[ENV04] Ecology of scleractinian corals in the waters of port dickson and their tolerance to sedimentation

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Introduction

The term 'sediment' refers to material composed of particles that have settled to the bottom of a liquid. Resuspension of fine sediments, mainly clay and silt found in abundance on the shallow continental shelf, is responsible for the constant high turbidity and poor visibility of the coastal waters off Port Dickson.

Sedimentation is considered to be a serious threat to coral reefs because the effects are long lasting, prevalent and difficult to remove. Suspended sediments in turbulent waters have also been known to cause abrasion on corals (Loya, 1976). Other negative effects of suspended sediment on corals are increased energy demands because most of the corals' energy goes into sediment rejection (Dodge *et al.*, 1974), tissue death (Rogers, 1983), disruption of coral's energy budget through reduced light availability (Abdel-Salam and Porter, 1989), and reduction of the coral's capacity to capture food (Stafford-Smith and Ormond, 1992). Consequently, suspended and overlying sediment in coastal waters are harmful to the health and growth of coral reef communities.

This study examines the effects of suspended sediments on the coral growth rates of two commonly found scleractinian corals in Port Dickson, *Porites lutea* and *Favites abdita*, determines their tolerance to short-term burial and the extent of sedimentation as well as how it has affected the coral reef community of Port Dickson.

Materials and Methods

Sedimentation Rate Measurement

Sedimentation rates were measured monthly using sediment traps comprising of Beatson-Clark bottles. These traps were deployed at 4 stations and collected monthly by SCUBA divers. Station 1 was Batu 7 ((2˚ 27' 48.0 N, 101˚ 50' 38.8 E), Station 2 was Batu 8 (2˚ 26' 53.1 N, 101˚ 51' 12.1 E), Station 3 was Batu 9 (2˚ 25' 50.2 N, 101˚ 50' 11.5 E) and Station 4 was Blue Lagoon (2˚ 24' N, 101˚ 51.2' E). Each station has 3 sites of sediment traps. For all stations, Site A was a sediment trap placed on the reef flat, Site B was a trap placed on the reef crest and Site C was a trap placed on the reef slope.

Sediment samples were filtered to remove large particles and foreign objects. Sedimentation rates were calculated after sediment samples were oven-dried to a constant weight. Sedimentation rate (mg cm^{-2} $day^{-1)}$ was determined by dividing the dry weight (in milligrams) with the aperture width of the sediment trap (in centimetres) times the number of days the trap was placed underwater.

Particle Size Analysis

The pipette analysis (Holme and McIntyre, 1984) is an application of Stokes' Law and was used to determine particle size of sediment captured in traps.

Twenty grams of sediment samples was pre-treated using 30 % Hydrogen peroxide and calgon solution (50 g sodium hexametaphosphate dissolved in one liter of distilled water).

Sedimentation and pipette sampling was then carried out in graduated cylinder. The temperature of the mixture was measured with a mercury thermometer. Settling times of clay and silt fractions are related to temperature.

X-Ray Diffraction Analysis

XRD was used to determine the types of minerals in the sediment collected from traps and from samples taken from nearby land. Results from XRD may help indicate that the source of fine sediments collected in the traps were of terrigenous origin.

The following sediment samples were sent for XRD analysis: ten grams of the dried sediment samples from each of the four stations; sediment scraped off the top of a coral head that had sediment accumulated on it; substratum from the Si Rusa River and a hill slope near the rocky shore of Batu 7.

Coral Survey Methods

Combined coral reef survey methods Line Intercept Transect (LIT) (English *et al.*, 1994) and stratified random sampling method (Hoisaeter and Matthiesen, 1979) yielded field data on the coral reef distribution and abundance of Port Dickson and Tanjung Tuan. LIT was used to provide a rapid assessment of the coral cover and other bentic lifeforms. The stratified random sampling method provided data on coral density and distribution of coral genus on the reef flat. Ambient environmental data such as salinity, temperature and visibility were also recorded using YSI Model of the Salinity-Conductivity-Temperature meter.

Suspended Sediment Experiment and Burial Experiment

Twelve specimens each for *Porites lutea* and *Favites abdita* from the reef flat of Tanjung Tuan were selected and pried off the substrate using a chisel and small hammer. They were carefully transported back to the laboratory aquaria and sustained by a flow-through seawater system. Corals were allowed to acclimatize for 33 days.

Methods for the Suspended sediment experiments (SSE) were adapted from Rice and Hunter (1992) with two treatments consisting of 11680 mg per L of 500µm sand (SSE 1) and 20290 mg per L of 500µm sand (SSE 2) were conducted on the experimental corals. Coral growth rates were measured using the buoyant weighing technique (Jokiel *et al.*, 1978) during acclimation period, before and after experiments.

After a recovery period of 16 days, the experimental corals of SSE were designated as controls and the control specimens in SSE were subjected to 4-day and 9-day burial experiments.

Calculation and Statistical Analysis

Sedimentation rates, percentage silt, clay and sand as well as coral growth rate were given as mean ± standard deviation. Sedimentation rates were analysed using Kruskal-Wallis One-Way ANOVA and Median Test, while coral growth rates were analysed using the F-Test.

Results

Sedimentation Rates in the Coastal Waters of Port Dickson

Initially, each station had 3 sites but some of the sediment traps were lost. A total of 27 sediment traps remained. Station 4 and Station 3 had 3 sites. For Station 2, sediment trap at its Site B was lost. Station 1 has only a sediment trap at its Site C.

Overall mean sedimentation rate for Station 4 for all the months at Site A was 76.47 ± 28.04 mg cm^{-2} day^{-1}, at Site B was 68.68 ± 34.38 mg cm^{-2} day^{-1} and at Site C was 189.54 ± 64.38 mg $cm^{-2}day^{-1}$.

Sedimentation rates for Station 3 were consistently high throughout the monitoring period. Site A has the highest sedimentation rates based on the overall mean sedimentation rates for all the months at 253.7 ± 131.63 mg cm^{-2} day^{-1}, for Site B was 220.76 ± 56.6 mg cm^{-2} day^{-1} and Site C was 246.61 ± 58.86 mg cm^{-2} day^{-1}.

The overall mean sedimentation rates for the Site A of Station 2 was 105.14 ± 41.36 mg cm^{-2} day^{-1} and at the reef slope was 133.79 ± 58.64 mg cm^{-2} day^{-1}. The Site C of Station 1 has a mean sedimentation rate that was comparable to Site A of Station 4 at 75.6 ± 49.82 mg cm^{-2} day^{-1}.

Particle Size Analysis

The percentage of the silt, clay and sand as well as organic matter in the sediments collected in the traps changed from month to month. The percentage of clay in the sediment samples ranged between 18.72 ± 4.45 % and 33.81 ± 7.19 %; the percentage of silt between 12.28 ± 9.95 % and 41.17 ± 4.46 %; percentage of sand between 29.1 ± 5.31 % and 46.83 ± 8.94 % and organic matter between 1.81 ± 1.64 % and 19.14 ± 16.03 %.

X-Ray Diffraction Analysis

The sediment samples from the traps at Station 1 and 2 contained quartz, kaolinite, muscovite and halite. Sediment samples from the traps of Station 3 were slightly different than Station 1 and Station 2 in not having muscovite. Station 4 sediment samples and sediment scrapped from the top of a coral have exactly the same mineral composition because they were taken from the same area. They differ from Station 1, 2 and 3 in not having muscovite and have instead illite and calcite in them.

Terrestrial soil does not contain quartz but has instead kaolinite, muscovite, illite and goethite. The river sediment has quartz, kaolinite, illite and calcite, almost similar in composition to sediment samples from Station 4.

Coral Reef Survey

The genus *Porites* is the most dominant coral on the reef flat of Station 4 with a percentage cover of 42.57 %. *Goniastrea* spp. is the second most dominant with a percentage cover of 20.87 %, followed by various species of *Favites* spp. with a cover of 9.81 % and *Favia* spp. with a cover of 7.84 % (Figure 1).

A prominent feature on the reef flat was fine sediment covering the surfaces of coral colonies, with a mean percentage cover of 27.01 %. Macro-algae have the second highest mean percentage cover at 22.97 %. In terms of percent cover of coral life forms, sub-massive corals were the highest at 11.2 % when compared to massive corals at 4.97 %. Foliose and encrusting corals were not common on the reef flat.

The amount of rocky substrate not grown by any benthic organism was 7.71 % while the mean percentage of dead coral covered with algae was quite significant at 8.05 %. The reef flat was found to be a suitable habitat for various species of algae and the mean percentage was as high as 12.4 %.

Other organisms such as sea cucumbers, zooanthids, sea anemones and sponges were minimal with a mean percentage of 1.06 %. Soft corals constitute a minor percentage on the reef flat at 0.18 %.

Overall, mean live coral cover on Blue Lagoon was found to be only 16.8 % while mean dead coral cover was estimated to be 20.25 %. The mean percentage of surface covered with silt was 35.6 % and for macro-algae the mean percentage cover was 27.3 %

The reef flat of Station 3 has a live coral cover of 14.2 % and dead coral cover as high as 10 %. Like the other reef flats along PD's rocky headlands, the macroalgae cover was significantly high at 55 %. Corals that are massive and sub-massive are more dominant life forms when compared to foliose and encrusting corals. Massive and sub-massive corals have a cover of 4.5 % and 7.8 % respectively while encrusting and foliose corals were only 1 % and 0.9 % respectively.

The reef flat of Station 2 was much degraded as it only recorded live coral at 4.8 %. Macro-algae dominate the reef flat at 54.8 %, indicating the presence of suitable substrate in the form of dead corals as only 2.1% of dead coral were recorded. No other life forms of corals were recorded at this particular transect except for massive coral with a cover of 4.8 %.

Live coral cover was slightly higher for Station 1 at 16 % when compared to the transect data of Station 2. However, dense growth of macro-algae on the reef flat of Station 1 made macro-algae cover at a very high 62.2 %. Abiotic component was also quite significant at 19 %. Other fauna only recorded 2.8 %. Variety of coral life forms was better represented at this transect with massive corals at 7.6 %, sub-massive at 4.6 %, foliose at 2 %, encrusting at 1.8 %.

Suspended Sediment Experiment and Burial Experiment

In SSE 1, *Porites lutea* experimental specimens seem to be unaffected by the concentration of suspended sediment. Mean growth rates were higher than control specimens, 4.454 ± 1.386 mg per gram body weight per 10 days and 1.668 ± 1.091 mg per gram body weight per 10 days respectively.

For *Favites abdita,* the experimental specimens had a mean growth rate of 2.397 ± 1.443 mg per gram body weight per 10 days, while the controls had a slightly higher mean growth rate at 2.563 ± 1.444 mg per gram body weight per 10 days.

Overall, SSE 1 did not affect the growth rates of experimental corals. In fact, the experimental specimens have a higher mean growth rate than the controls, 3.425 ± 1.694 mg per gram body weight per 10 days against 2.116 ± 1.245 mg per gram body weight per 10 days.

For SSE 2, *Porites lutea* experimental specimens showed relatively high mean growth rates except for the third specimen ePC. This particular specimen showed drastic negative growth rate, -21.9 mg per gram body weight per 10 days while the others displayed relatively high growth rates at 4.44 mg per gram body weight per 10

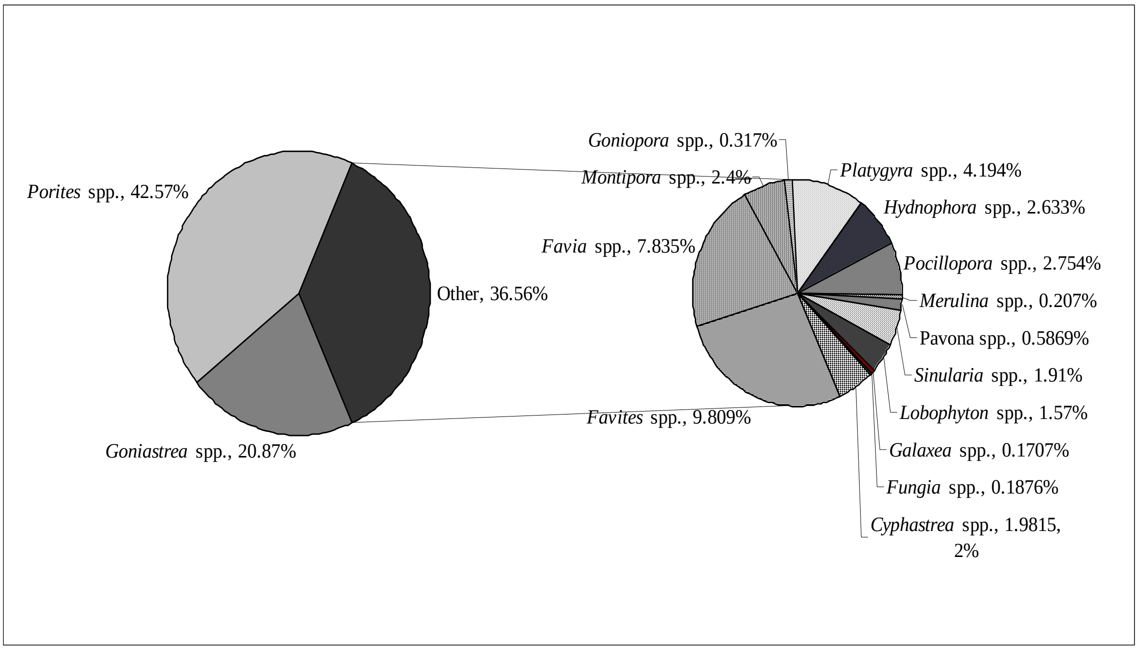

FIGURE 1 Percentage of scleractinian and soft corals encountered using the stratified random sampling method on the reef flat of Blue Lagoon, Tanjung Tuan (2˚ 24.4'N, 101˚ 1.2'E).

days. The control specimens have growth rates ranging from 1.31 mg per gram body weight per 10 days to 6.06 mg per gram body weight per 10 days.

For *Favites abdita,* experimental specimens in SSE 2 have started to show signs of being affected by the concentration of suspended sediment. The experimental group has slightly lower mean growth rates than the controls, 1.053 ± 0.6919 mg per gram body weight per 10 days as compared to 1.394 ± 3.617 mg per gram body weight per 10 days.

Overall for SSE2, the control group has higher mean growth rates than the experimental group with a mean growth rate of 2.19 ± 2.97 mg per gram body weight per 10 days as compared to -1.64 ± 10.1 mg per gram body weight per 10 days.

The sediment load in SSE 2 was stressful to the both coral species. Experimental specimens of *Porites lutea* were slightly bleached.

Overall results for both treatment SSE 1 and SSE 2 and for both species show that the control specimens have higher mean growth rates. There was significant difference in the mean growth rates between the control and experimental group. Suspended sediment stress could be a factor in reducing growth rates in *Porites lutea* and *Favites abdita*.

Fluctuation in temperature, salinity and pH was minimal and under-control throughout the acclimatization and experiment period. The mean temperature of the seawater in the aquaria was 28.67 ˚C ± 1.63 ˚C while PD's coastal water averaged at 29.5 ˚C ± 0.4 ˚C. The salinity the seawater in the aquaria was 29.95 ± 1.48 ppt as opposed to 30.1 ppt ± 0.9 ppt in PD. pH of the seawater in the aquaria was 8.37 ± 0.195.

At the end of SSEs, specimens were observed to be in good condition, with little change in the colour of the colonies.

In the burial experiments, all of the *Porites lutea* specimens were observed to have died during 4 days of burial. Most parts of the coral were blackened and decomposing and algae have started growing on them.

Favites abdita specimens demonstrated the ability to withstand short-term burial. The specimens were able to remove some of the sands from their surface through active sediment rejection, namely hydrostatic inflation of polyps and tentacle activity. These parts of the corals survived burial whereas none of the *Porites lutea* specimens could do so. The surviving part of the *Favites abdita* specimens showed severe signs of stress such as distended polyps, extended tentacles and extruded mesentrial filaments as well decolouration.

However, by the 4th day of burial, *Favites abdita* specimens have also observed to be dead especially the parts of the colony that could not remove sediment from their surface. As expected for the 9-day burial experiment, all 6 corals of both species showed 100 % mortality.

Discussion

Sedimentation rates of Tanjung Tuan that were recorded 24 years ago (Liew and Hoare, 1979) ranged from 0.95 to 54.3 mg cm^{-2} day^{-1}, increased drastically in comparison with current data that ranged from 27.31 ± 3.2 to 233.59 ± 52.04 mg cm^{-2} day^{-1}. This considerable increase in the amount of sediment in the coastal waters over the years may be attributed to various anthropogenic activities such as road-building and infrastructure development as well as dredging and shipping activities.

Up to 90 % of the coral colonies sampled in the quadrats showed partial colony mortality. The top parts of many colonies were dead while the sides of the colony are still alive. Similar conditions were observed on reef flats along Station 1, 2 and 3.

Based on the ASEAN-Australia Living Coastal Resources project where live coral cover >75 % = excellent, 75-50 % = good, 50-25 % = fair and <25 % = poor (Chou *et al*., 1994), the coral reefs of Port Dickson and Tanjung Tuan are considered to be in poor condition.

Growth form plays a role in survival in turbid environment. Short branching and sub-massive corals in certain species of *Montipora* and *Favites*, with a per cent cover of 2.4 % and 9.8 % respectively, have been seen thriving in certain parts of the reef flat and back reef of Station 4. The surfaces of these corals are relatively free of sediment and macro-algae suggesting that these types of growth forms are an advantage in turbid environment. It seemed that coral colonies not larger than 0.5 m in diameter endure sediment stress better than the micro-atolls. Small coral heads of *Favia*, *Favites* and *Platygyra* are generally less affected by sedimentation and macro-algae. This observation is true also for the reef flats of Station 1, 2 and 3. The hemispherical shape of these coral heads discourage accumulation of mud on their surface by allowing water movement to wash it away in addition to the coral polyps' active sediment rejection.

Porites spp. was found to be the the most dominant genera of scleractinian corals on the reef flats of Station 4. Experimental data show that *Porites lutea* specimens in SSE 1 were able to endure suspended sediment with little decrease in their growth rate. Metabolically, *Porites* depends more on zooxanthellae for its nutritional needs than corals with larger polyps (Sorokin, 1993). Therefore, as long as the coral gets sufficient light, it could survive in turbid environments. Based on sedimentation rates data on the reef flat of Station 4 the percentage of available light for photosynthesis was still not affected because the sedimentation rates seldom exceed 100 mg cm^{-2} day^{-1}. According to Riegl and Branch (1995), 100 mg cm^{-2} on a flat surface caused a 75 % reduction in available light.

In SSE 1, the experimental groups showed higher mean growth rates than the controls but this difference was not highly significant. This may indicate that at this concentration of suspended sediment, the corals may still be able to grow normally and not be affected physiologically although the experimental sediment load is almost 9 times higher than the quantity recorded in the waters of Port Dickson that was estimated to be 1254 mg L^{-1}.

Corals' ability to reject sediment has been positively correlated with calice size. The mean calice diameter of *Porites lutea* is 1 mm while for *Favites abdita* it is 10 mm. *Favites abdita* specimens have been shown to have better sediment rejection abilities than *Porites lutea* during burial experiments. Additionally, sediment size and density also play a role in how a colony as a whole rejects sediment from its surface. *Favites abdita* have been known to cope well in areas of high sedimentation because of its inherent ability to manipulate silt, fine and coarse sand actively while *Porites lutea* is more apt at removing silt from its surface (Stafford-Smith and Ormond, 1992). Because larger sediments (fine sand) were used in the experiments, the smaller polyps of *Porites lutea* were unable to actively remove sediment from their surface during burial and SSE.

In SSE 2 the experimental specimens of both species have a significantly lower mean growth rates than the control group. Growth rates were shown to be drastically reduced in *Porites lutea* and the overall value for both species reveals a significant decrease. When analyzed collectively, the concentration of suspended sediment in SSE 2 has a significant effect on the growth rates of *Porites lutea* and *Favites abdita*.

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