) estimated 256 gm $CaCO_3$ per m^2 substrate per year. In addition, Moore and Shedd (1977) estimated the clionid bioerosion rate at all location was 990 gm/m^2/yr.

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2.3 Sipunculids

Gardner (1903) noted that rock - destroying sipunculids was an important factor in coral reef destruction especially at Low Isles, (as referred by Otter, 1937). Very Little is known about the mode of boring, although some species have been presumed to posses acid secretion. Aspidosiphon steenstrupii, Phycosoma scolops and Cleosiphon aspergillum are three species from Low Isles. These animals are able to wedge themselves very securely within their burrows, and movements of the hard bands might be effective in grinding the rocks away. In addition, the boring activity of sipunculid worms was discussed by Rice (1969). Rice and McIntyre (1982) believed that all of them involved combination of both chemical and mechanical action. Chemical secretion from epidermal glands for weaken the substrate and facilitate removal by the scraping action of armoured structures (small cuticular papillae and horny shields) on the sipunculid body. From the report of Mc Geachy and Stearn (1976) they found 4 species of sipunculids of P.antillarum, Paraspidosiphon speciosus, P. fishers and Lithacrosiphon gurjanovae. Generally, the sipunculids prefer to bore in area already weakened by boring sponges and the other borers. Thus, the effect of boring sipunculids would depend on the amount of boreholes and coral reef environment (William and Margilis, 1974) Risk and Sammarco (1982) noted that the sipunculids bored actively at the damselfish territories where predators of worms disappear.

2.4 Polychaetes

Members of polycheate families Eunicidae, Cirratulidae, Flabelligeridae, Spionidae and Sabellidae are naturally boring organisms. Their boring process can be divided into two categories :

Mechanical process

The polycheates use strong mandibles to dig their ways through the coral substrates. The eunicids were reported to play the role in the destruction of corals. McGeachy and Stearn (1976) found several different polychaete families in Montastrea annularis and some of the specimens encountered had previously been described as borer such as Eunice schemacephala, E. mutilata and E. kinbergi. Furthermore, Eunice spp. also found to bore in Porites lutea. Kiene (1985) found that eunicids were included as the major group of boring polychaetes in coral substrates at Lizard Island. In case of some polychaetes like spionids and flabelligerids, they are the causes of abrasion by the combination of setae and strong muscles. In the study of coral associated polychaetes of Hong Kong, Mak (1980) found Pherusa parmata to be one of members of Flabelligeridae which bored in coral at the living part. Likewise, Tsuchiya et. al. (1986) also found that it also bored in Porites lutea. In addition, it was suggested that the polychaetes which posses jaws such as nereids, could bore in coral heads (Otter 1937, and Mak, 1980).

Chemical process.

Otter (1937) suggested acid secretion as mean of chemical boring. that Hein and Risk (1975) found spionid polychaetes of the genus Polydora in 'u' shape holes with a distinctive double 'o'aperture and spiral shape holes (1 mm or less in diameter) which are attributed to spionid activity. Study on burrowing morphology and microarchitechture of shell dissolution by spionid polychaete *Polydora websteri*. Zottori and Carriker (1974) concluded that it was able to dissolve shell which was calcium carbonate. McGeachy and Stearn (1976) suggested that they were dissolved by an acid product of metabolism. From their observations of boring activity on test substrates showed that the worms were capable of rapid rates of boring; conchiolin layers of visible thickness (in oyster shells) were penetrated within a month. Members of polychaetes family Sabellidae; *Hypsicomus* spp. are found as chemical borers (Otter, 1937; McGeachy and Stearn, 1976; Davies and Hutchings, 1983; Hutchings and Bamber, 1985; Kiene, 1985). Those of the Cirratulidae Family found that they were found to be the dominant borers in coral blocks which were laid in various coral reef environments (Davies and Hutchings, 1983; Hutchings and Bamber, 1985; Kiene, 1985).

Most of pioneer polychaetes were largely of short lived species such as sabellids and spionids. These pioneer borers were spawned in summer peroid which settle, mature, breed and die within 3 to 4 months (Davies and Hutchings, 1983). Pioneer polychaetes usually succeed algal growth. The coincidence of many eunicid and spionid bored with endolithic algal bands suggests that the worms may be using the algae as a food source McGeachy and Stearn (1976) . The feeding habits of borer polychaetes were noted and used as indicative of reefs undergoing construction i.e., containing filter feeding polychaetes such as sabellids and spionids and destruction i.e.,containing deposit feeding polychaetes such as eunicids, cirratulids, flabelligerids (Vittor and Johnson, 1977).

2.5 Molluscs

Gastropods : Not much information is available regarding boring gastropods. Three species of coralliophilida are reported (Soliman, 1969) Leptoconchus cumingii (Deshayes), bored in the living tops of Favia stelligera and Goniopora sp. and Echinopora sp. and Magilopsis lamarekii (Deshayes),in Cyphastrea sp., Soliman (1969) explained that they had the characters of the shell, foot and burrowers, which indicated that boring was likely to take place by mechanical abrading by the shell which was capable of incomplete rotation. In addition, histological examination of the fleshy parts protruding out of the shell revealed no acid glands. Thus, the shell apparently made its way through the coral in steps.

Bivalves. Highsmith (1980) referred to the results of many workers on boring bivalves which had known to occur in live portions of various hermatypic corals. Several species of boring bivalves are of families Mytilidae and Gastrochaenidae. The only two mytilid genera; *Fungiacava* and *Lithophaga* were the true chemically boring bivalves (Kleemann, 1980). The burrows formed by the genus *Lithophaga* can always be distinguished by aperture at the surface of calcareous rocks. The aperture consists of a "dumbel" or "figure-of-eight" shaped hole, the two lopes of which a joined by a narrow slit-like aperture (Otter, 1937). Kleemann (1980) concluded that *Lithophaga laevigata*, *L. lessepsiana*, *L. lima*, *L. simplex*, and *L. purpurea* were found in a number of corals; *L. kuchnelti* had been observed only in *Acropora palifera*. In addition, Otter (1937) also found *Lithophaga lithophagus*, *L. obesa*, *L. teres*, *L. cumingiana* in Great Barrier Reef. In Thailand, Nielson (1977) found at Phuket Island, in the Andaman sea that the boring bivalves in coral heads were *Botula cinnomea* and *Lithophaga teres*, *L. nasuta* (Nielson, 1977)while in the Gulf of Thailand *Lithophaga lima* were dominant boring bivalves, both in live and dead *Porites lutea* on the coral reef at Kang Kao island (Tsuchiya et al., 1986). The pallial gland of Lithophaga lithophaga which found that the rock boring activities of Lithophaga had been related to secretion from pallial glands in the mantle (Bolognani and Bolognani, 1979). This might concern the function of Ca^{++} binding activity and is probably due to lipoproteic components with acidic groups. Barthel (1981) studied on the boring technique of Lithophaga obesa. The interrelation of gas exchange and calcium metabolism in molluscs particularly in bivalves usually enhanced the dissolution of carbonate substratum. The obstruction of gas exchange lead to anaerobic oxygen production which inturn increase the carbon dioxide in the tissues. Ansell (1969) described the mechanical boring bivalves using their shells as boring tool. Where as boring in the epifaunal form the surface the major force applied to the shell in abrading the burrow is provided by contractions of the pedal or byssal retractor muscles. In contrary, where boring has been derived form a deep burrowing habit, the adductor muscles provide the major force in abrasion, and the basic digging cycle has become specialized by the addition of the rocking action of the valves which succeeds retraction. These bivalves are Petricola lapicida, Arca imbricata, Tridacna maxima. (Otter, 1937). In case of Gastrochaenidae, the foot is very powerful, and when protuded on anchor the shell firmly against the anterior region of the burrow by suction (Otter,1937) Gastrochaena cuneiformis is always found in dead coral even. in Thailand it was found both in Andaman sea and Gulf of Thailand (Neilson, 1976; Tsuchiya et al., 1986). Furthermore, Tsuchiya et al. (1986) found the other species of Gastrochaenids such as Spengleria mytiloides at Kang Kao island.

These siphonated bivalves usually feed on phytoplankton. Thus, in productive areas, these bivalves are significantly indicated relative bioerosional damage to corals. Highsmith (1980) found boring bivalves per coral head, can be ranked by regions as follows Eastern Pacific > Western Atlantic > Indian Ocean > Western Pacific. This ranking also corresponds to primary productivity differences. He also found that if primary productivity was raised about 150 - 200 mg C/m^2/day, the abundance of boring sponges and bivalves, with concomitant damage to coral skeletons. The estimation of the rate of bioerosion of Lithophaga at Aldabra was approximately 0.911 cm/yr (Trudgill, 1976 as refered by Davies, 1983).

2.6 Crustaceans

Otter (1937) referred to the work report of Canon in G.B.R. Exped. Report that the pedunculate barnacle Lithotrya valentiana was the only rock - burrowing barnacle found at Low Isles. The burrows were easily distinguished on the surface of the rock at low tide, being oval on the surface and approximately 1 cm. by 0.7 in diameter in the largest individuals, which average about 3 cm in length. Ahr and Stanton (1973) found that the rock - boring lepadomorph barnacle Lithotrya was a vigorous agent of

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bioerosion in pachy exposures at beach rock around the Island of Icacos, Puerto Rico. McGeachy and Stearn (1976) also found Lithotrya in Montastrea annularis. Boring of another barnacles, tentatively identified as Kochlorine were occasionally found. These boring barnacles with the characteristic slit shaped aperture and were less than 4 mm in diameter. The boring methods of Lithotrya nicobasica was described as the result of friction of scales on the peduncle and the edges of laminas of the valves against the walls of the burrow as the animal moves. The bioerosion by Lithotry was about 0.844 cm/yr at Albadra (Trudgill, 1976 as refered by Davies, 1983).

2.7 Echinoderms

In Echinometra mathaei and Echinortrephus molare, the teeth and spines of these sea urchins are the organs use for grinding the corals. The body of the animals are anchored in position by means of the tube - feet, the jaw is opened and the five teeth are protuded from the buccal chamber to the required length, depending on the hardness of the rock. The five teeth strike the rock like picks, thereby dislodging fragments, and as the teeth are curved, a powerful glancing blow is ensured. If the rock is very hard, the sea urchin can close its jaws to form a single bundle of its five teeth, which strike the rock as one pick. (Otter, 1937).

3. Effect of environmental factors on bioerosion by boring organisms

3.1 Productivity

Primary producers are the regulator of productivity in the sea. In case of coral reef ecosystem, the plant communities are the most important primary producers such as phytoplankton, endo - and epilithic algae, crustose coralline algae, seagrass, zooxanthellae. Especially, Phytoplankton and zooplankton, contribute and facilitate the abundance of planktivores which most of them are boring organisms in coral reef. These boring organisms were found to be pioneer animals in new dead coral in field experiments Davies and Hutching, 1983; Kiene, 1985. Hutchings and Bamber (1985) suggested that the sabellids and polydrorids are short lives which in some way modify the substrate and make it be suitable for other agents of bioerosion. The primary producers have also regulated the quantity of organic matter on coral reef which directly facilitate to deposit feeders. Some of them are the boring polychaetes in coral substrates (Davies and Hutching, 1983), and are also the destructive condition indicator of coral reef.

3.2 Sedimentation and suspended sediment

Otter (1937) concluded that the layer of sediment covered on coral substrate probably forms an efficient barrier against the attach of the majority of boring

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organisms, both in the larval or adult forms, with the exception of certain groups of polychaetes and sipunculids. suspended sediment may also affect the feeding of some borers such as boring sponges since the concentrated suspended sediment may impede their feeding circulation. Wilkinson (1983) proposed that a suitable substrates for boring sponge larvae were remoted from excessive sediment.

3.3 Wave energy

Wave action can prevent the settlement of many free - swimming larvae and decrease succession of borers (Otter, 1937). In addition, moderate wave energy favor rapid growth which cause of porous and uncemented coral (Adey, 1978). Thus Highsmith (1981) proposed general hypothesis in the dynamic of bioerosion that fast-growing coral species constructed skeletons of low density, which are easily bored by borers. However, the results suggested that bioerosional damage to reef corals is positively correlated with skeletal density. For vertical fast-growing corals, they may due to difference in their ability to protect the skeleton from boring organisms by maintaining live tissue over them. However, the wave action influence the demage of reef corals, both direct and indirect ways. Bimley (1978) concluded that sipunculans occured mainly in low wave energy langoonal situations in Caribbean. However, Rice and Macintyre's (1982) reported that sipunculans occurred in greatest abundance in high energy reef crest areas.

3.4 Substrates

The space, porosity, shape of crevice and position can affirm the borer settlement interm of available substrates. Furthermore, size in mean of exposured time of live coral substrates are some special characters of coral substrates which may support larvae and adult recruitment of borers. These characters of coral substrates facilitate succession of boring communities, and provide protection from predators (Hutchings, 1983). McCloskey (1970) studied on coral heads of Oculina arbuscula of varying sizes and ages, he found that the larger (presumably older) coral heads were proportionally bored than smaller coral heads. Hutchings (1983) also concluded that coral ages determined the abundance of borers. The abundance of borers increased due to the longer exposure period in long term experimental coral blocks. Wilkinson (1983) suggested that the suitable substrate for boring sponge larvae must be deep enough to enable the sponge to penetrate. In addition, the shape of coral substrates themselves are also a factor influencing bioerosion by sponge. Wilkinson (1983) concluded that the basal parts of living, branching and plate-like coral colonies not covered by coral polyps are more susceptible to sponge boring than more massive or solids forms.

3.5 Zonation

It was found that the bioerosional damage of coral depended on the quantity of boring organisms. Bomley (1978) suggest that total borer impacts may be zonally distributed in means of abundance and species diversity of borers at each zone.

3.6 Grazing organisms

Both parrot fish and echinoids are the importance biodestructive agents on coral reefs. Although browsers and grazers are important predators of juvenile sponges. Moreover, Hatcher (1983) reviewed and discussed the effects of grazing on the evolution of benthic invertebrates in the tropics. The removal of live tissue of coral, including the underlying superficial skeleton, increase the space for succession of borers (Bak and Steward-Van Es, 1980).

4. Effects of bioerosion by boring organisms on coral reef

Boring organisms have a marked effect on the morphology and ecology of coral reefs. They played the role of carbonate sediment producer. These carbonate sediment can change the bottom character and some benthic community. Wilkinson (1983) reported that the effects of boring sponges are most obvious on reef slopes where large areas are available for sponges larval settlement. The effects of borers on coral community structure may thus be great by comparison with the small amount of carbonate which they excavated (Done, 1983). Most of massive corals themselves, which are bored into the basal regions of colonies by borers can topple or accelerate dislodgement by wave action and human activities. Therefore, Highsmith (1981) concluded that bioerosional damage to corals depended primarily on the amount of skeletal surfaces not covered by live coral tissue. Moreover, he also suggested most of massive corals having a potential escape in size from catatrophic bioerosion, and proposed the models relating coral growth forms to skeleton density and stability in currents, resistance of coral skeletons to breakage by water movement. In addition, Highsmith (1982) described that the boring organisms facilitated asexual reproduction (fragmentation) of coral. They usually caused weak points in the skeletons which increased the probability of breakage at those particular points. Thus, asexual reproduction could success by producing many small fragments. Tunicliffe (1979) reported that boring sponge is important in asexual reproduction of some branching corals. For example, as in <u>Acropora cervicornis</u> as the broken branches lodge in crevices and regenerate new colonies.

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