Graduate School of Frontier Sciences, The University of Tokyo

Department of Socio-cultural Environmental Studies

2012-2013

Master's Thesis

Effect of Light and Water flow on growth of the hard Coral *Acropora formosa*

Submitted: August, 2013

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER'S OF SCIENCE IN ENVIRONMENTAL STUDIES

Department of Socio-cultural Environmental Studies,
Graduate School of Frontier Sciences
The University of Tokyo

13 September, 2013

ABSTRACT

Experiments were designed to observe the growth of Hermatypic branchial hard coral *Acropora formosa,* under different predefined water flow and lighting conditions in the laboratory. The sample is placed in the 36 cm long, 28 cm wide and 18 cm high tank. Different light intensity in terms of PAR is used. Light enhances coral calcification appeared to be highest in PAR 789.15 µmol/m^2/S (growth 29.23 µmol/kg/hr). Beyond this PAR growth of the hard coral reduced, though PAR increased (PAR 1098.26 &1450 µmol/m^2/S gives growth 25.40 & 18.92 µmol/kg/hr). High constant flow gives better growth than low and medium constant flow. Continuous stop and start oscillatory flow yields higher growth rate than constant flow. Tank covered with plastic paper along with stop and start oscillatory flow exhibits higher growth rate. Third period of plastic covered oscillatory flow gives highest growth of 12.96 µmol/m^2/s where same oscillatory flow without plastic cover gives 10.69 µmol/m^2/s growth rate. Actinic, Blue and White colored light was used to observe the growth of coral. Blue light performs maximum growth with minimum PAR (Only 2.71 µmol/m^2/s gives maximum growth of 6.00 µmol/kg/hr). As blue light can penetrate more depth than other color of the spectrum, it helps coral to grow where other lights can not reach. Again, only single light with high PAR does not give better growth.

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ACKNOWLEDGEMENT

Studying Japan is really a nice experience. At first I would like to express my deepest gratitude to Almighty Allah. This two years study, which was full of exciting new experiences, far away from my beloved country, Bangladesh. I have succeeded to accomplish my Masters thesis in the University of Tokyo, Japan. Here, I would like to take the opportunity to express my sincere appreciation and deep gratitude to those who assisted me in my work and supported me a lot in one way or another during this particular period.

I would like to express my deep sense of gratitude, sincerest indebtedness and profound respect to my supervisor Dr. Yukio Koibuchi, Associate Professor, Department of Socio-cultural Environmental Studies, Graduate School of Frontier Science, The University of Tokyo for his kind supervision, excellent guidance, continuous encouragement and valuable advice and suggestion during all stages of my study. He was always very helpful for discussion about research and I sincerely acknowledge his contributions for providing me with new research thinking and suggestions.

Special thanks are extended to former Professor of our lab Masahiko Isobe, Department of Socio-cultural Environmental Studies, The University of Tokyo, for his continuous guidance and instructions during this study and also for his comments and suggestions during lab-seminars. I would like to extend my thanks to our new professor Jun Sasaki, Department of Socio-cultural Environmental Studies, Graduate School of Frontier Science, The University of Tokyo, for his advice in every aspect especially about technical writing.

I express my gratitude to Dr. H. Satoh and Dr. Masahiro Fukuda, Associate Professor, Department of Socio-cultural Environmental Studies, Graduate School of Frontier Science, The University of Tokyo for his valuable comments and suggestions as my co-supervisor.

Special thanks to Mr. Hiroto Higa, Doctoral student and Mr. O, Haechong, post doctoral fellow for their continuous supports for my research. I would like to thank Mr. Hideki Furuya, who was assigned as my tutor, and he provided me assistance after my arrival in Japan. I am ever grateful to him for his continued support.

My heartfelt thanks go to all of my contemporary lab mates and former students. I again acknowledge my lab-mates Mrs. Soulichan, Mrs Des, Mr. Masud, Mr Zhu, Mr. Toufiq, Mr. Youshimu and Mr. Sano for their assistance related to language matters in my research and oral communications with others. I would be very unkind if I don’t mention Mrs. Muruzono who was always with me in every step of my new life in Japan. She arranged special occasions during leisure time with her hand made dishes. I am also thankful to my wife Sanjeda for her continuous support.

Finally, I would like to express my sincere gratitude to the University of Tokyo and Asian Development Bank for providing such a great opportunity to pursue my masters program here.

Md. Aktar Hossain
Thank you
September 13, 2013

CHAPTER 1: INTRODUCTION

1.1 General

Coral reefs are found in the tropical water area of the world. Formation of coral reef require several hundred years. Because the formation process is very slow. Formation of $CaCO_3$ rate varies from 40 mol $CaCO_3/m^2/yr$ to 8 mol $CaCO_3/m^2/yr$ (Smith 1978). Of the world coral reefs about 90-95% formation rate is slow, rest of the reefs are fast (40 mol $CaCO_3/m^2/yr$). The formation of coral reefs takes long time. But the destruction of the coral reef may occur within a very short period of time (Eakin et al., 1997). Coral reef is very important for the marine environment as different kind of flora and fauna is available in the habitat. Because of its biodiversity, coral reefs have become the habitat of different kind of fish also. The species finds this area safe to escape from the pray. It is also thought that coral reef area is the most productive ecosystem under water.

In the vast ocean coral reef are available only in the temperature restricted areas. Some country can use the coral reef for many of their needs. Coral reef plays important role to attract tourists. Many people all over the world visits the country that posses coral reefs. This activity has positive effect to the economy of that country. Moreover, fisheries resources achieved from coral reef area also take a major part for the support of nutrition to inhabitants of that country. An estimation found that 9-12% of the total fisheries production of the world is supplied from the coral reefs (smith 1978). This fisheries resource also brings foreign currency if it is exported to other country. Coral reef supplied the livelihood to the people living near the reef area. Many seaweed species are available in coral reef area and it is used to produce agar. Some of the species is used to make medicinal product. But till lots of services are yet to explore from the reef area, that we could not reveal (Moberg and Folke, 1999). As a result coral reef areas become a part of culture of the people living near the reef. Many of their festival, tradition are based on coral. Sometimes the dress and ornaments also shows that the people are living coral reef area. About one hundred countries have coral reef and very few country can take benefit from it. If the coral reef is maintained well and the coral is not disturbed by human activity, it can protect the country shoreline from different natural calamity. Hurricane and other natural disaster are primarily consumed by the coral reefs.

It is estimated that about 500 million people live in this vicinity of coral reef. But in the mean time 19% of coral reefs of the world is lost and 35% of coral reef is in vulnerable condition (Wilkinson, 2008). So, reef building corals are in great risk. The species *Acropora formosa* is one of the hard corals. It is a branchial coral and present research is on this coral species. To protect the coral reef and its species, proper research and its implementation is necessary.

1.2 World Coral Distribution

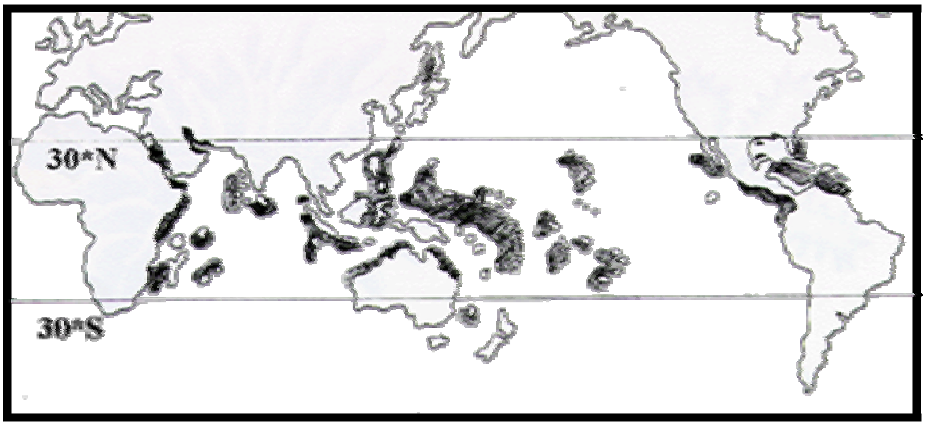


Fig. 1.1 World coral reef distribution.
(Source: http://www.seaworld.org/infobooks/coral/habdiscr.html)

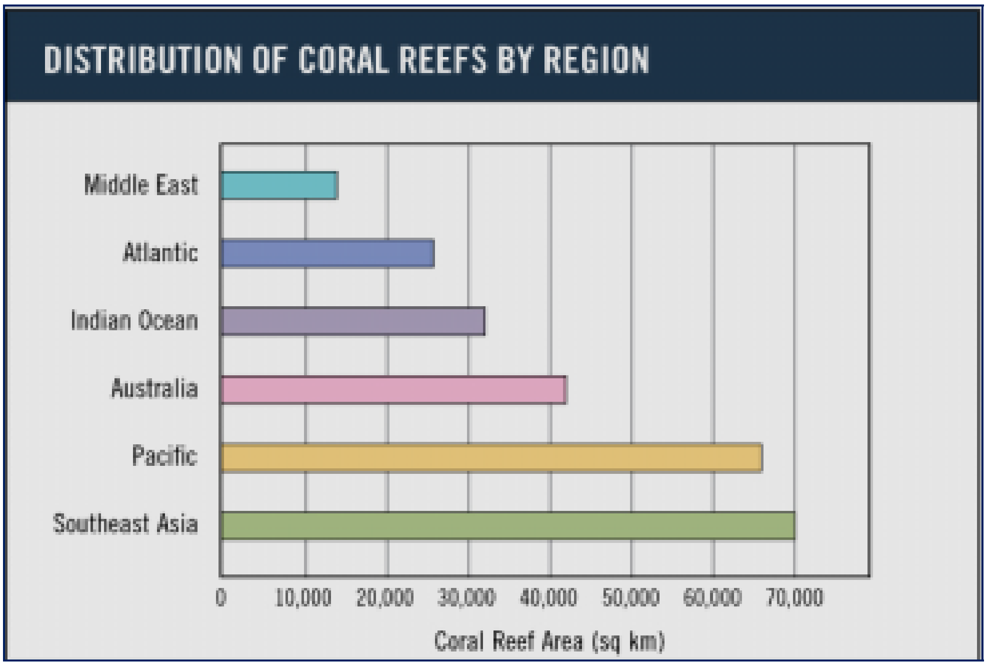


Fig.1.2 Area of coral reefs (sq km) for each coral reef region of the world. (Source: IRD, NASA, UNEP-WCMC, World Fish Center WRI 2011)

Wilkinson, (2008) revealed that most of the coral reef are available in the Middle East, Asia (Indian Ocean, South East Asia, North East Asia), Pacific and Australia, West Caribbean countries. Generally the coral can live and grow within 20-30^{0}C temperature. Corals are dependent on photosynthesis, so the growth is permitted to the depth where light penetrates. Generally the depth where the coral grows is less than 50 meters.

1.3 Coral Biology

There are some corals that do not have any symbiotic relation with algae. But that coral species are not reef building corals. Reef building corals have symbiotic relationship with algae, zooxanthellae. We know that in symbiotic relationship both coral and algae are benefitted. The algae supply photosynthetic product glucose, amino acid, glycerol to the animal host. It also supplies oxygen and removes waste products. Coral uses these products for their requirement to produce fat, protein, carbohydrate, calcium carbonate etc (Lalli and Parsons, 1995). Corals have arms named tentacles that are used to collect food. It secrets outer skeleton of calcium carbonate that is hard (figure 1.3). Gradually when the coral polyps grow and die then the dead coral creates the reef. Among different species there are varieties of colored fish available in the coral reef ecology. This is to attract the pray or to escape. Some species uses there color as camouflage to attract the pray. Different colored coral and colorful fauna makes the coral reef area attractive in the marine environment. Human being also gets attraction to pass leisure time in this place to enjoy the natural beauty by diving.

1.4 Coral Ecology

The coral reef environment is very productive and posses best biodiversity among all other ecosystems (Moberg and Folke, 1999). Huge variety of organisms, about 4000 fish species, different variety of plant and animal etc are available. Coral reef area is very clean and safe from turbidity. So, sunlight can penetrate about 50 meters of water. And there is regular refreshment of sea water due to wave and current. The phytoplankton or zooplankton is grasped by the coral polyp. This safe environment attracts different species of fishes to this environment. This coral reef ecology gives them favorable environment to live and grow, help them to avoid being eaten. Coral reef helps the organism to hide from other animals. Here, in the niche, each and every flora and fauna have its individual role to play. Different kinds of ecological goods and services are provided to human from the coral reef. Sustainable use of coral reef can provide different economical activity.

Coral reef is experiencing different kinds of threats at present time. Broadly the threats can be categorized into two, man made and natural. Of this two, man made threats are playing big role for the destruction of coral reef all over the world. Environmental pollution all over the world is causing direct and indirect effect to coral reef. All polluted material ultimately reaches to the sea, thus gradually affects the ecology of the coral reef. Other manmade cause includes sediment loading, coastal habitat modification, overfishing, grenade fishing, coastal structure etc. Presently many development works are done by many countries and it results the sedimentation. Different coastal structures are built and it destroys the coastal habitat and ultimately affects the nearby coral reef area. Human action on coastal zone, can create unlimited ecological consequences. Human effort like air base runway construction, harbor, land reclamation, shoreline protection activity, dredging and other destroying activity have serious effect on coral reef habitat. Thus ultimately reduces the area of coral reef area in the world. For excess demand of protein, fishermen are catching fish from different coral reefs. But the fishing is turning to overfishing and it breaks the ecological balance of the area. Again some fishermen are using some sort of destructing fishing gear like poison, grenade etc that is making harm to the coral reef area. Grenade blast fishing destroys the habitat. During fishing by catch (other than target species) is removed in the reef area, thus it pollutes the environment.

Of the natural causes, flood, tsunami, under sea volcanic eruption, El Nino is also threat for coral reef. When flood occurs in the land part, it washes away all the waste product, sediment etc. which is very harmful for the coral. Sedimentation hinders coral growth and even it covers the coral colony. Thus it causes the death of coral. Volcanic eruption suddenly changes the temperature of the water. It bleaches the coral. Other natural calamity like tidal surges tsunami, causes a drastic change of the coral reef. Sometimes strong wave action can break the branches of coral.

1.5 About the species *Acropora formosa* (Dana 1846)

The species *Acropora* is a genus of small polyp stony coral in the Phylum Cnidaria. Some of its species are known as table coral, elkhorn coral and staghorn coral. Over 149 species are described in this genus. Its classification is Kingdom: Animalia, Phylum: Cnidaria, Class: Anthozoa, Order: Scleractinia, Family: Acroporidae, Genus: *Acropora*, Species: *formosa*. The species *Acropora formosa* is one of the major reef corals responsible for building huge calcium carbonate substructure that supports the reef. *Acropora formosa* is most common in shallow reef environments with bright light and moderate to high water motion. Color of the species is usually dark grey or brown, with pale pink, purple or blue growing tips. Habitat of the species maybe dominant in lagoons and sheltered reefs with water movement. This species is found in different areas of the world. Such as the Red Sea and the Gulf of Aden, the south-west and north-west Indian Ocean, the Arabian Gulf, the northern Indian Ocean, the central Indo-Pacific, Australia, Southeast Asia, Japan and the East China Sea, the oceanic west Pacific, and the central Pacific. This species is susceptible to bleaching and disease. The species is collected for the aquarium trade. So the species is treated as near threatened. As the species is predicted threatened due to climate change and acidification, it is obvious to have vast research of the species within ten years or sooner. (Source: Wikipedia)

1.6 Background of the research

The importance of coral reef to the human civilization can not be denied. People's livelihood, food, recreation, biodiversity etc is contributed by the coral reefs. Tourism accelerates the economy of that country that posses coral reef area. Different kind of activity evolved by coral reef creates different source of income to the inhabitants of the vicinity. Sustainable fisheries can meet the demand of protein in the coral reef area. Coral reefs act as a natural barrier against erosion, wave action, tsunami and storm etc. In this context coral reef are facing serious manmade and natural threads. In the rate the coral reef is destroying recently, is a great concern world wide. In this critical situation, concentration is required to find the best condition for coral growth. At the same time knowledge gap is necessary to cover up. Effect of different abiotic factor on coral growth is time demanding research need.

Movement of water is extremely important for any aquatic environment. Even in closed water system like lake or pond wind driven water flow exists for the ecology of that particular environment. In open river or sea water flow is a part of the ecology of the environment. We can not think any marine environment with out water flow. So, all the plant and animal is habituated with this flowing condition of water. Eventually, with out water flow marine life can not be imagined. In case of coral growth also, water flow is important abiotic factor. Growth and metabolism of symbiotic zooxanthellate is affected by water flow. Coral biology is affected from different aspects by water flow, as the physiology of coral is more or less complex. Previous research on the effect of water flow was done only using low or high flow. But specific flow speed was not used earlier. In this research different water flow rate are considered to find out the best flow speed for the growth of coral. In controlled condition the flow regime is applied to find the best condition.

Solar system is treated as the main source of energy in the universe. Primary, secondary and tertiary production of food is supported by the solar energy. For coral growth especially for hard coral light or irradiance is extremely important. But we still don't know the details of coral growth regarding light intensity. Even we don't know the effect of spectra on coral growth. This aspect of coral growth is necessary to reveal. Extensive research is the only solution to get the knowledge. We have enough knowledge gap to understand coral reefs characteristics, how coral grows in different pattern of current and lighting condition. Only up to date research can fulfill this of our knowledge gap. Now we have to focus on basic research in this aspect.

1.7 Purpose of the study

About one fifth of coral reefs are threatened all over the world and will be lost within 20 to 40 years (Wilkinson 2008). Some coral reefs in the mean time are permanently died and some are in threat. Now we have to consider the practical situation of the world environment. Due to industrialization and different development works, we are producing some threats to the environment. But we can not deny the reality. We need to accept what happened and what can be done in future to protect the coral reefs of the world.

Hence, the present study is aimed to understand the condition that gives best growth of reef building corals. To achieve the goal, a series of intensive laboratory experiments were performed. The findings from the study would better serve scientists, decision makers and managers in their attempts to address the best possible environmental condition for coral growth and for its better management. The main objectives of the study are as follows:

• To describe the best light intensity for coral (*Acropora formosa*) growth.
• To provide a detailed description of coral growth by the influence of current in different pattern and speed.

CHAPTER 2: LITERATURE REVIEW

This chapter summarizes the literature review on effect of light on coral growth, effect of water flow on coral growth and different changed environmental condition for coral growth.

2.1 Effect of light on coral growth

Light plays an important role on growth and physiology of coral as because of the symbiotic relationship with Zooxanthellae, the algae. Zooxanthellae grow on the surface of the host coral and in return it produces food for the host. Being a phototrophic algae, zooxanthellae performs photosynthesis while exposed to light, hence release oxygen and produces organic compounds. This photosynthesis by products is primarily utilized by the zooxanthellae to satisfy their own respiratory needs. Later, the excess photosynthetic products are being translocated to the coral host (Muscatine et al., 1981). Similarly, zooxanthellae provide a substantial proportion elements needed for soft tissue growth of coral but also for skeletal growth. Coral skeletal growth is commonly referred to as light enhanced calcification. Generally, calcification has been reported as 3-4 times faster under light as compared to dark condition (Gattuso et at., 1999).

Many research were executed to find and explain the complex interaction and the link between the coral and symbiotic algae (Gattuso et al., 1999). Some other study also tried to explain the role of some other factors that stimulate the skeletal growth (coral growth) apart from the zooxanthellae algae’s role. Among the abiotic factors that influence the skeletal growth of scleractinian corals, light has been rated as one of the most important factor (Schutter et at., 2012). Moreover, Schutter et al.,(2012) explained, “The growth of coral is stimulation with the mediation of the photosynthesis zooxanthellae algae”. However, the available quantity of light for diurnal coral growth can be determined by both in terms of light intensity (i.e. irradiance) and photoperiodity (i.e. length of day light). On the other hand, the importance of light in coral growth as reported the elevated rate of total photosynthetic energy fixation by corals during sunny days as compared to the cloudy days (Davies 1991). Photosynthetic energy fixation in sunny days exceeded the respiration requirement, while, in cloudy days, energy expenditure exceeded photosynthetic energy fixation.

2.2 Effect of water flow on coral growth

Water flow has effect on the physiology of coral. It helps the acceleration of coral growth (Patterson et al., 1991). Corals can use dissolved nutrient. So flowing condition is better for coral growth. Based on available literature, the effects of water flow on coral growth can be grouped broadly as (i) effects on symbiotic relationship (ii) effects on individual growth and development and (iii) effects on the structure of coral community (Sebens et al., 2003).

Effects of water flow on symbiotic relationship

Patterson et al., 1991 stated "the importance of water flow on the photosynthesis of the symbiotic algae". Again water flow aids respiration of coral. Based on these literatures (Patterson 1991; Lesser et al., 1994; Atkinson et al., 1994), water flow enhances the rates of photosynthesis by the Zooxanthellae algae and the subsequent rates of respiration by the coral. Similarly, few articles documented the effects of water flow on photosynthesis as relieving diffusion limitation for dissolved gasses (Patterson et al., 1991; Atkinson et al., 1994; Lesser et al., 1994).

Effects on individual growth and development

Literature suggests that coral growth is usually more rapid in environments with higher water motion. Water flow influences the rates of food particle ingestion (Helmuth and Sebens, 1993) and carbon uptake by the coral (Lesser et al., 1994). Moreover, dense skeletons of corals (useful to withstand against physical damage) was observed in corals that cultured under elevated hydrodynamic stress (high flow regimes) condition (Smith et al., 2007). Schutter et al., (2010) also suggests that coral growth and skeletal quality is increased by the water flow.

Effects on the structure of coral community

The effects of water flow on structuring the coral community in different reef zones are not clearly understood by the available literature (Sebens and Johnson 1991; Helmuth and Sebens 1993). Adey (1983) claimed that adequate water motion is essential to long term maintenance of corals in aquaria.

CHAPTER 3: MATERIAL AND METHOD

This chapter outlines the methodologies used in this study. The first section of this chapter provides the general description (i.e., experimental set-up and laboratory condition) while the second part discussed about the process of measurement and the calculations used in conducting the experiment.

3.1 General description

In order to evaluate the effects of light and current on coral and to know the optimum condition for coral growth, series of experiments were undertaken in the laboratory. As it is difficult to control some ocean's physical parameters such as water flow and light intensity (PAR) in the natural condition, experiment in the laboratory condition was conducted. The most obvious condition of salinity, light, water flow, solar effect etc were created artificially in the laboratory for coral growth. All the experiments were done in the Water Environment Science Technology Laboratory. Primarily the samples were acclimatized in the laboratory tank. In the experiment, effects of varying light intensity, water velocity were determined. Figure 3.1 shows the experimental design of the study. Since corals are very sophisticated and dies with slight change of the favorable environment, utmost care was taken during the experiment. Water temperature, salinity, pH, water flow etc are the important factors for coral growth. So during and after the experiment all the parameters are examined. Action was taken if the change of the parameters were found.

Generally when the experiment started, it continued for some days. It was done to get the most accurate result. Generally the coral have a steady state of growth. If a long interval is taken for the observation or research, then the pattern of growth of coral may change. Again, the environmental condition may have some effect on coral. So, care was taken to select the timing of research. One experiment was done in a specific time period. Most commonly, the experiment was done in the mid day for the coral when the growth of coral comes to steady state.

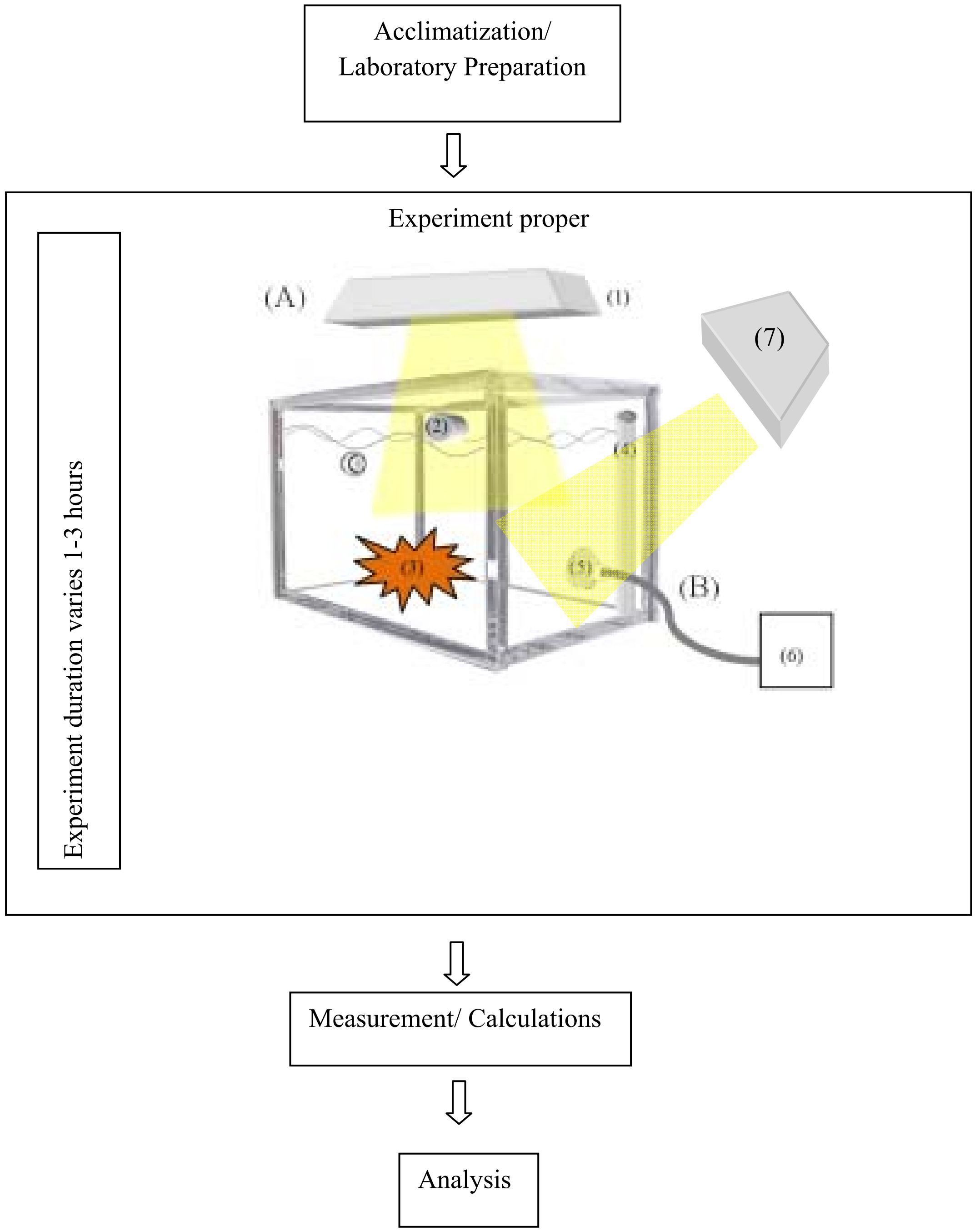


Fig. 3.1 Flow chart showing the total system of the experiment. (A) Light experiment (B) Water Flow Experiment. (1) Light Bulb/set-up. (2) Inflow of water (3) Coral (4) Outflow (5) Water Pump (6) Control Box of the Pump (7) Side Light

3.2 Aquaria set up and maintenance

Before coral colony was put in the tank, the tank was prepared for the coral. Then tank water was same as sea water with salinity 33-35 PPT, water temperature 25^0C. The tank water was circulated by a central pump and purified in sand stone bio-filter. The tank was lightened by a top and side light of MD-3100A HAGS Company and converter (GSYU ASA GW 0103A) (Figure 3.2 c, d). Day and night condition was controlled by an auto switch. Automatically the light was turned on at 05.00 AM and turned off at 01.00 PM. This particular time was day time and remaining hour was night time for the corals. The tank was renewed with new sea water every week. At that time some part of the water was removed from the tank and fresh sea water was added. The tank was cleaned intensively every week. Care was taken during the maintenance so that the corals are not damaged.

Monitoring:

During the experiment the tank was closely monitored. Every time the tank salinity, temperature were checked. Sea water was exchanged after a regular interval (generally one week). In this connection natural salt (Instant Ocean, Tyler Blud, Mentor, Ohio, 44060, USA) was added to distilled water. Clean pump was used to pump the water to the bucket. After preparing the sea water salinity, conductivity and temperature is checked.

a. **Salinity**

   The tank water naturally evaporated regularly. Every day the salinity was checked by the salinity meter (Figure 3.2 a). In case of any deviation of expected salinity, action was taken promptly. In case of increased salinity, little distilled water was added to bring it in accepted level. Naturally salinity seldom deviated.

b. **Temperature**

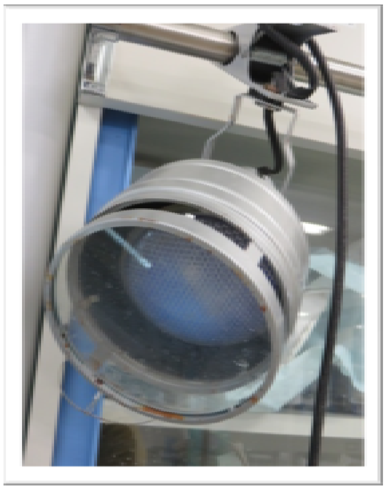
   A thermometer was attached with the tank to monitor the temperature of the tank (Figure 3.2 g). Every time the temperature of the tank was measured. Generally the temperature was with in acceptable limit as the room temperature was controlled by the air conditioner. So during summer or winter the temperature of the tank was $25\text{-}30^0$C.

c. **Water Renewal**

   The tank water was circulating and there was bio-filter (Figure 3.11) in the tank system. So, fresh sea water was always supplied in the tank regularly. The filter (figure 3.12) was cleaned at a regular interval. So the tank was a perfect natural environment. Getting good environment some algae grew in the tank. At that time algae was removed very carefully using small net (Figure 3.4, d) and plastic drawer (Figure 3.4, e).

a. Salinity meter

b. Bottle used for Total Alkalinity Measurement



c. Side light

d. Top light

e. Pump Control Panel

f. Coral *Acrpora formosa*

g. Thermometer for Water temperature measurement

h. Water transfer pump.

Fig. 3.2 Different equipments used for the experiment. Salinity meter, Bottle, different light, Pump, coral, thermometer.

3.3 Description of the tank system

The tank is made of Acryl Plastic and it is mounted in steel frame to facilitate the operation. The tank is 36 cm long and 28 cm wide. The tank is designed with an inlet and outlet for sea water inflow and outflow (figure 3.11 and figure 3.1, 2 & 4). Two tank of same size is placed. Any of the tanks are used for the experiment. One of the tanks is used for keeping corals and another one is used for the experiment. Figure 3.1, 3.4 and 3.11gives the clear sketch of the whole tank system. The inflow and out flow is designed in the manner that normally the flow can remove the waste product in the tank. Inflow of the tank is from one side of the tank and the outflow is in another corner of the tank. Normally it circulates the water and outflows the water previously entered. In this way the coral gets fresh water every time like the marine environment. To facilitate the coral with flowing water condition, a pump (Figure 3.6) is set at the wall of the tank. The pump (Figure 3.6) Vor Tech MP10W (Eco-smart Driver) (Figure 3.2, e) was used in the tank. By the control box of the pump, the speed of water flow can be controlled. The pump can produce start and stop oscillatory flow. The pump is used to conduct the oscillatory flow experiment. Two lights are mounted at the top and side of the tank (Figure 3.2 c and d). Top light model was MD-3100 A HAGS (GSYU ASA GW 0103A) and the small light model was OKAMURA Super Cool 115-150W. The height of the tank light was flexible. It can be brought close to the tank for increasing the light intensity or PAR (Photosynthetically Active Radiation). Two coral colony of *Acropora formosa* (Branches of coral) were used for the experiment (Figure 3.2 f). However, one coral colony died during the water flow experiment. So the growth rate was less in flow experiment than previous light experiment results.

In case of single light experiment Intelligent LED Aquarium light was used. (HouYi Auqa System, Produced by Shenzhen HouYi Lighting Co. ltd.) (Figure 3.9). This light can produce single light. In the experiment White, Blue and Actinic light was used. In the laboratory the whole tank system was restricted from sunlight or daylight. The total area was illuminated by electric light and thus day and night was created.

3.4 Cleaning procedure of tank

Routine cleaning up the tank was done every week. The purifying tank which is situated in the floor of the tank system, refreshes the water every time. When water level of that tank goes below a certain level, it indicates that the system needs to add fresh sea water. Then the cleaning of the tank is done. The instruments used to clean up the tank is shown in figure 3.4. The flow chart showing the clean up procedure (Figure 3.3).

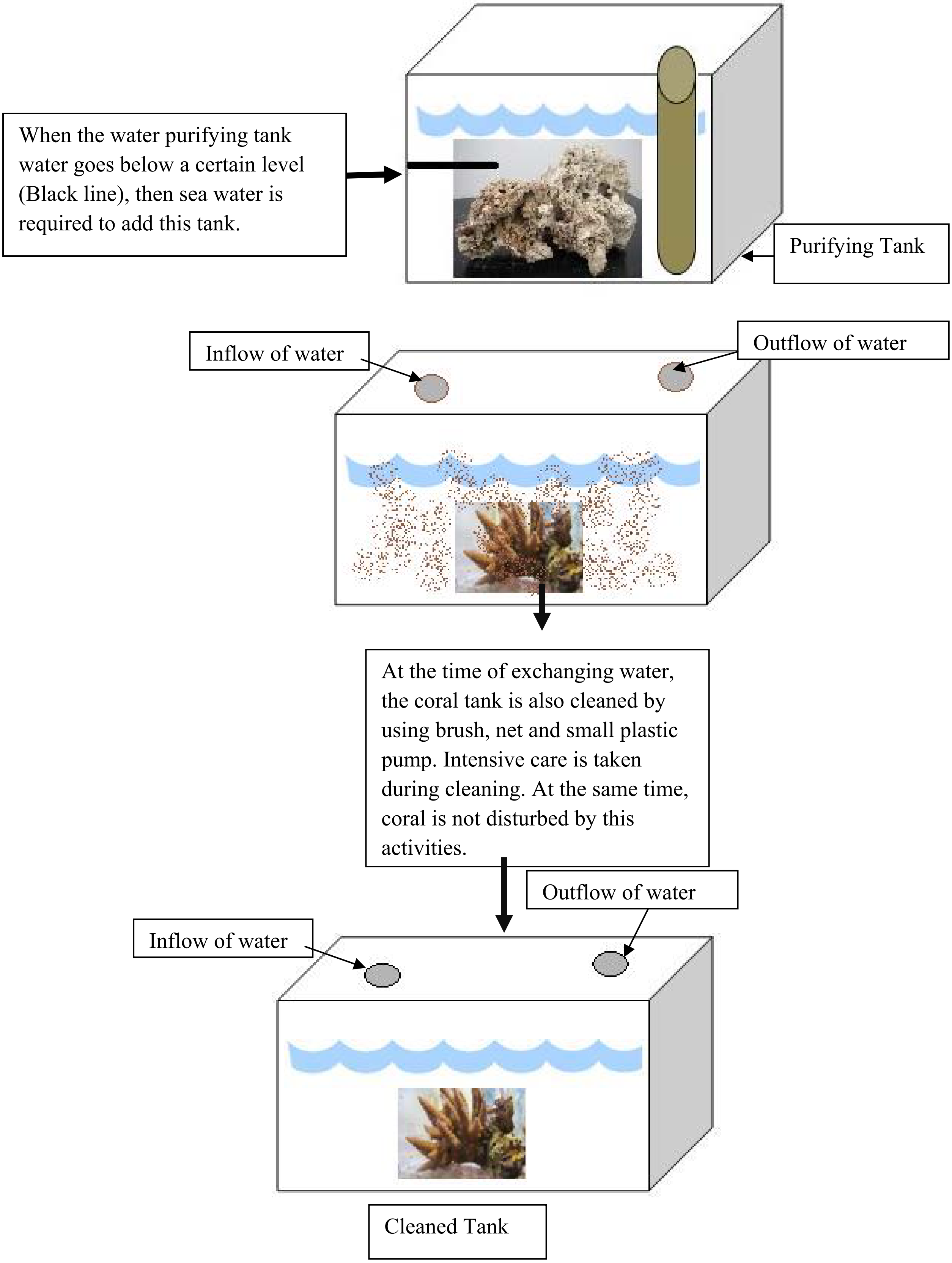


Fig 3.3 Flow chart showing the maintenance of the tank system.

a. Plastic Cleaner brush.

b. Cleaner brush attached with tank.

c. Long brush to clean the tank wall

d. Scoop net to collect the solid waste from the tank

e. Plastic pump to collect the algae

Fig. 3.4 Different equipments used to clean the tank. a. Plastic Cleaner brush, Cleaner brush attached with the tank, c. Long brush to clean the tank wall, d. Scoop net to collect the solid waste from the tank, e. Plastic pump to collect the algae

Fig. 3.5 Sensor used for PAR measurement.

Fig. 3.6 Pump used in the experiment. Top view (left) and front view (right).

3.5 Growth measurement

The growth rate of corals was measured by using Alkalinity method (Hata et al., 2004). The titration alkalinity of seawater was determined from a hydrochloric acid titration of seawater. It was done by using Total Alkalinity Titrator (ATT-05, Produced by Kiroto Electrical Industry) (Figure 3.7). Photosynthesis fixes CO_2 in organic materials, whereas the reverse reaction, respiration, releases it. Overall, the excess organic production in a coral reef community, i.e., the difference between gross primary production and respiration, acts as a source of CO_2 via the simplified equation:

Fig. 3.7 Total Alkalinity Meter

Fig.3.8 Total tank system of the experiment

$Ca^{2+} + 2HCO_3 \rightarrow CaCO_3 + CO_2 + H_2O$----(1)

Nitrates, Phosphates, other anions contribute to alkalinity (Skirrow, 1975). Edmond (1970) was one of the first to use this method and the technique was automated for the measurement of Total Alkalinity is defined as:

$TA = [HCO_3^-] + 2[CO_3^{2-}] + [B(OH)_4^-] + [OH^-] - [H^+]$ ------------- (2)

"Inorganic carbon metabolism (Calcification: g µmol/kg of water /hr) is equal to half the change in TA" (Hata et.al., 2004).

$g = K(-\frac{\Delta TA}{2} \times \frac{1}{t})$---- (3)

Here, K = factor (It is calculated from mass of coral in a unit volume of water)

TA = Total Alkalinity (μmol/kg) and ΔTA = Change of Total Alkalinity (μmol/kg of water)

In this experiment the growth of coral was measured by determining the change of total alkalinity of water. The real existence of coral in the water is not homogeneous practically. And the weight of coral may vary from location to location. So, to make it realistic the factor K is incorporated with growth of coral. Then the growth of coral can be expressed in context of coral weight.

So from equation 2 and 3 inorganic carbon metabolism (Calcification: g μmol/kg of water /hr) can be calculated as follows

$$g = K\left(-1/2 \times \Delta\{[HCO_3] + 2[CO_3^{2-}] + [BOH_4^-] + [OH^-] - [H^+]\} \times 1/t\right)$$

The value of TA is determined by direct measurement. An equation related with Alkalinity Anomaly Technique can be in examined as follows

$$g = \{-\Delta pCO_2 + \Delta k \times TA_i - \Delta(k \times ([B(OH)_4^-] + [OH^-] - [H^+]))\}/\{2 \times (k_i + \Delta k)\} \times 1/t$$

where $k = (a_H^2)/(K_0 \times K_1 \times a_H + 2 \times K_0 \times K_1 \times K_2)$

3.6 Total Alkalinity measurement

For analyzing the seawater, the water is necessary to keep in a bottle (figure 3.2 b). At first the bottle volume was determined by using an electric scale. Before taking the sea water sample from the tank, the inflow of the water was stopped by closing the inflow button. At the same time sea water salinity and water temperature is recorded by the salinity meter (figure 3.2 a). For accurate measurement three replications are taken. The water is stored in plastic bottle and measured sequentially. The bottle was placed in the Total Alkalinity Meter (figure 3.7), and it took 15 minutes for measurement. For the measurement 0.1 mol Hydrochloric Acid was used. Then all three results were taken under consideration and standard deviation was calculated. To reduce the stress to the corals from closed condition, sample water was taken after every 30 minutes. In this way all time water flow and light experiment total alkalinity was measured.

Table 3.1 An example of result found from Total Alkalinity Meter.

	First Hour			Second hour		
	R1	R2	R3	R1	R2	R3
Sample Volume (ml)	103.533	103.813	103.533	103.813	103.533	103.813
Salinity (ppt)	33.0	33.0	33.0	33.0	33.0	33.0
Sample Temperature (degree centigrade)	25.9	25.5	25.1	26.3	25.9	25.5
Room Temperature (degree centigrade)	22.9	23.1	23.2	23.4	23.5	23.5
Total Alkalinity (μmol/kg of water)	1978.88	1977.92	1978.81	1965.78	1967.86	1967.57
Total Inorganic Carbon (μmol/kg of water)	1702.21	1696.55	1700.73	1664.08	1667.16	1674.13
pH	8.037	8.050	8.050	8.079	8.083	8.078

From the table the Total alkalinity difference is calculated from Replication 1 (R1), Replication 2 (R2), and Replication 3 (R3) respectively.

3.7 Light intensity and water flow measurement

Light intensity was measured in terms of PAR (Photosynthetically Active Radiation). Light have different spectral band. But only 400-700 nm wave length can be used by the photosynthetic organisms. So, this range of spectral band is termed as Photosynthetically Active Radiation, abbreviated as PAR. Different PAR was used to find the growth of coral. To increase the PAR, light intensity was to increase. To get the expected PAR the top light and side light was brought closure. To measure the exact PAR inside the tank (just at the point of coral location) DEFI-L (Small memory total photon senor. It is a high-precision photon total of long term continuous observation) sensor, produced by JFE Advantech co. ltd. was used (Figure 3.5). For water flow measurement the Vor Tech MP10W (Ecosmart Driver) pump control box was used (Figure 3.2, e). By using the pump expected water flow can be created.

Fig 3.9 LED light used for Coral growth measurement.

The flow that creates a continuous back and forward flow is termed as Oscillatory flow. In the present experiment we used a little different kind of Oscillatory flow. By using the pump stop and start oscillatory flow was created. And the duration of stop and start was one second. The explanation of this flow is shown in figure 3.10. For the present experiment this kind of oscillatory flow was used. In this context the speed of oscillatory flow was determined by using the average of highest and lowest flow speed.

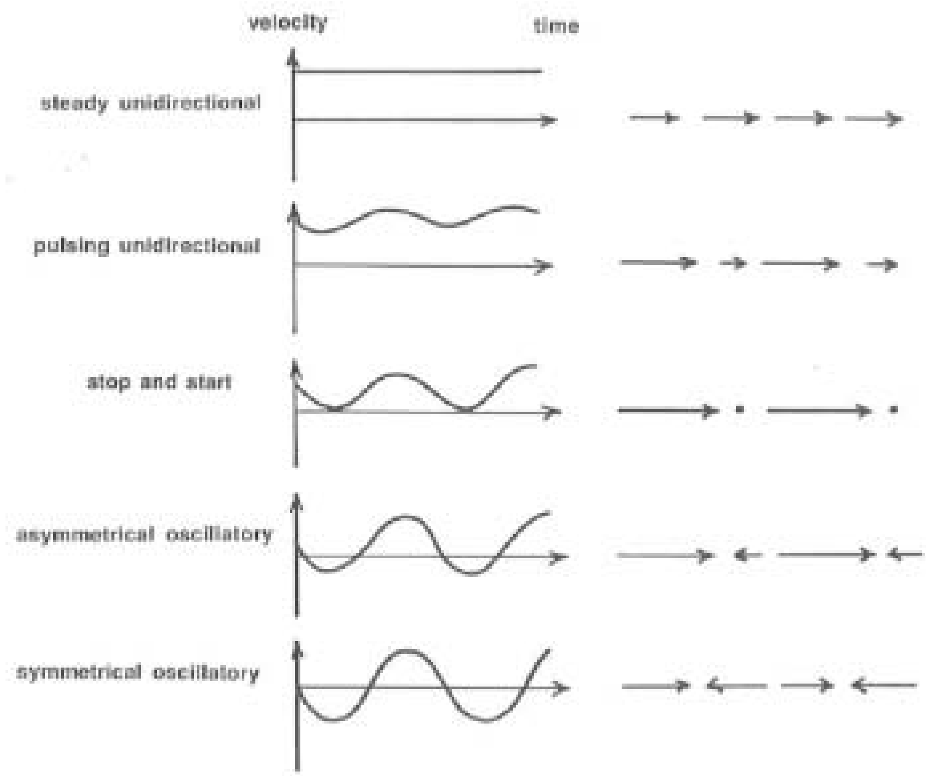


Fig 3.10 Different kind of oscillatory flow. (Source : ocw.mit.edu.)

3.9 Experiment Calendar

To avoid the seasonal variation of the weather, the experiment laboratory temperature was controlled. The temperature of the room was always within 25-30^0 C. The total experiment period was from January, 2012 to May 2013. While the experiments were performed, continuous two weeks the same condition was continued. Any of the experiments were repeated more than once for the accuracy of the result. At first five months was used to make some test experiments. By this time all the practical things regarding growth measurement of *Acropora formosa* was learned. At the same time the behavior of coral was noticed. For the light experiments, it was started from June 2012 and continued for November 2012. Then water flow experiments were initiated. This water flow experiments were continued till May 2013.

Fig 3.11 Top view of the tank showing Inflow, outflow of water, pump and coral position.

Fig 3.12 Water purifying unit of the tank system.

3.10 Maintenance of the system

It is well known to the coral reef researchers that coral can tolerate a very narrow range of environmental change. And the change should be steady. For example, coral's favorable temperature is 20-30^{0}C. And this change should be slow. If the change of temperature is drastic, then it affects the growth of coral. For the first time, the coral expels the algae from their body. In severe condition, it dies. So, obvious is that the change of the environmental parameters should be steady. Natural calamity and man made disasters, creates such situation that changes the environment suddenly. This situation is harmful for coral.

So, the maintenance and water exchange of coral tank is important for coral research. During cleaning the instruments used are, plastic cleaner, scoop net, plastic water pump, plastic brush (Figure 3.4) etc was used. During the maintenance period constant water flow was on. New sea water was added in the lower purification tank. In the tank there are shell and rock (Figure 3.12). This shell and rock controls the pH of the water. And it also mixes the new and old water. So that it can create minimum pressure to the coral.

CHAPTER 4: RESULT

Experiment result

Laboratory condition coral research is convenient in terms of designing the expected experiment. Before executing any experiment, the tanks were furnished with coral and other environmental conditions. Before doing the experiment the environment of the experiment was continued for some time for the acclimatization of the coral. When the designed experimental condition was fulfilled then the water sample was taken for the measurement of growth. Finding the best growth of *Acropora formosa* is the ultimate aim of this research. So the growth of the coral was measured in different light intensity (PAR) and flowing water condition.

4.1 Coral Growth with light effect

The growth rates of Coral were measured under different conditions. Firstly the growth rates during day time and night time were measured.

Table 4.1 Table showing the growth of Hard Coral *Acropora formosa* with Standard Deviation (SD) during day and night time.

		1	2	3	4	5	6	7	8	9
Growth	day	18.82	20.16	15.63	19.12	17.60	18.39	15.24	18.11	15.32
	Night	-0.08	0.62	-3.19	1.05	1.86	-1.99	2.21	-1.64	1.14
SD	Day	1.84	1.60	2.80	2.37	2.65	3.50	2.70	3.20	2.90
	Night	1.03	1.96	3.36	1.70	3.67	3.49	3.80	3.83	3.63

Here we can find that data shows the growth performance of the species *Acropora formosa*. Here highest growth of the species was found in second period. Here the growth was maximum with standard deviation of 1.6. Lowest growth was in the seventh hour and the standard deviation was higher than that of highest growth. It was 2.7. During night time, the growth showed positive and negative value. And during night time standard deviation was higher in comparison to day time. This indicates the growth is not stable during night time.

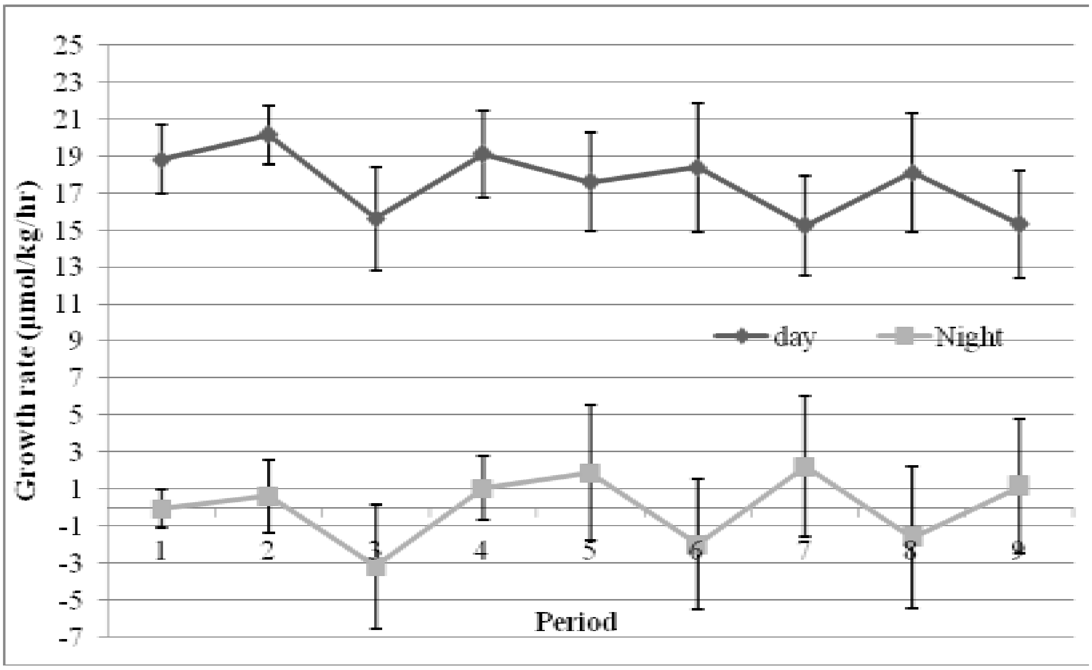


Fig.4.1 Growth comparison of hard coral (*Acropora formosa*) during day and night with error bar.

Growth rate during day time was significantly higher than night (Figure 4.1). During night time growth of *Acropora formosa* was very low and sometimes took negative value. The experiment was conducted continuously to get the consistent result. Period one and two was consistent in terms of growth. But period three growth was little lower than the previous two. In case of period four and five the growth was consistent, but in period six growth rate took negative value like period three. Period seven and nine was same positive value but period eight suddenly changed like period three and six. During night, because of metabolism and respiration, growth of coral sometimes become negative.

Table 4.2 Table showing the growth of Hard Coral *Acropora formosa* during day and night.

		1	2	3	4	5	6	7	8	9
Growth	day	18.82	20.16	15.63	19.12	17.60	18.39	15.24	18.11	15.32
	Night	2.48	0.63	3.62	3.46	1.5	-2.68			
SD	Day	1.84	1.60	2.80	2.37	2.65	3.50	2.70	3.20	2.90
	Night									

To find the clear idea and comparison, night time experiment was done again. In this time the night time growth is showing different scenario from the figure 4.1.

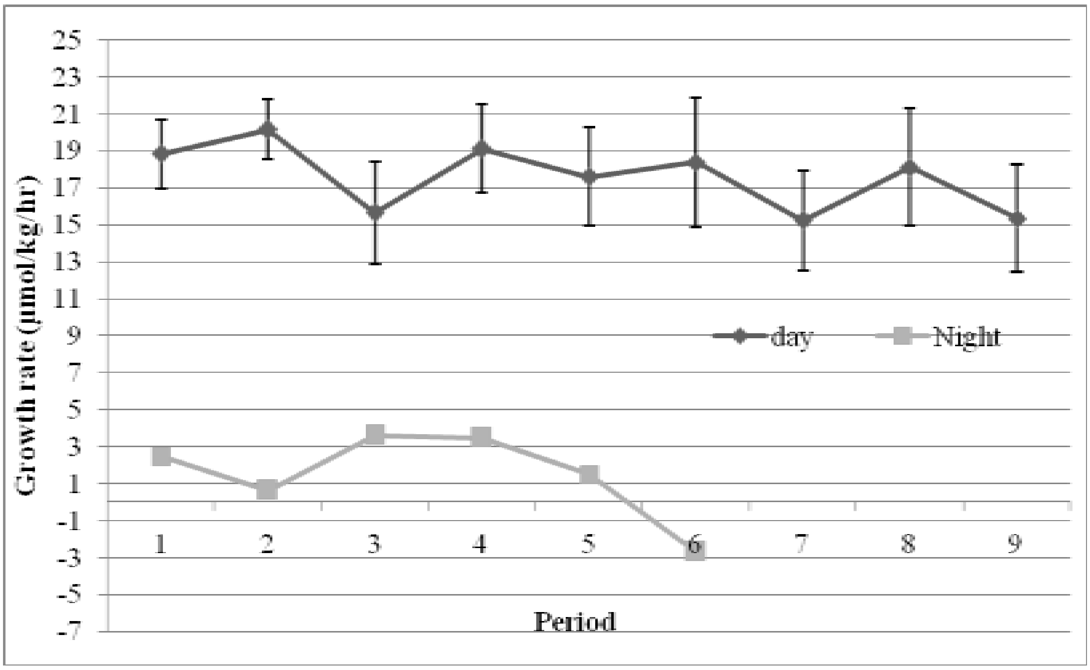


Fig.4.2 Growth comparison of hard coral (*Acropora formosa*) during day and night (Different from the previous.

Here the day time phenomenon is same as the previous one. But important thing to describe here is the night time phenomenon of the growth trend of the species *Acropora formosa*. In this experiment six hours of growth at night time is observed. The growth of the species gives a positive value in all the period except sixth period. For the first period the growth was 2.48 µmol/kg/hr. In second period the growth was a little bit less than previous hour. Again period three, four and five showes a consistent growth trend of 3.62, 3.46 and 1.5 µmol/kg/hr respectively. But in case of sixth period growth of the species is negative. This result does not completely agree with the previous result of figure 4.1. But it shows the practical scenario of growth during night time for the species *Acropora formosa*.

To find the growth of hard coral *Acropora formosa* different irradiance of PAR was used. In this condition the growth of the species increased as the PAR increased. Coral have symbiotic relation with algae. Algae perform photosynthesis with the presence of light. As photosynthesis increases, supply of food to coral is increased. So growth increases. For this experiment light intensity in terms of PAR was increased gradually. In the early stage the growth of coral increased sharply. But after 400 to 789 PAR growth also increased. After that growth decreased though PAR increased.

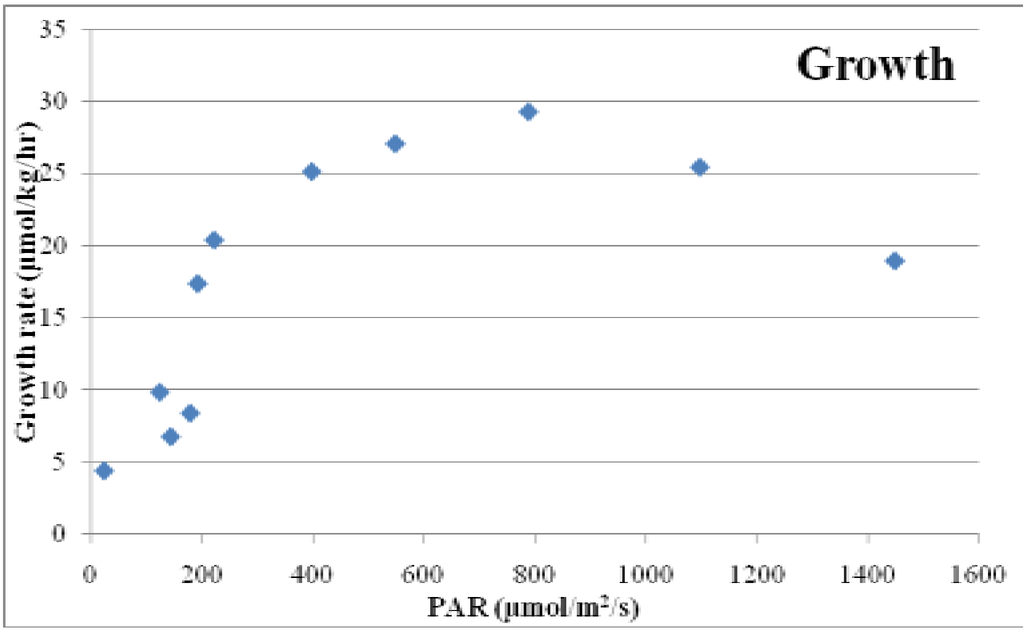


Fig.4.3 Light curve in different PAR (Photosynthetically Active Radiation).

Table 4.3: Showing the PAR and growth of hard coral *Acropora formosa*.

PAR (µmol/m^2/s)	Growth (µmol/kg/hr)
24.00	4.4
124.02	9.83
144.00	6.76
179.00	8.39
192.51	17.35
222.17	20.36
398.35	25.10
548.83	27.03
789.15	29.23
1098.26	25.40
1450.00	18.92

Growth rate when plotted against different PAR, showed the clear trend of light-growth curve (Figure 4.3). Normally growth increases as PAR increased. In the initial stage of growth the graph 4.3 shows an irregular growth points. In this experiment different PAR was used to observe growth rate of hard coral . PAR was used from 24.00 to 1450.00 µmol/m^2/s. Growth of hard coral *Acropora formosa* is different in different PAR. Growth of the species increases till 789.15 µmol/m^2/s PAR. After 789.15 µmol/m^2/s PAR the growth of the coral *Acropora formosa* decreases (Figure 4.3). From PAR 124.02 to 222.17 µmol/m^2/s growth increase was highest. At that point the growth curve shows upward movement. Growth increases 4.40 to 20.36 µmol/kg/hr in this range of PAR. Growth increases two times by the increase of 98.15 µmol/m^2/s PAR. This was the most productive region of growth for the species *Acropora formosa* though there were some irregular growth points at the beginning. After 222.17 to 789.15 µmol/m^2/s growth also increases but the slope is lower then the previous PAR.

Table 4.4: Showing the PAR and growth of hard coral in different lighting condition with error bar.

	LED Light PAR 179 µmol/m^2/s	Top Light PAR 144 µmol/m^2/s	Small side light PAR 34 µmol/m^2/s
Period 1	7.55	5.44	3.87
Period 2	8.39	6.18	4.40
Period 3	8.29	6.76	3.88
SD (Standard Deviation)	2.39	2.55	2.41
SD (Standard Deviation)	1.63	3.21	1.06
SD (Standard Deviation)	1.39	1.32	0.28

From the Table 4.4 we can see the data represents growth of hard coral in different lighting condition. In case of small side light growth was highest in second period 4.4 µmol/m^2/s. In case of LED light, it is same like side light. But incase of Top light highest growth is in third period. In case of standard deviation top light showed highest variation. Least error is found in case of small side light. Highest growth performance is given by LED light as it gives best PAR value.

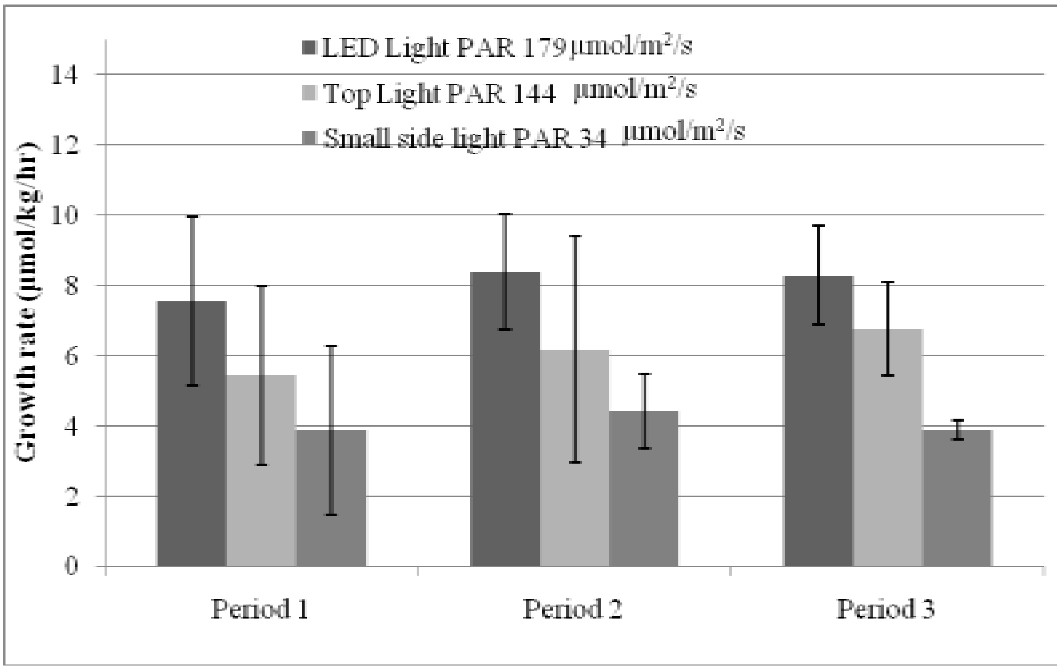


Fig.4.4 Growth using different light having different PAR (Photosynthetically Active Radiation) with error bar.

Different light scheme was used in the experiment using different light continuously three period (Each period is consists of 30 minutes). Best light is LED light as because it showes comparatively high growth in comparison with the other top and side light (Figure 3.2). In all three periods growth trend was same. Here the small side light PAR (34 $\mu mol/m^2/s$) was less in comparison with other two lights (LED light 179 $\mu mol/m^2/s$ and Top light 144 $\mu mol/m^2/s$). So, minimum light can perform coral growth as the coral colonies remain several meter to hundred meters deep in the water. Again, LED light yields less light intensity but higher PAR thus produces less heat.

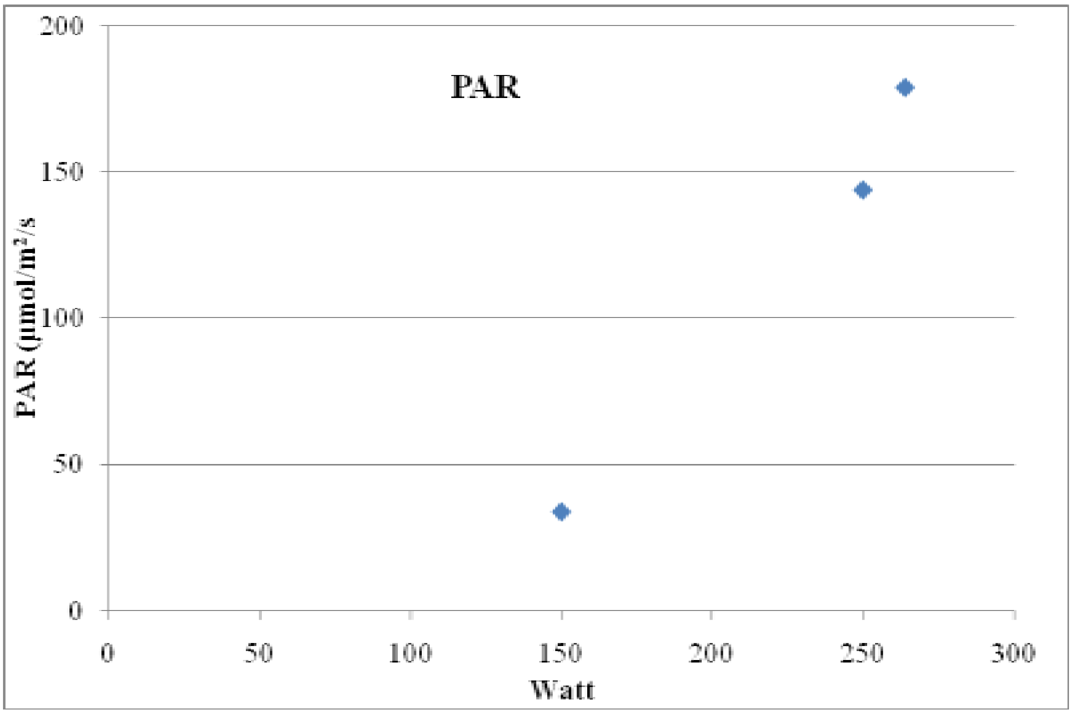


Fig.4.5 Watt is plotted against PAR to show the trend to find the growth of *Acropora Formosa*.

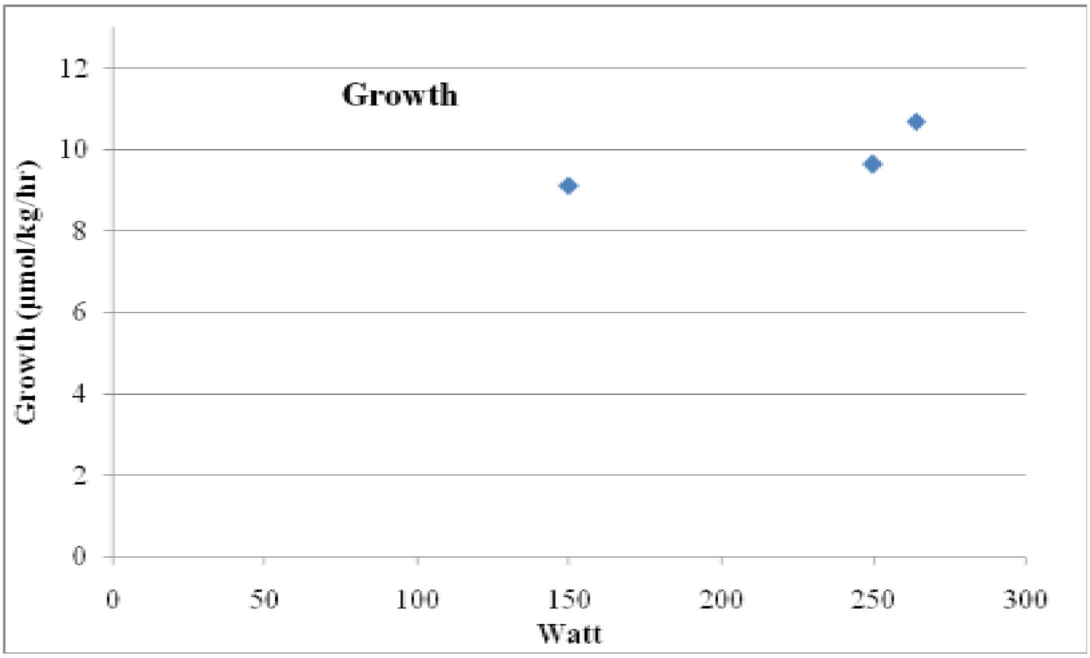


Fig.4.6 Watt is plotted against growth of coral to find the growth of *Acropora Formosa*.

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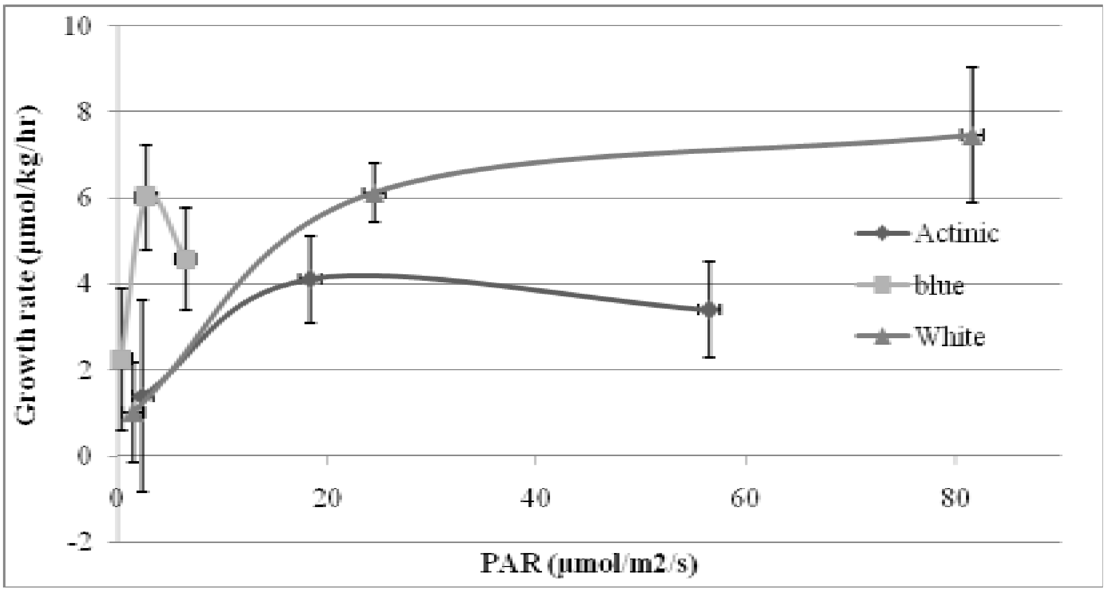

Fig.4.7 Single light growth performance of the coral *Acropora formosa*.

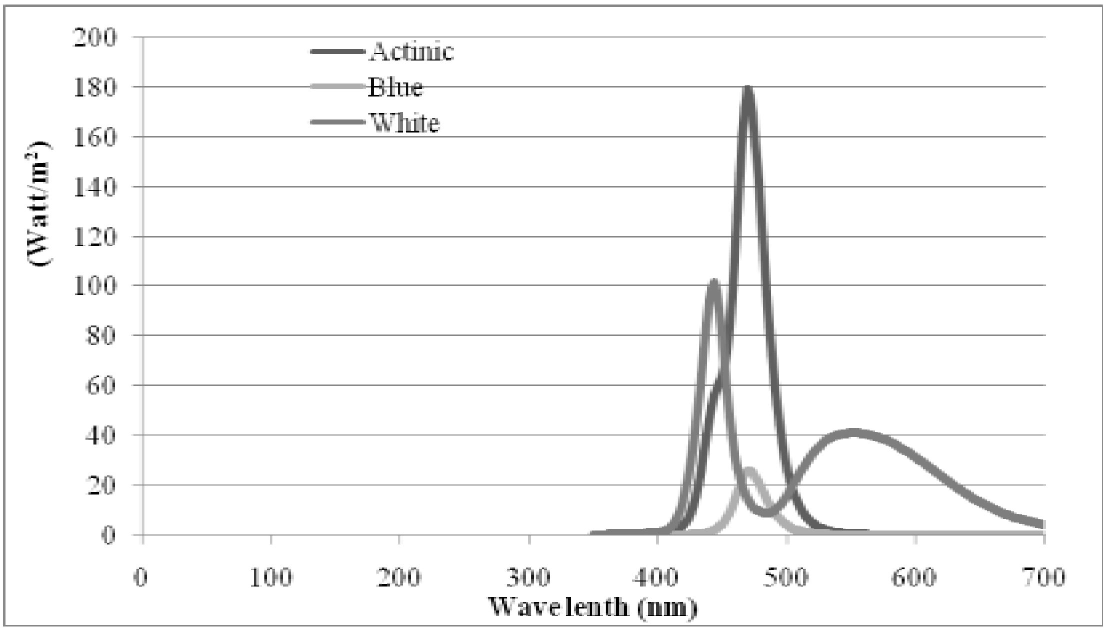

Fig.4.8 Wavelength of different single light of the spectrum.

In the above two figures single light i.e., Actinic, Blue and White color was used to show the growth performance. The web length of different single color is also presented (Figure 4.8). In this case blue light PAR is very low but it gives more growth in comparison with Actinic and white color. But PAR 2.71 gives maximum growth 6 µmol/kg/hr. When PAR is increases to 6.45 µmol/m^2/s, growth decreases to 4.57 µmol/kg/hr. In case of Actinic it is also true. PAR

18.35 gives 4.11 μmol/kg/hr growth but PAR 56.44 gives 3.39 μmol/kg/hr growth. In case of white color of the spectrum the growth increases as PAR increases. But the growth curve falls after 24.47 PAR.

If we give a look to figure 4.8, we will find the wave length of the three color. Here Blue and Actinic shows the same pick but the expand of Actinic is larger than blue color. So, the growth curve has the large expand in Actinic than blue color. Again white color shows comparatively wide span of wavelength than the Blue and Actinic. So from the figure 4.7 it is clear that blue color growth never goes downwards as it covers a wide wavelength. But as Blue and Actinic have narrow wavelength range, so the growth reduces after a certain PAR.

To understand the single light growth performance the result is shown in the bar graph. Here it is clear from the graphs (Figure 4.9, 4.10 & 4.11) that though the PAR is different in different color but the growth trend is same in case of Blue and Actinic color. After a certain PAR growth of the species *Acropora formosa* decreases. But in case of white color growth increases gradually. But after 24.47 PAR the growth increment is not like previous value. This means the growth of the species have a better performance area. In this area growth trend is maximum.

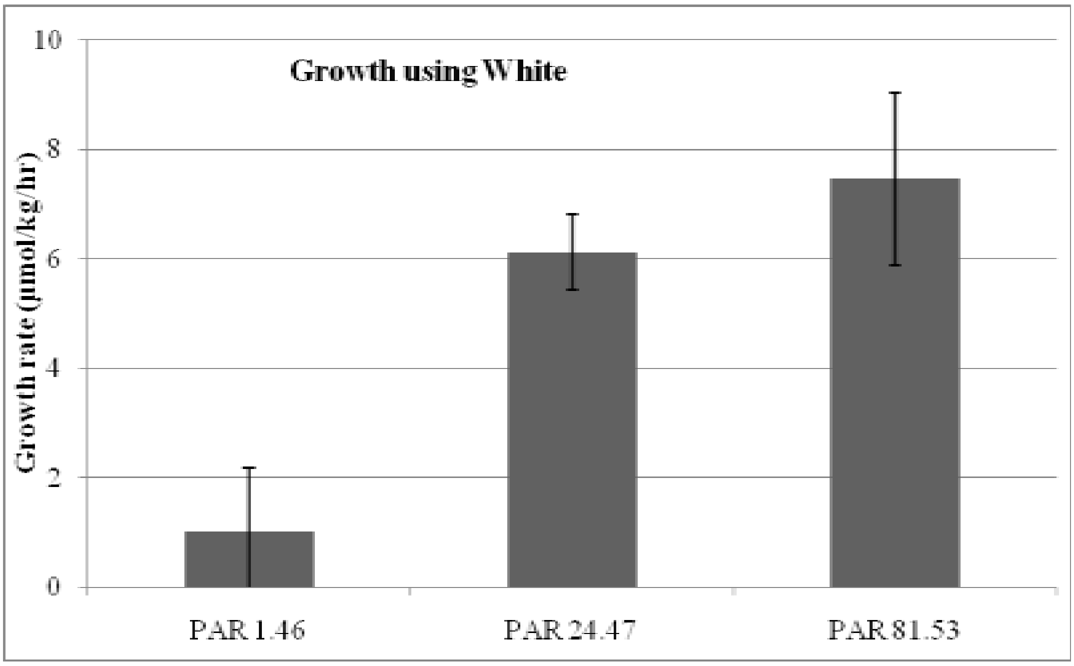

Fig.4.9 White color growth performance of the coral species *Acropora formosa* (In bar graph)

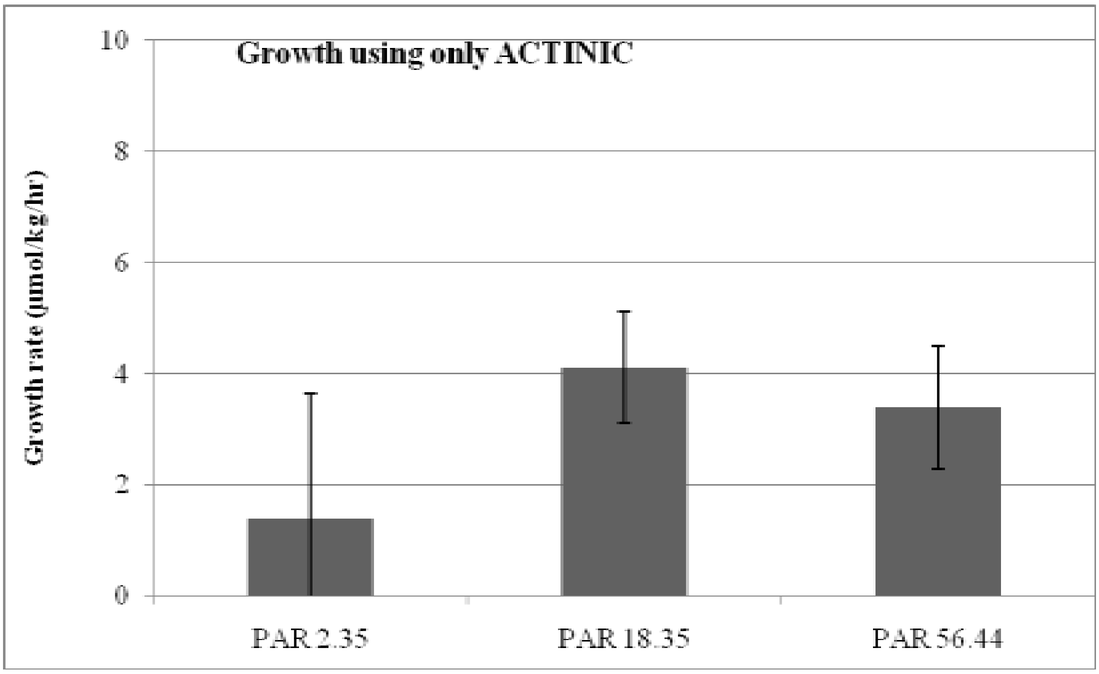

Fig.4.10 Actinic growth performance of the coral species *Acropora formosa* (In bar graph)

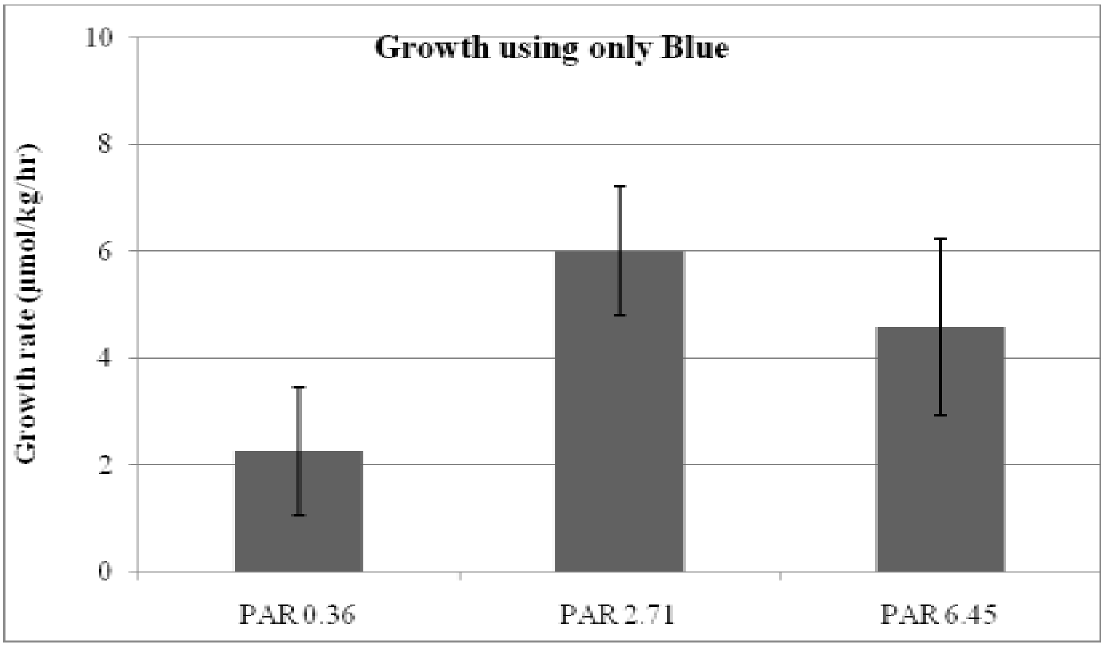

Fig.4.11 Blue color growth performance of the coral species *Acropora formosa* (In bar graph)

4.2 Coral growth in respect with water flow

Water flow is one of the most important nonliving factors influencing the growth of coral colony. Growth and metabolism of zooxanthellae and other symbiotic algae is influenced by the ambient environment. If the ambient water environment is stagnant, there will no exchange of gas and nutrient. By the process of photosynthesis unicellular algae fixes carbon to their animal host coral. This symbiotic relationship allows the coral to benefit from both heterotrophic and phototrophic carbon sources. The importance of water flow for different aspects of coral biology is much important. Generally water flow affects physiological process of the organism. Water flow affects the circulation of different nutrient in the aquatic environment. Thus flow showed considerable change in coral growth.

Table 4.5 Data showing the growth of *Acropora formosa* in oscillatory flow and constant flow of water with standard deviation.

	Low water flow (15 cm/s)PAR >200	Medium water flow (30 cm/s)PAR >200	Standard Deviation	Standard Deviation
Period 1	14.92	13.74	2.55	3.91
Period 2	15.33	16.63	2.56	3.70
Period 3	13.88	15.04	1.35	2.92
Period 4	16.51	15.47	3.75	2.21

The table 4.5 represents the data of growth in different speed of water flow. Here low water flow was 15 cm/s and high medium water flow was 30 cm/s. Growth of *Acropora formosa* shows better growth in medium water flow. In second and third period the growth of medium water flow is healthier. But in first and fourth period low water flow was better. This may be due to the limitations of controlled condition. In open water where water flow exists all the time, there the growth remains consistent in flowing condition. Standard deviation of the growth of *Acropora formosa* shows higher value in medium water flow than low water flowing condition.

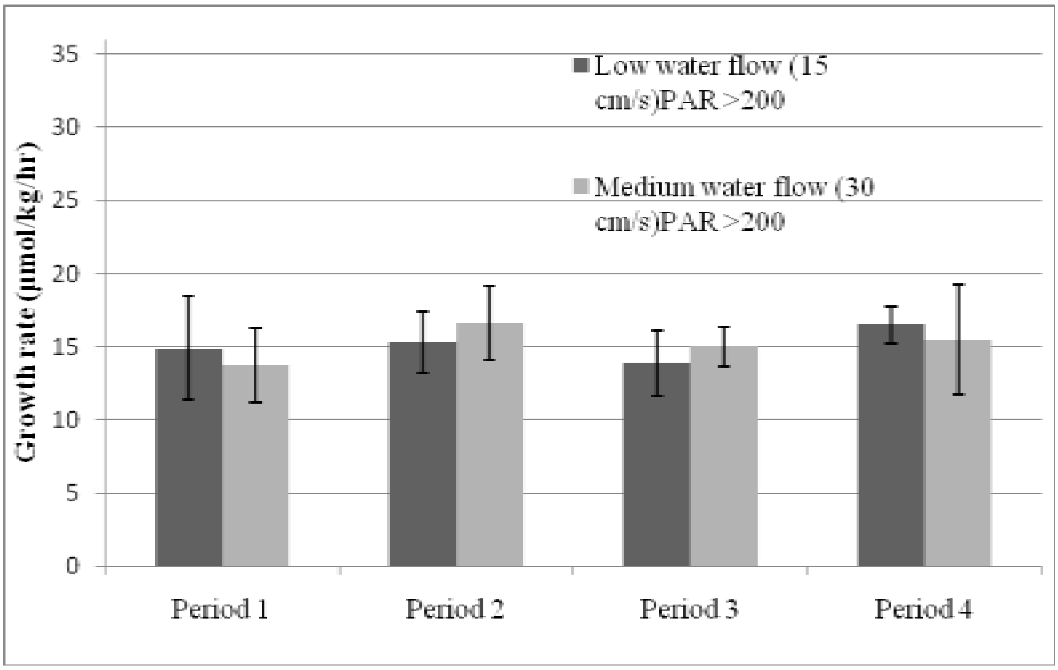

Fig.4.12 Growth of the coral *Acropora formosa* in low and medium water flow.

In this experiment (Figure 4.12) two kind of water flow was used to get the growth of coral. Low speed water flow was 15 cm/s and medium speed water flow was 30 cm/s. In the very fast period low speed water flow shows better growth performance than medium speed water flow. But when the condition continued for some time, then the growth performance of the species *Acropora formosa* is better in medium speed water flow. At the last period the growth of hard coral *Acropora formosa* shows better growth in low flowing condition. The probable explanation for this incident may be the condition of the coral at that time. This result does not go in the same line with other treatments (Figure 4.14).

Table 4.6 Table showing the growth of *Acropora formosa* in different flow speed and oscillatory flowing condition with standard deviation.

Constant flow	Water Flow 15 cm/sec	Water Flow 35 cm/sec	Water Flow 65 cm/sec
Growth (µmol/kg/hr)	7.32	10.26	13.74
SD (Standard Deviation)	1.20	1.95	3.40
Oscillatory flow	**Water Flow 16 cm/sec**	**Water Flow 30 cm/sec**	**Water Flow 40 cm/sec**
Growth (µmol/kg/hr)	8.37	9.84	10.22
SD (Standard Deviation)	1.75	1.25	0.95

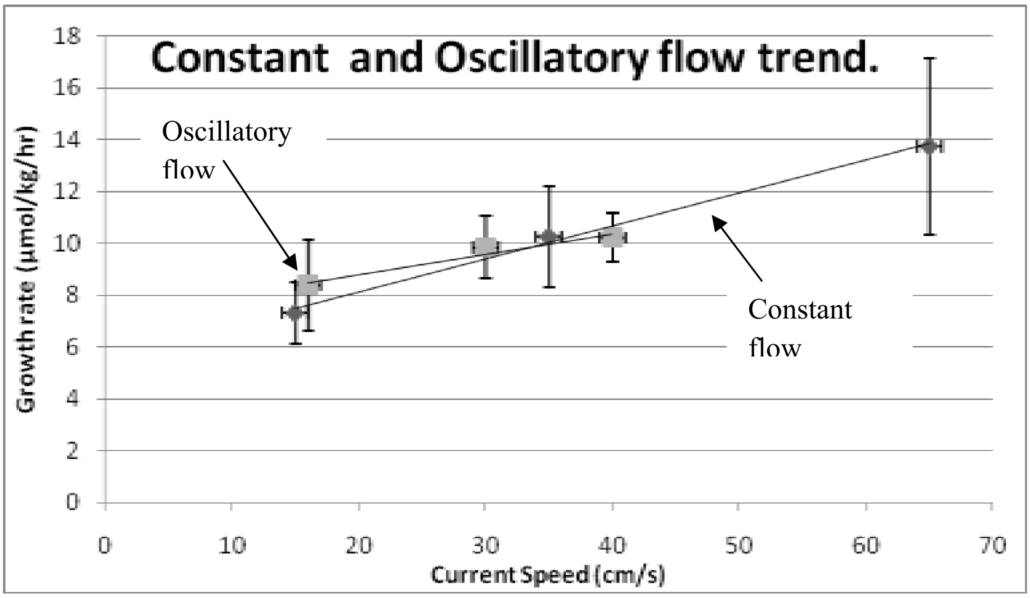

Fig.4.13 Growth of coral in different flowing condition with PAR value 320 µmol /m2/s

In the figure 4.13 different flow speed was plotted against their growth. It shows the pattern of growth in different flow rate. Growth shows clear high growth in high current speed. Three flow regime of 15, 35 and 65 cm/s was used and 7.32, 10.26 and 13.74 µmol/kg/hr growth was obtained. It is noticeable that as flow rate increases, the growth of coral also increases. It is due to the availability of nutrient element and fresh sea water inflow. In marine environment, water flow occurs in different perspective. Wave action, current, tide may cause water flow. Thus this entire incident helps the acceleration of coral growth.

In case of oscillatory flow, the growth rate is comparatively better than constant flow in low speed. In case of oscillatory flow highest water flow is 40 cm/sec. If we concentrate to the trend line drawn on the two, we will find that oscillatory flow yields better growth in low flowing condition. But high speed constant flow performs better growth.

Table 4.7 Data showing the growth of *Acropora formosa* oscillatory flow and oscillatory flow with plastic cover.

	Oscillatory flow	Oscillatory flow with plastic cover		SD	SD
Period 1	9.11	8.37		2.30	1.75
Period 2	9.63	12.32		1.80	1.12
Period 3	10.69	12.96		1.21	1.73

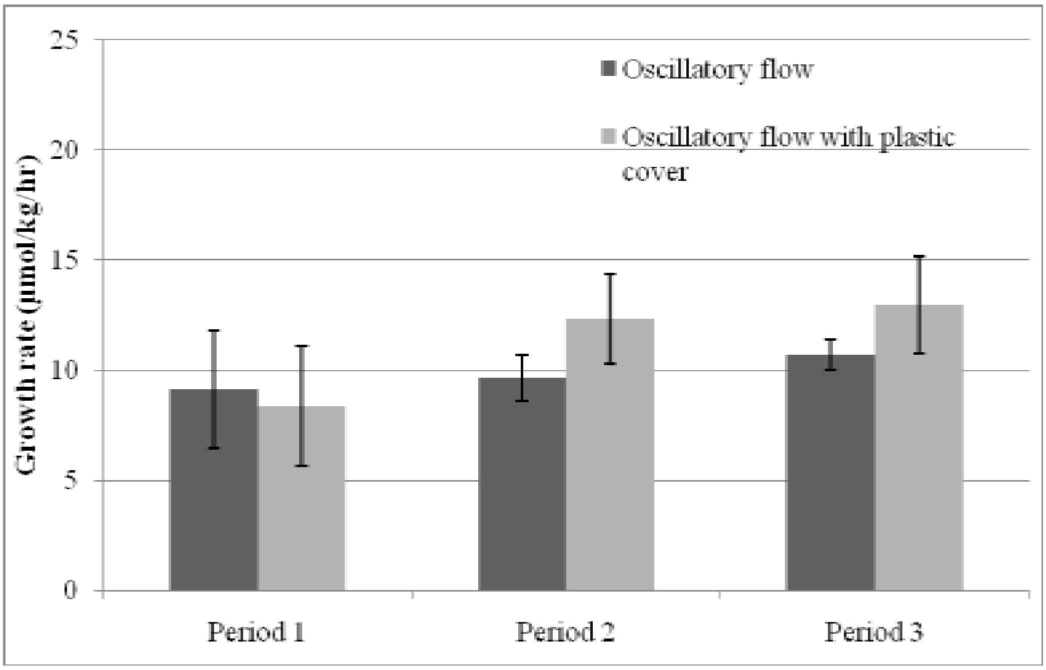

Fig.4.14 Growth of coral in consecutive Periods (30 minutes) by using Oscillatory flow and Oscillatory flow with covering the top of the tank by plastic cover. (Vertical line represents error bar.

Coral (*Acropora formosa*) growth was examined by using oscillatory flow and plastic cover. During the experiment to observe the growth in oscillatory flowing condition, the tank was covered with plastic wrap and growth was monitored. Again without plastic cover growth was also experimented. The oscillatory flow was stop and start oscillatory flow. Once the top of the tank was covered with plastic cover. Figure 4.13 shows the result of the experiment. In the first period oscillatory flow and oscillatory flow with plastic cover yields 9.11and 8.37 µmol/kg/hr growth respectively. Second period the growth rate was 9.63 and 12.32 µmol/kg/hr respectively. In third period the growth rate is 10.69 and 12.96 respectively. Both the oscillatory flow and oscillatory flow with plastic cover increases the growth of coral. But in the very first period oscillatory flow give higher growth. But in second and third period oscillatory flow with plastic cover gave better growth performance. It means oscillatory flow increased the growth gradually. In case of covering the top with plastic paper, growth of coral shows better performance that oscillatory flow. Plastic paper acts as restrictor between water and air. So, CO_2 can not mix with air. It increases the rate of $CaCO_3$ formation.

Table 4.8 Data showing the growth of *Acropora formosa* in oscillatory flow and constant flow of water.

Speed of water flow	22 cm/s	30 cm/s	36 cm/s	50 cm/s	60 cm/s	65 cm/s	70 cm/s
constant flow	6.08	7.77	7.04	9.41	11.25	11.09	12.98
Oscillatory flow	8.17	8.5	8.05	9.58	10.96	10.01	12.54
SD	0.71	2.42	0.62	2.11	0.74	1.18	3.54
SD	1.46	1.71	1.15	0.44	0.88	2.65	1.73

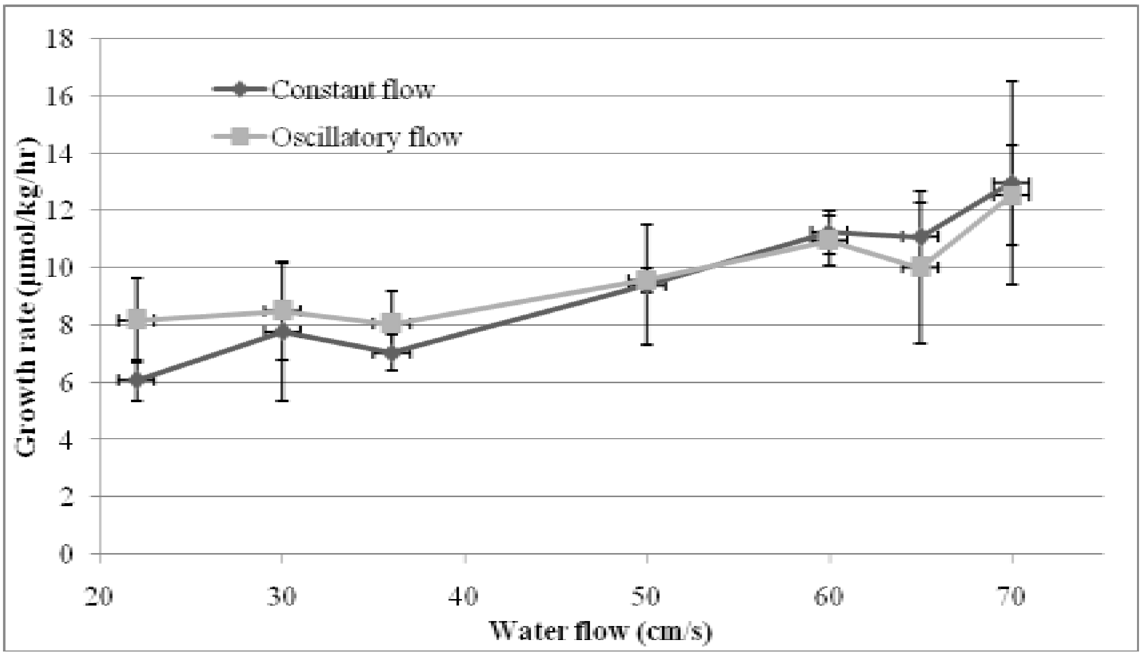

Fig.4.15 Growth of the coral *Acropora formosa* in consecutive period by using Oscillatory flow and Constant flow.

Constant water flow and oscillatory water flow applied in different speed in the tank of the experiment room. Highest flow was 70 cm/s and lowest flow speed was 22 cm/s. According to flow speed the growth rate of coral increases with irregular variation. In case of constant flow the highest and lowest growth is 12.98 µmol/kg/hr and 6.08 µmol/kg/hr in 70 cm/s and 22 cm/s flow speed respectively. In case of Oscillatory flow the highest and lowest growth is 12.54 µmol/kg/hr and 6.17 µmol/kg/hr in 70 cm/s and 22 cm/s flow speed respectively. From the figure 4.8 we can observe that growth with constant flow was higher than oscillatory flow till 55 cm/s flow speed. Below this flowing condition, oscillatory flow performs better growth than constant flow. From this graph 4.14, it is clear that low speed oscillatory flow is better for coral growth.

CHAPTER 5: DISCUSSION

5.1 Effect of light on coral growth

For any kind of primary production light plays the prime role to govern the process. In case of coral growth, as coral have symbiotic relationship with algae, light plays an important role for the growth of coral (Gattuso et al., 1999). Scientists could not give exact explanation of coral growth till now. Day and night growth rate (Figure 4.1) gives clear idea about the effect of light on coral growth. During night light is not available, thus it stops all kind of photosynthesis and growth activity of coral. Some explanation about the relationship between calcification and photosynthesis was given by some scientists who worked on the growth of coral. They argued that during photosynthesis process CO_2 is removed thus intracellular pH is increased. Again state of intracellular saturation becomes more favorable for crystallization and deposition of carbonate. Another explanation regarding calcification and photosynthesis is the necessity of energy for the production of organic matrix, Calcium ion and carbonate ion transport etc. And these things are being influenced by the status of energy of the coral that the host gets from the symbiotic algae. The symbiotic algae produces the energy from photosynthesis. The more the photosynthesis the more production of food and more supply to the host and more growth. During day time coral gets sunlight and photosynthesis occurs. But during night sunlight is not available so, growth stops. Photosynthesis process uses Carbon dioxide and releases Oxygen. At the same time the coral uses Oxygen. As production of Oxygen stops during night, so growth of coral also stops (Figure 4.1).

It is said earlier that growth of coral is indirectly related with photosynthesis. The factors inhibits photosynthesis also restricts calcification of coral species. (Davies 1991). Goreau et al., (1971) also argued in the same way like other researchers that lighting condition gives better growth performance. These studies are in the line with present study of *Acropora formosa*. Muscatine et al., (1981) explained the whole system of calcification from carbon budget context. He argued that during day time photosynthesis accelerates the carbon cycle and during night it is stopped. This carbon cycle indirectly helps calcification. Again as the production of O_2 is stopped during night, removal of CO_2 is also stopped. Thus growth during night time is stopped. Figure 4.1 shows the growth of hard coral *Acropora formosa* in present and absence of light. This result agrees with other researchers findings. Some scientists tested the effect of light on coral growth from different point of view. They tried to find “deleterious effects of increasing depth on coral growth” (Macintyre, 1972). Macintyre 1972, tried to find the deleterious effect of light on coral growth. They found that hermatypic corals and reefs are primarily found in shallow water area. The restricted growth of the coral is the result of the light requirement. But still the whole process especially the theoretical mechanism is still in mystery especially the cellular and molecular nature. (Rinkevich and Loya, 1984)

Coral receives the photosynthesis byproducts from the photo-synthetically active algae. Hence, by using these photosynthesis byproducts, coral produces energy and utilize it while required for the calcification (organic matrix production, Calcium ion and Carbonate ion transport) process. Additionally, algal photosynthesis process requires CO_2 which is up taken from its surrounding environment thus results the elevation of intracellular pH. This elevated pH condition is reported as favorable for crystallization and deposition of carbonate. Therefore, presences of light, thus algal photosynthesis enhance/accelerate the coral growth literature (Johnston, 1980).

On the other hand, *Acropora formosa* (coral) growth rates fluctuate with varying light intensities. Coral growth rate tend to rise with the increment of Photosynthetically Active Radiation (PAR) up to certain range (Figure 4.3). Minimum coral growth rate (4.4 µmol/kg/hr) was observed at 24.00 µmol/m^2/s PAR. While, it is maximum (29.23µmol/kg/hr) at 789.15µmol/m^2/s PAR. Similarly, Roth (1982) described that “light enhances a certain level of coral calcification”. This observation could be explained as the positive relation between the PAR and rate of photosynthesis. Algal photosynthesis accelerates with the increment of PAR, thus, photosynthetic byproducts become more available for the coral, ultimately contributed to the growth of coral. Energy fixation by photosynthesis is higher in sunny days than cloudy days (Davies 1991).

In contrast, growth rate showed declining trend with further increase of PAR (Figure 4.3). Beyond 789.15µmol/m^2/s PAR yielded reduction of growth rate. This observation holds well agreement with the existing literature. Roth (1982) discussed the inhibition of photosynthesis at 1751 µmol/m^2/s PAR. Another example was given by Roth (1982) in this context. He documented that light induced inhibition of coral calcification occurs at PAR 1950 µmol/m^2/s. Excess light or irradiance could be detrimental for both the algae and the coral. Excess light could cause oxidative stress to the species. Therefore, photosynthesis rate declines (Roth 1982). Additionally, light stress could reduce coral growth with the damage of pigment due to heat shock. Under excessive light condition, coral utilizes its energy to protect against this heat shock, thus energy become less available for the growth process (Anthony et al., 2002).

In contrast to the present study, Schutter et al., (2010) claimed that "photoperiod or irradiance has no effects of on coral growth". Schutter et al., 2010, did experiment on photoperiod. He used 16 hour and 8 hour photoperiod in his experiment. But the daily net photosynthesis was not factually different in those two photoperiods. In the present study for all treatments photoperiod was same i.e., 8 hours.

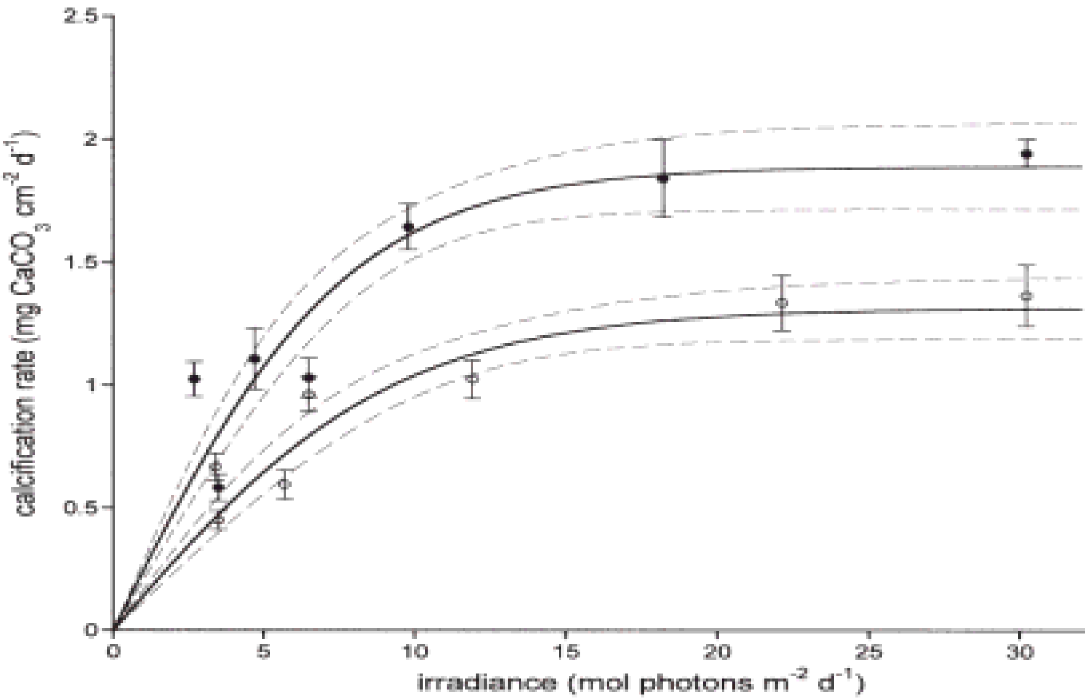

Fig. 5.1 Daily calcification rate plotted against irradiance (PAR) of coral (*Porites compressa*) considering Last Glacial Maximum and year 2100. (Marubini, et al., 2001)

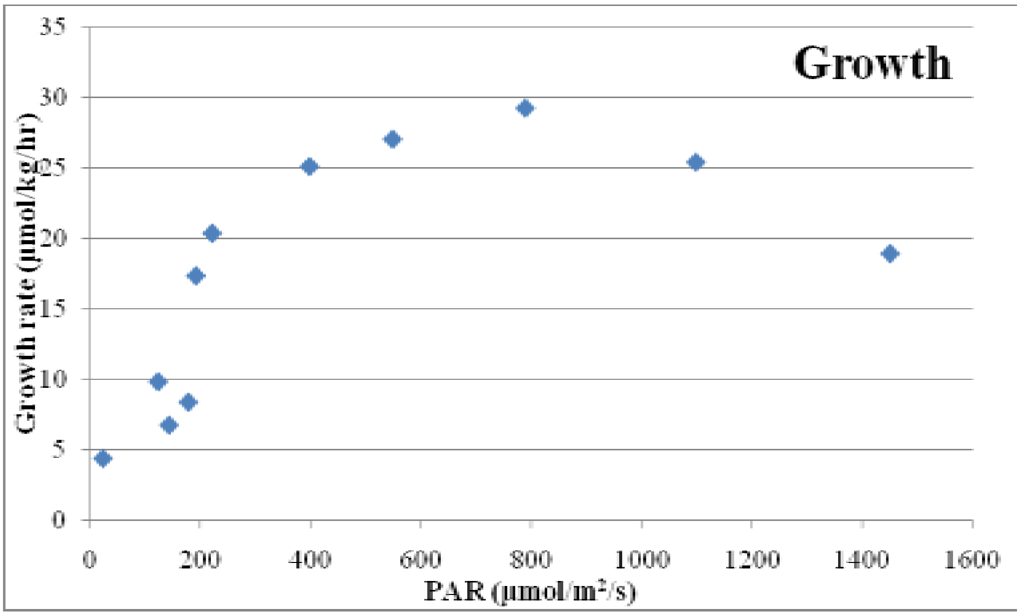

Fig. 5.2 Growth of *Aropora formosa* at different PAR. (present study)

From the above two figure 5.1 and 5.2 we can see the similarity of growth performance of coral colony. Marubini et al., 2001 presented the figure in two hypothetical condition. The upper curve is considered for LGM (Last Glacial Maximum) and the lower curve is considered as Y2100 (Year 2100). In both the cases growth curve showed similar trend with present study (figure 5.1 & 5.2). In the same paper the author also compared the growth of corals in different depth. The result also showed that as depth increase the growth performance reduces (Marubini et al., 2001). But Marubini et al., 2001 did not find the point where growth curve goes downwards. Present research made the attempt to find the peak point of growth curve (Figure 5.2).

Different light scheme also changes coral growth (figure 4.4). Different source of light produces different heat. This also affects the coral growth. The species *Acropora formosa* shows different growth in different light pattern (figure 4.4). LED light that produces light without hear is better for the growth of the species. Other traditional light which is stronger but PAR is not so high creates heat thus growth of *Acropora formosa* is less. One noticeable point here is the small light that gives less PAR than other two source of light, but it gives better growth of *Acropora formosa*. On the other hand LED light growth is better in comparison with Top light. This is because the light is gentle and produces less heat. If we have a look to figure 4.5 and 4.6, then it appears clear that as watt increases growth and PAR also increases. But the increment of LED light is better than the top light. Here the side light uses about 150 watt of energy and produces less than 50 µmol/m^2/s PAR. So the light is not so effective in terms of PAR production. For culture of coral we need to consider the best light that uses comparatively less power, produces enough PAR (light intensity) and contributes to the growth of coral.

Again, single light Actinic, Blue and White gives different growth rate for the coral species *Acropora formosa* (figure 4.7 and 4.8). Very little amount of blue light can give better growth. Again excess blue light is not favorable for growth of the species. For Actinic it is also true. But white color gives better growth as PAR increases. Generally under water all spectrum are not available like the air. So, the presence of different light affects the growth of coral species (figure 4.7). It gives an idea that only single color can not give expected growth. Blue color of the spectrum can penetrate deep of the water because of its small amplitude of wave length (figure 4.8). Other two light Actinic and White have long wavelength that can not penetrate so depth like Blue. And this Blue light is used by the coral for photosynthesis and growth. A very small PAR of blue light can help hard coral *Acropora formosa* to grow. Where other light can not penetrate, Blue light can penetrate in that area. No other research was found to compare the findings of the present research, but some researchers did the experiment with plasma light and LED light. That shows plasma light is better because its light is smooth and comfortable for the coral.

Blue and Actinic light shows the same wave length (figure 4.8). Among this two colors Actinic have wider wavelength than Blue. So the growth curve of Actinic and Blue light shows the reflection of their wave length in the figure 4.7. But white color has more wide range of wavelength (figure 4.8). As a result white color helps growth of coral as the light intensity increases. So, from the result we can say that wide range wavelength light helps coral grow as PAR increases. But narrow range of wavelength restricts the growth if the PAR is increased.

5.2 Effect of water flow on coral growth

Present study made some scheme of water flow and found different growth rate in laboratory condition of branchial hard coral *Acropora formosa* (figure 4.12 and 4.13). Some of the previous study also did the same experiment which is also discussed. In all cases the respond to flow speed varied substantially. Besides that, different coral species that might respond differently to flow speed were used in previous studies, thus making it difficult to compare results. Therefore, from the available data, it is difficult to make any final comment about flow and coral growth. Present study did different flow treatments on a single species of hard coral *Acropora formosa*. The result (figure 4.13) of the present research shows clear acceleration of growth of hard coral with increased flow rate. Schutter et al, (2010) did the same study and found water flow is important for scleractinian coral growth. Corals get lower growth rate in the stagnant condition. Generally flowing condition refreshes the ambient condition of the coral. It affects the renewal of nutrients. The ultimate result is the increased growth of the coral.

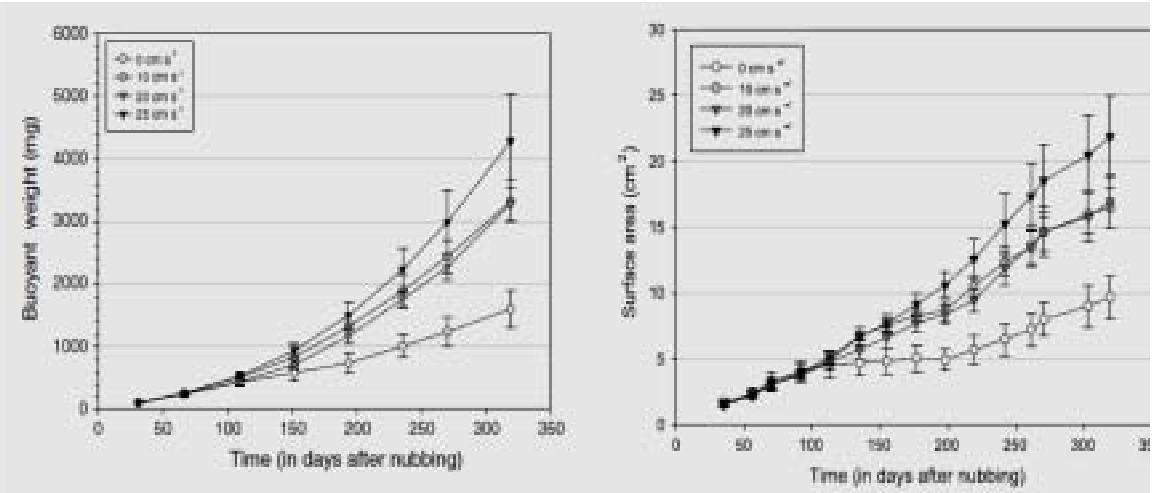

Fig. 5.3 Hard coral in different flow regime shows weight (left) and surface area (right). (Source: Schutter M. et al, 2010)

The figure 5.3 which was taken from Schutter et al, 2010, that shows clear picture of the relationship of flow speed and scleractinian coral *Galaxea fascicularis* growth. As the flow speed increases the weight and surface area increases. The experiment was done for 350 days. So, apparent picture of flow speed and growth was found. This result completely agrees with the present study. The result is in contrast with Forsman Z. H. (2012)'s experiment. He stated high flow speed (about 11cm/s) yields slightly less growth than low flow speed (about 4cm/s). Higher water motion resulted in slightly less tissue growth. This different result with present and other study may due to species selection. As because, the response to water flow varies with species.

How water flow affects the coral growth, can be explained by different point of view. The effect of water flow on coral also depends on the surface area of the coral that are exposed to the open water. The surface area of the coral has to face the adjacent water. If the water motion renews the water frequently, it accelerates the respiration and metabolism, thus growth increment occur. Coral metabolism can be affected by the alteration of the thickness of boundary layer adjacent to coral. Diffusion of dissolve substance among coral tissue and surrounding water occur due to water flow. For calcification and photosynthesis CO_2, should diffuse the cell wall of the organism. Before that CO_2, would go through the boundary layer of the animal. This whole process is influenced by water motion. Some researchers found that higher flow gives denser skeleton to coral. And it can withstand different pressure damage (Smith et al., 2007).

Coral growth gives better growth rates in oscillatory flowing condition (figure 4.13 and 4.14). In the very first hour the growth of oscillatory flow is better than constant flow. As the situation exists for some time, then growth of coral shows better growth in oscillatory flowing condition (figure 4.14). Again, the air water exchange is hindered by plastic cover, it also accelerates coral growth. In any coral reef, location of the coral is important. Wave exposed area or surf zone of any reef are better for coral growth (Forsman Z. H. 2012). But water flow can also restrict the capture of food and nutrient uptake. But this is not true for all the species of hard coral and location.

Present study of *Acropora formosa*, made the comparison of flowing condition and flowing condition covering the tank with plastic. This plastic cover acted as a protector against the water and air. It helped to remain the gases inside the water. Similar research was not found in this context to compare. But this result (figure 4.14) gives an idea that air water gas exchange reduces the growth of coral. Theoretically zooxanthallae produces oxygen and the oxygen is used by the coral. In return corals also use the CO_2 produced by corals. If the produced gases are allowed to remain in the water environment then the growth is accelerated. Plastic paper in the experiment acted as a protector against gaseous exchange.

Another experiment was done to find the best growing condition in oscillatory flow and constant water flow. Comparison of growth was made by using different flow speed. The result showed the clear picture of growth at different flowing speed (figure 4.15). The result says that in high speed constant flow is better. On the other hand oscillatory flow less than 50 cm/s yields better growth performance than constant water flow. Here one thing is noticeable that the oscillatory flow data of figure 4.13 and figure 4.15 is showing different value. The two experiments were done in different time. And the coal condition may have changed. So, there is a little deviation of the two results. But the basic trend of oscillatory flow was same. In both two cases the oscillatory flow in low speedy flow gives better growth. But High speed constant flow is better that high speed oscillatory flow.

Dennison (1988) did experiment on the same coral species *Acropora formosa* (Dana). He measured calcification rate in stagnant (Unstirred) condition and flowing condition (Stirred), dark condition and lighting condition. He found that "Net photosynthesis and respiration were significantly reduced (about 25% lower) in unstirred conditions compared with stirred conditions." Night time calcification also reduced by 60% in stagnant condition. Light enhanced calcification reduced about reduced about 25% in non flowing condition. In comparison with present result of the same species *Acropora formosa*, the result agrees with the result of Dennison (1988).

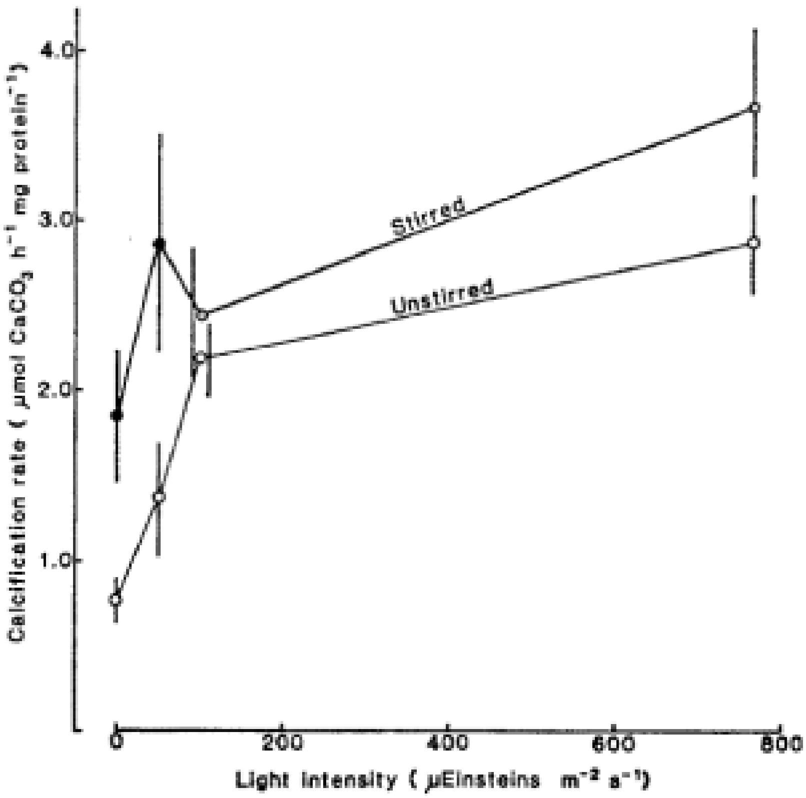

Fig. 5.4 Comparison of net calcification rates of *Acropora formosa* as a function of average light intensities in stirred and unstirred condition. Source: Dennison (1988).

CHAPTER 6: CONCLUSION

This study of hard coral *Acropora formosa* shows that light and water motion have effects on coral growth rates. Increased PAR increases growth of *Acropora formosa* at a certain limit. After that limit the irradiance makes obstacles for the photosynthesis of the symbiotic algae thus hinders the growth of the species. At that point light inhibition of calcification occurs. At the same time water flow increases coral growth. The mechanism behind this accelerated growth with is the renewal of the ambient water. This new water changes the thickness of the boundary layer of the coral. New nutrient is brought and waste product produced from the metabolism of coral is washed away. Strong water flow also affects the skeletal density of coral.

There are varieties of hard coral available in the world. So the behavioral pattern of *Acropora formosa* can not be unique. Surely the pattern of growth of the species is more or less different from other species. There may be different pattern of morphological adaptation in different hydrodynamic environments. So, there is much knowledge gap between these events of light and water flow. For detailed knowledge in this concern, we need more attention on research. Strong species-specific effects imply that corals are adapted to specialize on a particular niche in a highly heterogeneous environment. Further studies are needed to explain the mechanisms behind these differences. We have more room to work on coral polyp, tentacle size and ingestion of food, density of zooxanthellae in coral body etc. Global warming, sea level rise etc can be incorporated with this research. In this present research we got some idea about the light and water flow effect. But still we need to know about the details of its effect on coral biology and metabolism. The species specific effect of light and flow need to know. Present study was done only the hard coral *Acropora formosa*. The same treatment to other species can naturally give deviated result. But in which scale this deviation occurs is necessary to consider. Future research on this species specific coral can give us clear idea. If this kind of research can sketch the outline of growth performance in different condition, this result can be implemented to accelerate the coral colony formation in natural coral reef areas which area is on thread due to global warming and other environmental hazards.

Many of the coral reefs of the world is destroyed in the mean time and remaining coral reefs are damaged due to some environmental and man made factors. These damaged reefs can be recovered by transplanting the corals produced in coral cultivation farm. In the coral cultivation farm this research knowledge can be used to accelerate the growth. Improved coral cultivation can be a potential for rehabilitation of damaged coral reef, biodiversity conservation etc. Coral farming not only has the potential to benefit a wide variety of studies that use corals as model experimental organisms, the process of cultivation itself is likely to provide important insights to coral ecology and organism biology. It is not so clear to what extent heterotrophic and phototrophic capacities are affected by different environmental conditions, morphology and taxonomy. The overall implication of this study is that non-living (abiotic) conditions can be optimized to have large beneficial effects on coral growth. A systematic research of a species of hard coral can result more successful cultivation of that species, and may give interesting knowledge about basic ecology and species specific biology in future.

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