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Metabolic Responses of the Hermatypic Coral, *Acropora yongei* (Veron & Wallace) to Changes in Salinity

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ABSTRACT

Three different laboratory experiments were conducted to determine the effects of seven salinity levels: 5, 10, 15, 20, 32, 35 and 42 ppt (or g/L) on the hermatypic coral, *Acropora yongei,* and to what extent the coral may be restricted metabolically. The Photosynthesis-Irradiance (P-I) curve was also used as a means to quantify the rate of oxygen evolution at different light irradiances and as a tool to investigate the physiological effects of salinity variations. Salinity tolerance of *A. yongei* ranged from 20-35 pt but the coral was observed to tolerate lower salinity levels down to 15 ppt under short-term fluctuations from 32 ppt. Large variations in salinity induced a reduction in the photosynthesis and respiration of *A. yongei* which were most apparent at lower salinities (<20ppt). Net photosynthesis was higher in corals subjected to 20 ppt and 32 ppt at 76.4 $mg.O_2.mg^{-1}AFDW.h^{-1}$ and 57.0 $mg.O_2.mg^{-1}AFDW.h^{-1}$, respectively, while respiration rates were higher at 5, 10 and 42 ppt. Maximum photosynthetic rate (88.12 $mg.O_2.mg^{-1}AFDW.h^{-1}$) at saturating irradiance (232.3 µmol photons $m^{-2}s^{-1}$) was higher at 32 ppt . The generally steeper slopes of the curves obtained from the three salinity levels may indicate that the coral has the ability to photoadapt or acclimatize to the ambient environment. On the other hand, the higher photosynthesis to respiration ratio (1:81) and daily oxygen production at 306.2 $mg.O_2.mg^{-1}AFDW.h^{-1}$ at 32 ppt were observed to be adequate for autotrophic maintenance of *A. yongei.* Results of the experiment suggest that the coral *A. yongei* is a good candidate for transplantation particularly in areas where short-term fluctuations in salinity do not reach lethal levels of salinity less than 15 ppt.

Key words: photosynthesis-irradiance, respiration, net photosynthesis, bleaching

INTRODUCTION

The physiological aspects of the remarkable relationship between reef-building corals and endosymbiotic dinoflagellates have brought increasing interest, particularly on the rates of both respiration and photosynthesis which are the main driving factors of this symbiosis. Observations on the rate of metabolism, distribution and vigor of corals have suggested a relationship between light availability, wave action, sediment load, salinity, temperature and tidal range (Veron, 1986). Although there have been a few experimental studies on the effects of temperature and sedimentation on the physiology of corals, the effects of salinity remain poorly studied (UNEP, 1988). Corals, like most cnidarians, have few mechanisms for osmoregulation and any deviation from ambient salinity can influence basal metabolic functions resulting in decreased growth potential, reproduction, survival and lower rate of calcification (Muthiga and Szmant, 1987).

The purpose of this study was to examine the stress tolerance and changes in rates of photosynthesis and respiration of the hermatypic coral, *A. yongei,* to salinity variations. Measurement of photosynthetic-irradiance (P-I) responses is a helpful tool to determine the metabolic responses of the coral to changing salinity levels and to predict diurnal photosynthesis. Variations in seawater salinity usually occur during heavy rains especially on areas largely affected by river run-off, precipitation, and periods of prolonged drought. The results of the study would contribute essential information on the physiology of this coral species that would guide the selection of appropriate sites for transplantation activities.

MATERIALS AND METHODS

Salinity Tolerance Test

The hermatypic coral, *Acropora yongei,* has irregular radial corallites and thick-walled rounded margins (Fig. 1). Collection was done by breaking off the coral tips from the parent colonies using a wire cutter and placed in 3 cm x 16 cm plastic bags filled with 100 ml seawater. Coral tip samples should have good pigmentation and show no mucus and other active polyp responses to cutting. Upon arrival, the coral branch tips were immediately placed in glass aquaria with ambient seawater and continually aerated while being kept for 3-4 days before the experiments. Several authors recommended different conditioning periods before experiments are to be conducted. Moberg *et al.* (1997) immediately did oxygen measurements after collection from the field, while Montebon and Yap (1995) prepared the coral nubbins after three hours. The present study extended the conditioning period to ensure that stress was not due to mechanical handling but rather on the test parameters.

Six pieces of coral branch tips were placed in each of 21 glass aquaria (40-L cap.) containing seawater at varying salinity levels of 5, 10, 15, 20, 32, 35, and 42 ppt representing seven treatments and three replicates laid out in a Randomized Complete Block Design (RCBD). A hand refractometer (Atago, S/Mill) was used to measure the salinity of each setup. Light intensity was monitored three times a day with a light meter

(Extech 407026) at 07.00h, 1000h and 1400h for the whole duration of the experiment. An alcohol-filled thermometer was used to monitor the temperature of the water. The number of coral branch tips in each test which manifested bleaching was recorded and monitored every hour for the whole study period in each run. Stress symptoms were also monitored and presented in a graphical form.

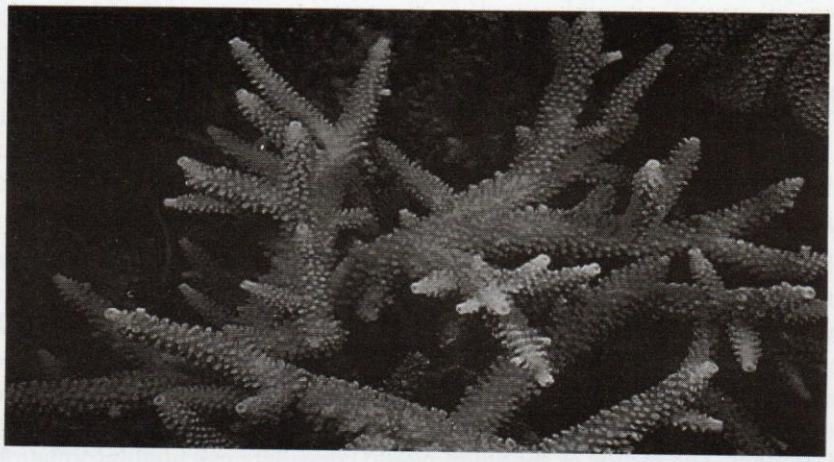

Figure 1. A colony of the hermatypic coral, *Acropora yongei* (Veron & Wallace). Colonies are arborescent or prostrate or form caespitocorymbose bushes. Branches are up to 20 mm thick. Radial polyps have projecting, rasp-like lower lips (Veron, 1986).

Physiological Measurements

Net photosynthesis and respiration of A. *yongei* were determined by two different methods in the laboratory. Dissolved oxygen was measured using titration by the Winkler method while a modified respirometry system was employed in the other.

1. Oxygen evolution measurement by the Light and Dark Bottle Technique

Twenty-eight BOD bottles were used in this experiment assigning four BOD bottles for each of seven salinity levels. Two of the BOD bottles contained one coral branch tip each. One bottle was covered with electrical tape wound around it to exclude all light (or dark bottle); the other (light bottle) allowed light to pass through. The two remaining light and dark BOD bottles did not contain coral branch tips. Values from the BOD bottles without corals were then subtracted from those with corals to account for plankton photosynthesis (light bottle) and bacterial respiration (dark bottle). The bottles were then placed randomly in a wooden frame partially submerged in water inside a 500L capacity fiberglass circular tank. The set-up was provided with flowing seawater to allow continuous flushing of seawater during the one-hour incubation and to minimize temperature fluctuations. The bottles were agitated manually by rocking the frame constantly. Incident light in the experimental area was measured before and during the

experiment using a LiCor quantum sensor to measure average photosynthetically active radiation (PAR). The set-up was situated outdoor and each experiment was conducted between 1100-1200h. The bottles were immediately fixed and brought to the MSUN-IFRD Chemistry Laboratory for dissolved oxygen determination using the Winkler Method. The coral branch tips were then taken out from the BOD bottles after acidification, washed several times in running tap water and oven-dried.

2. Determination of Photosynthesis-Irradiance Parameters

The characteristics of coral photosynthesis are primarily determined as the photosynthetic response of the coral to increasing light levels. Thus, photosynthesis-irradiance curve is seen as a convenient reflection of the environmental effects on photosynthesis of the organism (Parsons *et al.*, 1984). In this experiment, the effects of three salinity levels, namely, 15, 32 and 42 ppt on the photosynthesis-irradiance parameters of the coral, *A. yongei,* was conducted using a flow-through system adopting the procedure of Uy (2001). Earlier stress experiments showed that of the seven salinity levels, coral tips in lower salinity levels (5 and 10 ppt) immediately showed stress symptoms. Ambient salinity during the experiment was 32 ppt whereas the highest salinity level used was 42 ppt.

The coral branch tips were placed in transparent cylindrical Perspex tubes. Both tips of the tubes were sealed with rubber stoppers with glass tubings inserted for connections. Attached at the left side of the glass tubings were rubberized hoses connecting the Perspex tubes to three plastic pails containing waters at three different salinity levels. The chambers were suspended inside a seawater-filled glass aquarium to minimize temperature fluctuations. A peristaltic pump was used during oxygen measurements to regulate water flow at about 78 ml min^{-1} for constant exchange of materials at the tissue-water interface. At the other end of the chambers were out-flowing water lines that were directed to a three-way storage vessel containing the DO probe (Model Oxi 340). The set-up allowed all lines to flow but only one to make contact with the dissolved oxygen (DO) probe at any one time. The device was rotated to allow DO monitoring of any of the three chambers. The probe was connected to a DO meter attached to a computer for automated recording. Each chamber was initially supplied with ambient seawater to serve as the Control where initial D.O. readings without the corals were recorded. After ten minutes of ambient seawater exposure, water at 15 ppt and 42 ppt salinity levels were simultaneously pumped into the two tubes while one tube was continuously pumped with ambient seawater.

Six light levels (0.08, 3.5, 70, 330, 800 and 1,300 µmol photons $m^{-2}s^{-1}$) were applied and corals were incubated for 4.5 min per light level or a total of 27 min of incubation time. Light source was provided by a halide bulb (GE ENX 360W 82V) placed on top of the water bath, attenuated to the desired light intensities by adjusting the height of the bulb from the water bath. Black netting material was also provided to achieve the desired reduced light intensity. All experiments were conducted at daytime period from 11:00 to 14:00 h at the MSUN-IFRD Biology Laboratory.

Biomass Determination

The ash-free dry weight (AFDW) of each coral branch tip was used to normalize the data of the oxygen evolution experiments in order to compare the maximum gross photosynthesis and respiration values following the procedure of Moberg *et al.* (1997). Dried coral fragments were placed in a dessicator for one to two days before weighing in a digital weighing scale.

Data Management and Statistical Analysis

a. Salinity Tolerance Test

Stress resulting from exposure to various salinity levels was manifested through bleaching of the coral fragments. The frequency of bleaching incidents on coral fragments were compared among salinity levels and presented in a graph.

b. Oxygen Evolution (Light and Dark Bottle Technique)

Dissolved oxygen values derived from the Winkler method were normalized by AFDW values of the individual coral. The effect of salinity on oxygen production was analyzed using one-factor Analysis of Variance (ANOVA). When significant effect was found, the means were compared with a Tukey's *post hoc* test. Statistical analysis was performed using SPSS ver. 10 for Windows. Data were reported as mean values ± standard error of the mean. The data were further subjected to a curve-fitting technique to illustrate the relationship between salinity and net photosynthesis of the coral. A scatter plot from MS Excel was used to derive a polynomial equation of the relationship.

c. Photosynthesis-Irradiance (P-I)

Oxygen values derived from the P-I experiment and normalized by AFDW values of the individual coral were regressed against time as rates of photosynthesis expressed as $mg.O_2.mg^{-1}AFDW.h^{-1}$. The rectangular hyperbola also known as Michaelis-Menten model introduced by Jassby and Platt (Hootsman and Vermaat, 1991) was used to describe the P-I relationship since photoinhibition did not occur in the experiment:

Where:
$$P_{net} = \frac{P_{max} x\, I}{K_m + I} - R$$

P_{net} = net photosynthetic rate ($mg.O_2.mg^{-1}AFDW.h^{-1}$)
I = irradiance (μmol photons $m^{-2}s^{-1}$)
P_{max} = gross maximal photosynthetic rate ($mg.O_2.mg^{-1}AFDW.\ h^{-1}$)
K_m = the half-saturation constant (μmol photons $m^{-2}s^{-1}$)
R = respiration rate ($mg.O_2.mg^{-1}AFDW.h^{-1}$)

Derived parameters were the LCP, light compensation point or the calculated irradiance level at zero photosynthetic rate, and a which is the initial slope of the curve. All curve fittings were done using Slidewrite V2.10.

The data obtained from the P-I curve were used to estimate the daily irradiance and photosynthetic rates on a 24-h basis. The result was then used to estimate the carbon balance of the coral. ANOVA was used to determine significant effects of light on the rate of coral photosynthesis. The general linear model obtained was further used to test the effect of light and the interaction of light and salinity on the rate of photosynthesis using univariate analysis. ANOVA was again used to test for significant differences between treatment values.

The maximum photosynthetic (P_{max}) and respiration rates from the P-I data were used to determine the photosynthesis to respiration (P:R) ratio. Values were transformed to daily carbon balances by multiplying P_{max} by daily light period of 12 hours and respiration by 24 hours (Marsh *et al.* 1986, Ferrier-Pages *et al.* 1999; Uy, 2001):

$$P:R = \frac{(P_{max} \text{ x } 12h)}{r \text{ x } 24\,h}$$

To determine the oxygen balances of both zooxanthellae and the coral, *A. yongei*, values of the predicted net photosynthetic rates during daylight period were added. Oxygen demand was obtained by adding respiration rates, which was reduced by 50% to account for low temperature conditions during dark period (Uy 2001). Subtracting oxygen demand from production yielded values for excess oxygen.

RESULTS

Salinity Tolerance Test

The first visible signs of stress on the corals as a response to a deviation from ambient seawater salinity were mucus exudation, pale coloration, and subsequent coral bleaching. It was also noted that live corals emitted a characteristic smell and such observation also served as basis for identifying a still living coral (Fig. 2).

Water temperature in the aquaria ranged from 26°C to 28°C while light irradiances monitored during the experiment ranged from as low as 4.2 µmol photons $m^{-2}s^{-1}$ in the early morning and late afternoon to as high as 1900 µmol photons $m^{-2}s^{-1}$ at noon time. Ocular observations showed that all coral branch tips subjected to 30-32 ppt did not exhibit stress signs and no mortality was recorded throughout the study period. On the other hand, the same healthy condition was observed in corals subjected to 20 ppt during the first four days (96 h) of exposure. However, on the fourth day, these corals became pale in coloration and eventually 80% of the total population manifested bleaching during the fifth day or after approximately 110 h. Mucus secretions were

evident in the corals after 10 min exposure to 35 ppt but were no longer observed after 30 min and throughout the study period. Those subjected to 42 ppt had excessive secretions after 10 min of exposure and resulted in 100% mortality after two hours (Fig. 3). Corals incubated at 20 ppt produced the highest photosynthetic rate of 76.4 $mg.O_2.mg^{-1}AFDW.h^{-1}$ followed by corals subjected to 32 ppt at 57.0 $mg.O_2.mg^{-1}AFDW.h^{-1}$. (ANOVA $p<0.01$) (Fig. 4). There were variations in the respiratory responses of the coral in the dark bottle but difference among the seven treatments was not significant ($P>0.05$), although it was observed that oxygen consumption values were higher at extreme salinity levels, at 20 ppt, and ambient seawater. Comparison of respiration values showed that coral branch tips subjected to 35 ppt had the highest oxygen consumption at -65.3 $mg.O_2.mg^{-1}AFDW.h^{-1}$ and lowest at 42 ppt (-125.1 $mg.O_2.mg^{-1}AFDW.h^{-1}$) and 5 ppt (-122 $mg.O_2.mg^{-1}AFDW.h^{-1}$).

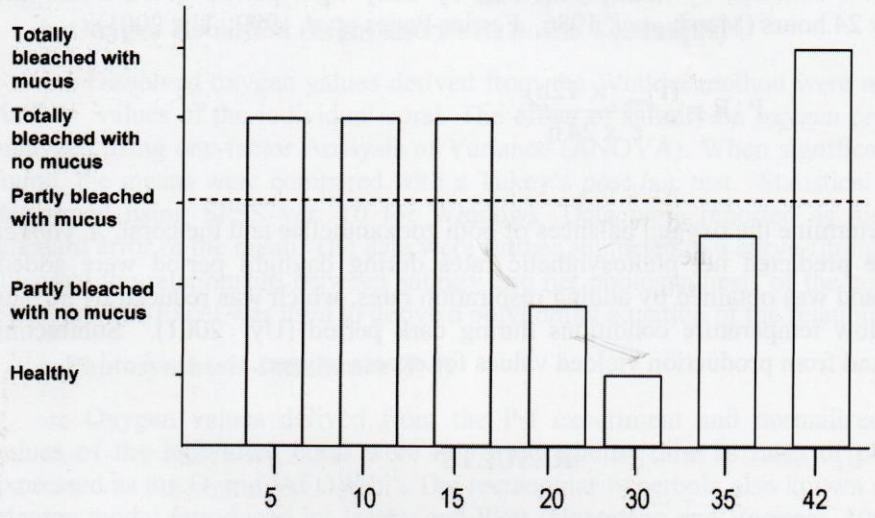

Figure 2. Effects of the various salinity levels on *A. yongei*. Stress symptoms represent 95% of the colonies (N=198) being affected (after Marcus, *et al.*, 1981). Data above the horizontal Line indicate a severe moribund condition.

Based on the calculated r^2 value, 66.26% of the net photosynthesis of corals can be explained by the effects of the different salinity levels. A non-linear relationship exists between salinity and net photosynthesis of *A. yongei* as defined by the polynomial equation $y = -0.2746x^2 + 15.811x - 160.09$. The rate at which the net photosynthesis changes with corresponding salinity is $dy/dx = -0.5292 + 15.811$. In this case, the point at which the slope, dy/dx, reaches zero (P_{max}) is 67.5 $mg.O_2.mg^{-1}AFDW.h^{-1}$ at 29 ppt. No photosynthetic responses were exhibited when *A. yongei* was exposed to salinity lower than 14 ppt and higher than 44 ppt. The computed predicted and average observed net photosynthesis at certain levels of salinity at the same period of incubation showed that corals would have recorded net photosynthetic values of 63.6 $mg.O_2.mg^{-1}AFDW.h^{-1}$ at

salinity level of 25 ppt and 33.0 mg.O_2.mg^{-1}AFDW.h^{-1} at 40 ppt (Fig. 5). There were variations in the respiratory responses of the coral in the dark bottle but were not significantly different among the seven treatments (ANOVA $p>0.05$).

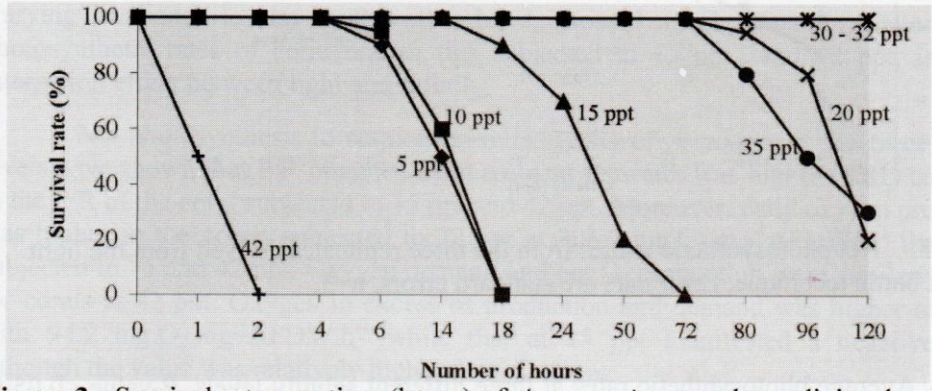

Figure 3. Survival rates vs. time (hours) of *A. yongei* exposed to salinity levels of 5, 10, 15, 20, ambient (30-32 ppt), 35 and 42 ppt. for five days.

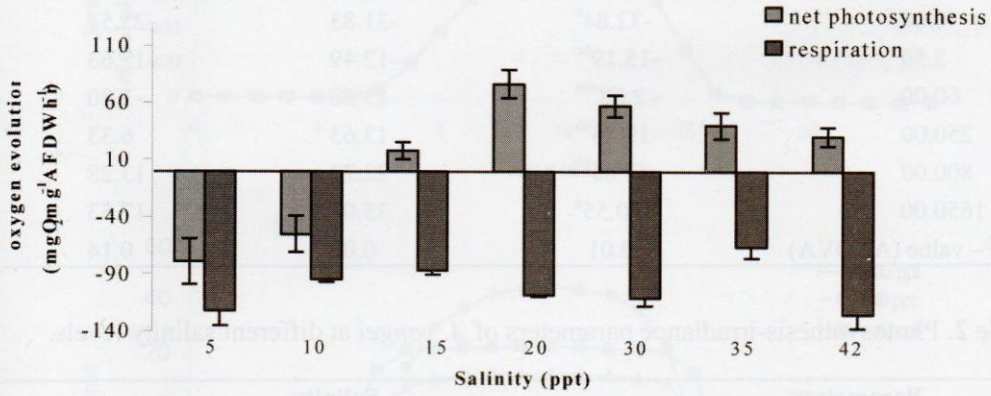

Figure 4. Average net photosynthesis and respiration of the coral, *A. yongei* at different salinity levels during one-hour incubation and under one light level. Error bars are standard error of the means, n=3

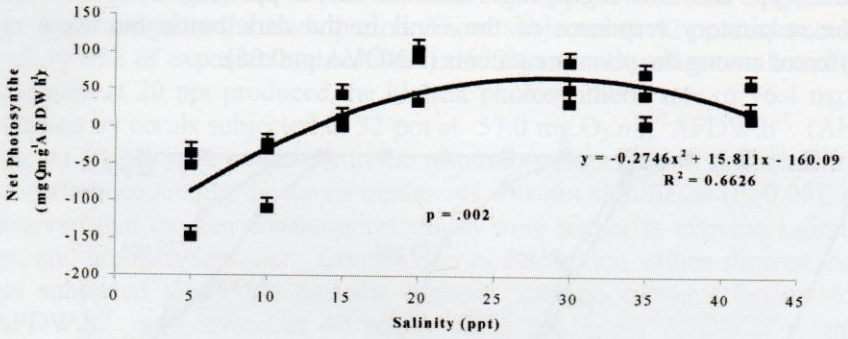

Figure 5. Net photosynthetic values from the three replicates derived from the light and dark bottle technique. Error bars are standard errors, n=3.

Table 1. Average photosynthetic rates at three different salinity levels. P-value <0.05 is considered significant. Values in the same column with the different superscript are significant ($p<0.05$)

Mean Irradiance	Average Photosynthetic Rate ($mgO_2mg^{-1}AFDWhr^{-1}$)		
	32 ppt	15 ppt	42 ppt
0.08	-32.84^{c}	-31.83	-25.51
3.50	-15.19^{bc}	-12.49	-12.63
60.00	-2.68^{abc}	13.38	-1.20
250.00	19.15^{ab}	13.63	6.33
800.00	42.86^{ab}	22.72	13.28
1650.00	50.55^{a}	35.01	17.53
P– value (ANOVA)	0.01	0.06	0.14

Table 2. Photosynthesis-irradiance parameters of *A. yongei* at different salinity levels.

Parameters	Salinity		
	15 ppt	32 ppt	42 ppt
P_{max} ($mgO_2mg^{-1}AFDWhr^{-1}$)	54.14	88.12	36.34
I_k (µmol photons $m^{-2}s^{-1}$)	11.54	232.00	49.39
R ($mgO_2mg^{-1}AFDWhr^{-1}$)	29.42	24.39	20.64
LCP (µmol photons $m^{-2}s^{-1}$)	13.73	88.79	64.93
P:R	0.92	1.81	0.88

Photosynthesis-Irradiance Curve

The effect of irradiance on the rate of photosynthesis was found to be significant ($p<0.05$) only at 32 ppt resulting in an increase in photosynthetic rate (Tables 1-3). Varying irradiance levels, on the other hand, showed no significant variation in the photosynthetic rates of coral branch tips subjected to 15 ppt and 42 ppt, including interaction effect between light and salinity.

Net photosynthesis to respiration ratios (P:R) of *A. yongei* at the three salinity levels have shown that P:R obtained from ambient seawater was higher (1:81) compared to the P:R of the coral subjected to 15 ppt and 42 ppt. Moreover, daily oxygen production was higher in the corals subjected to 32 ppt at 306.2 $mg.O_2.mg^{-1}AFDW.h^{-1}$ than those subjected to 15 and 42 ppt. Oxygen demand and net O_2 production were similarly lowest for corals at 42 ppt. Oxygen in excess of production and demand was higher at 32 ppt with 94.2 $mg.O_2.mg^{-1}AFDW.h^{-1}$ while that at 15 ppt manifested a negative value, although the value was relatively higher than at 42 ppt.

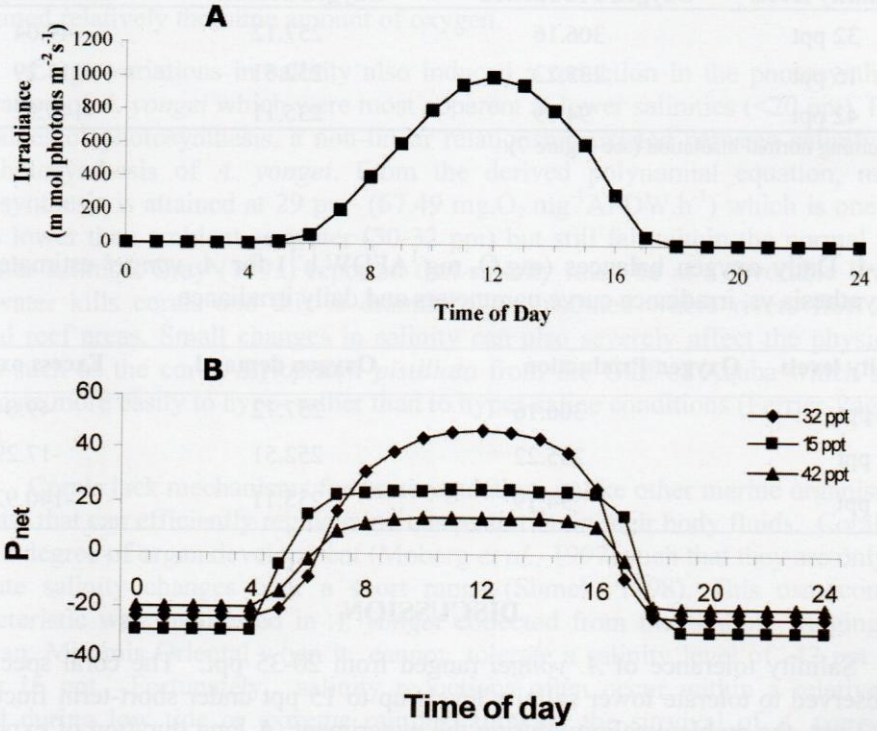

Figure 6. Estimated daily irradiance (A), and net photosynthesis (B) for *A. yongei* grown in the laboratory.

The Michaelis-Menten rectangular hyperbolic model fitted to the photosynthesis-irradiance data sets was used to predict the P_{max} rate of photosynthesis and irradiance levels on a 24-hour basis (Fig. 6). The estimates showed a directly proportional relationship between the photosynthetic responses of the coral and irradiance which peaked between 1100 h to 1300 h and decreased towards late afternoon.

Oxygen balances for *A. yongei* estimated from the hourly-predicted net photosynthesis obtained from the P-I curve parameters are shown in Table 4. The daily oxygen production was higher in the corals subjected to 32 ppt at 306.16 $mg.O_2.mg^{-1}$ $AFDW.h^{-1}$ while a very low O_2 production was exhibited by *A. yongei* at 42 ppt. Oxygen demand and net O_2 production were similarly lowest for corals at 42 ppt. Oxygen in excess of production and demand was higher at 32 ppt with 94.19 $mg.O_2.mg^{-1}AFDW.h^{-1}$ while a negative value was obtained at 15 ppt suggesting that oxygen demand exceeded production at these two levels.

Table 3. Daily oxygen balances ($mg.O_2.mg^{-1}AFDW.h^{-1}$) for *A. yongei* estimated from photosynthesis vs. irradiance curve parameters and daily irradiance.

Salinity levels	Oxygen Production	Oxygen demand	Excess oxygen
32 ppt	306.16	257.12	49.04
15 ppt	235.22	252.51	-17.29
42 ppt	94.19	235.11	-140.92

*assuming normal insolation (see Figure 7).

Table 4. Daily oxygen balances ($mg.O_2.mg^{-1}AFDW.h^{-1}$) for *A. yongei* estimated from photosynthesis vs. irradiance curve parameters and daily irradiance.

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42 ppt	94.19	235.11	-140.92

DISCUSSION

Salinity tolerance of *A. yongei* ranged from 20-35 ppt. The coral species was also observed to tolerate lower salinity levels up to 15 ppt under short-term fluctuations from 32 ppt, the ambient salinity during the experiment. A long duration of exposure to these low levels, however, can be damaging to the corals so that when recovery rates are low, the damage may be irreversible and the corals will eventually die. Sublethal symptoms in the form of partial and total bleaching with or without the presence of mucus secretions occurred at 5, 10 and 42 ppt. More severe stress symptoms, on the

other hand, were exhibited in corals subjected to 42 ppt as evidenced by instantaneous mucus secretions in just two hours of exposure. An initial stress symptom of corals incubated at 35 and 42 ppt was the expulsion of mucus from the coralla which was heavy at 42 ppt. This may probably explain the relatively lower photosynthetic rates as mucus film also reduces the irradiance received by a part of the zooxanthellae population.

The reduction of oxygen in the dark bottle indicated the extent of respiration by the corals and the subsequent decreasingly available oxygen resulted in a diminished respiration. Corals incubated at lower salinity levels, which exhibited negative net photosynthetic values also recorded higher respiration values. In addtion, the results would seem to indicate that the corals at lower salinities and those at 42 ppt consume oxygen more than their oxygen production both in the presence and absence of light.

The relatively higher respiration of *A. yongei* at 10, 15 and 35 ppt than at 20 and 30 ppt, however, would tend to indicate more oxygen consumption at these levels probably due to their response to salinity stress. Reduced respiration values indicated the occurrence of oxygen consumption among the coral branch tips subjected to the different salinities. However, respiration rates did not show significant variation among treatments which would seem to indicate that corals exposed to the different test salinity levels consumed relatively the same amount of oxygen.

Large variations in salinity also induced a reduction in the photosynthesis and respiration of *A. yongei* which were most apparent at lower salinities (<20 ppt). Based on the values of photosynthesis, a non-linear relationship existed between salinity and the net photosynthesis of *A. yongei*. From the derived polynomial equation, maximum photosynthesis is attained at 29 ppt ($67.49\ mg.O_2.mg^{-1}AFDW.h^{-1}$) which is one to three levels lower than ambient seawater (30-32 ppt) but still fall within the normal range of seawater salinity. Gray (1993) reported that salinity must be at a favorable level since freshwater kills corals and this is dramatically illustrated where rivers flow out into coastal reef areas. Small changes in salinity can also severely affect the physiology of corals such as the coral, *Stylophora pistillata* from the Gulf of Aqaba which seems to acclimate more easily to hypo- rather than to hyper-saline conditions (Ferrier-Pages *et al.*, 1999).

Corals lack mechanisms for osmoregulation, unlike other marine organisms (e.g., teleosts) that can efficiently regulate ion concentration in their body fluids. Corals have a limited degree of organ development (Moberg *et al.*, 1997) such that they are only able to regulate salinity changes over a short range (Shmek, 1998). This osmoconforming characteristic was manifested in *A. yongei* collected from the shallow fringing reef of Naawan, Misamis Oriental when it cannot tolerate a salinity level of 42 ppt and that below 15 ppt. Fortunately, salinity reductions often occur within a relatively short period during low tide or extreme rainfall, allowing the survival of *A. yongei* in the neashore reef ecosystem. Massive coral lifeforms such as faviids appear more tolerant to salinity change than acroporiids and pocilloporids (Van Woesik, 1994).

Results from observations of stress manifestations in the present study suggest that *A. yongei* is more tolerance to narrow fluctuations at lower salinities (<20 ppt) than at

higher salinities (42 ppt). Excessive mucus secretion as a sign of stress (Moberg *et al.*, 1997) was observed only in corals exposed to 42 ppt with subsequent bleaching after two hours. Bleaching occurs when environmental stresses cause the corals to suffer a loss of zooxanthellae (Ferrier-Pages, *et al.*, 1999). Polyps usually become inactive when bleaching begins as the symbiotic algae are expelled (Marcus & Thorhaug, 1981). Mucus samples frequently contain zooxanthellae (Klumpp, 1995) which are symbionts of hermatypic corals, producing O_2 and helping the corals remove wastes. Recovery rates from bleaching appear to differ with species and the time required to attain full recovery of the symbiotic algae may also vary (Moberg *et al,*. 1997). A possible reason for the reduction in photosynthesis is the natural tendency of corals to contract their polyps in order to minimize contact with low saline water (Muthiga & Szmant, 1987). Although corals can survive for brief periods in salinities well outside their normal ranges, they eventually die when the level of environmental stress is high and sustained, or when they are kept longer outside of that range (Van Woesik, 1994).

Reduced respiration values indicated oxygen consumption among the coral branch tips subjected to different salinities, however, variations in respiration rates at different salinity levels were small, implying that the corals consumed relatively the same amount of oxygen. Results of this study agree with the findings of Ferrier-Pages *et al.* (1999) on *Stylophora pistillata* where a significant decrease in the respiration of the organism was observed following reduction in salinity. A direct relationship between the rate of respiration and photosynthesis in *A. yongei* has been shown in the present experiment. Moberg *et al., (*1997) have reported that a reduced photosynthesis is also accompanied by a decreased respiratory rate. Such a reaction entails metabolic costs for maintenance, which is described as an important function in the cellular response of the coral to stress (Ferrier-Pages *et al.*, 1999). Respiration at extremely low and high test salinity levels (5 ppt and 42 ppt) were lower than those at ambient salinity which suggests that the coral at these levels has reached the stage when adaptive response to stress was progressively weakened (Pickering, 1981).

The turbid condition on some periods when the coral was collected may further explain the ability of *A. yongei* to reach saturation irradiance sooner at lower light levels. Light compensation point recorded at 89.9 µmol photons $m^{-2}.s^{-1}$ at 32 ppt may also supplement the observation that the area where *A. yongei* was found abundant can be silted in the aftermath of rainfall or freshwater runoff events. The minimum light to initiate photosynthesis was, however, lower at 15 ppt (67.4 µmol photons m^{-2} s^{-1}) and at 42 ppt (65.7µmol photons.$m^{-2}.s^{-1}$) compared to the observed LCP at 32 ppt. Although *A. yongei* at these salinity levels (15 and 42 ppt) had efficient use of low light intensity, the curve reached a plateau sooner than expected and stopped its maximum potential to photosynthesize. Turbidity levels in the area after rainfall, however, were not measured during the conduct of the present study but a reduction in salinity from runoff has been shown to be often accompanied by sedimentation (Veron, 1986; Yap and Montebon, 1992). This would limit the path of light for the corals (Van Woesik, 1994) and affect the photosynthetic rates of the zooxanthellae (Titlyanov, 1981; Veron, 1986). The observed and predicted photosynthesis to respiration ratios of *A. yongei* at different salinity levels revealed that photosynthesis to respiration ratio varied as a function of salinity. The ratio

was reduced when the corals were subjected to salinity lower than 20 ppt and higher than 35 ppt. The P:R ratio of *A. yongei* at ambient salinity (1:81) was higher compared to the P:R ratio obtained in *Stylophora pistillata* at 1:3 at 34 ppt (Ferrier-Pages *et al.*, 1999). Sorokin (1981) suggested normal ranges in the P:R ratio between 0.8 and 3.5 for *Pocillopora* and 0.3 and 3.6 for *Porites*. Based on these values, it would appear that the P:R ratio obtained in the present study is assumed to be adequate for autotrophic maintenance of *A. yongei*.

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