

The effect of high and extreme temperature increase on the coral *Porites lutea* and five different algae in northern Vietnam

T.L. Jörgensen¹, S. Faxneld¹, M. Tedengren¹

1) Department of Systems Ecology, Stockholm University, SE-106 91 Stockholm, Sweden.

Abstract. Global warming and increasing sea surface water temperatures have shown to induce bleaching events and generate phase shifts on coral reefs. Here we investigated the physiological responses (gross primary production, respiration and GP/R ratio) to high temperature (30°C, i.e. +5°C above control) and extreme temperatures (34°C, i.e. +9°C above control) during 24 hours on one coral species (*Porites lutea*) and five algae species. The result from the organisms' GP/ R ratio showed that only *Sargassum sp.* (*Phaeophyta*) was significantly negatively affected by elevated temperature (34°C). However, the results showed a positive correlation between the GP/ R ratio and temperature for *Gracilaria asiatica* (*Rhodophyta*). None of the other organisms showed any significant changes in GP/R ratio as a result of treatment. *Asparagopsis taxiformis* (*Rhodophyta*) showed an increase in both gross primary production and respiration. *P. lutea* showed a decrease in both gross primary production and respiration. The physiological responses to increased temperatures differed among the coral reef organisms', even within the same phylum. As a result, this may indicate that the consequences of the imminent global warming may be severe, since it may not only have a negative impact on coral reef organisms directly, but also indirectly, by altering competitive ability between species.

Key words: Increased sea water temperature, physiological responses, algae, *Porites lutea*.

Introduction

Global warming and increasing sea water temperatures have shown to induce bleaching events (Hoegh-Guldberg 1999) and coral mortality (Wilkinson 2004), which furthermore may generate phase shifts on coral reefs (Hughes et al. 2003). In combination with other anthropogenic factors, such as over-fishing (Jackson et al. 2001; Berkes et al. 2006), sedimentation (McCulloch et al. 2003) and pollution (reviewed by Fabricius 2005), this has caused worldwide coral reef degradation (Wilkinson 2000; Jackson et al. 2001).

Coral bleaching causes coral mortality and thereby opens up substratum, which leads to a "window of opportunity" for opportunistic algae to colonize (McClanahan et al. 2001). If herbivores are present they can prevent the algae to overgrow the corals (Hughes et al. 2007). However, if macroalgae successfully establish, a phase shift from coral dominance to macroalgae-dominated state may occur (Done 1992).

On many reefs there have already been transitions from coral dominance to macroalgae dominance due to overfishing of herbivores (Gardner et al. 2003; Hughes et al. 2003; Bellwood et al. 2004). These reefs may therefore lose biodiversity and essential ecosystem services (Nyström et al. 2000) and thus be

more vulnerable to climate change (Hughes et al. 2007).

The aim of this study was to investigate the physiological effects of high (30°C) and extreme temperature (34°C) increases on one coral species (*Porites lutea*) and five different algae from three different phyla *Ulva compressa*, *Ulva torta* (*Chlorophyta*), *Gracilaria asiatica*, *Asparagopsis taxiformis* (*Rhodophyta*) and *Sargassum sp.* (*Phaeophyta*).

Material and methods

P. lutea, *A. taxiformis* and *Sargassum sp.* were collected at Long Chau Island, Halong Bay (N 20° 37' 27", E 107° 09' 41") in northern Vietnam. *U. compressa*, *G. asiatica* and *U. torta* were collected in aquaculture ponds close to the lab. Both coral and algae organisms had 72 hours to acclimatize to the lab environment before the experiment started. The experiment was carried out during March 2007 in an outdoor lab at Tram Bien Research Station in Do Son, northern Vietnam.

For the experiment 3 large tanks (1 m³ each) were used in order to minimise temperature fluctuations (Nyström et al. 2001; Nordemar et al. 2003). In each tank four aquaria (20 l each) were placed. In each aquarium 14 coral pieces or algae tissue were placed

using a randomized block design. During measurements the corals and algae were individually placed in separated transparent jars with air-tight lids, containing 1.5 litre of water each, with the same temperature as the exposure treatments. The three tanks represented: a) control (25°C), b) high increased temperature (30°C, i.e. +5°C above control) and c) extreme increased temperature (34°C, i.e. +9°C above control).

In the two exposure tanks, the temperature was increased by applying external heating regulators (ZEBO 300W or FLUVAL Tronic 200W). Aeration pumps mixed the sea water in both the aquaria and the tanks, thus maintaining high oxygen concentrations and distributing water temperature evenly. The experiment was conducted during natural moderate light conditions and the irradiance was 700 (± 308) $\mu\text{E}/\text{m}^2/\text{s}$ during the measurements.

The organisms were exposed for 24 hours. Thereafter changes in dissolved oxygen concentration were measured in light (net production) and in darkness (respiration) according to Moberg et al. (1997) using an oxymeter (WTW Oxi 330). To measure the net production, the oxygen level was noted initially and the containers were placed outdoor in full daylight. The oxygen levels were noted again after 30 minutes. To measure the respiration, the organisms were placed in darkness for 30 minutes to adapt to darkness and stop primary production (Moberg et al. 1997), before the initial oxygen value was measured. The oxygen levels were measured once more after 2 hours in darkness.

Before the statistical analyses, the volume of the whole coral was measured by submerging the coral into a beaker filled with a known volume of water, to compensate for volume dependent differences in dissolved oxygen concentration. Thereafter the coral's surface was measured by using the aluminium foil method (March 1970).

Gross primary production rate and respiration rate data were calculated per hour and per cm^2 coral surface area (Moberg et al. 1997) and expressed as O_2 (mg)/h* cm^2 . Furthermore, the dry weight of the algae was noted and then the gross primary production and respiration rates were expressed as O_2 (mg)/h*dry weight (g).

For both corals and algae the respiration rate was added to the net production value in order to achieve gross primary production rate (here after referred as gross production). Gross primary production/respiration (GP/R) ratios were also calculated.

A one-way ANOVA was performed to analyse the effects of treatments for each species. Where the one-way ANOVA showed differences, Tukey HSD was used as a post hoc test ($p < 0.05$). To investigate correlations in the data, Pearson correlation test was

used. All data were tested for homogeneity of variances using Levene's test ($p < 0.05$) before the ANOVA was carried out. For *U. compressa* and *U. torta* only the data from the control and 30°C treatment group was included in the statistical analysis, since the values from the 34°C treatment group were considered inaccurate. A t-test was used as a statistical test. For the statistical analyses the software SPSS 13.0 edition for Mac OS X was used.

Results

GP/R ratio

The result from the organisms' GP/R ratio showed that *Sargassum sp.* was negatively affected by elevated temperature ($p < 0.001$, $r = -0.893$ Pearson correlation) (Fig. 1). The 30°C treatment ($p < 0.05$, Tukey HSD) and the 34°C treatment ($p < 0.001$ Tukey HSD) had a lower GP/R ratio compared to the controls (Fig. 1).

For *G. asiatica* the GP/R ratio showed a trend with a higher GP/R for the algae in the 34°C treatment group compared to the controls ($p = 0.071$ Tukey HSD) (Fig. 1). There was also a positive correlation between the GP/R ratio and temperature for *G. asiatica* ($p < 0.05$, $r = 0.488$ Pearson correlation). None of the other organisms (*P. lutea*, *A. taxiformis*, *U. compressa* and *U. torta*) showed any variation in GP/R ratio as a response to high or extreme temperature increase (Fig. 1, 4).

Gross primary production rates

The results from the gross production rates showed that increased temperature had variable effect on the coral and the algae species.

The gross production rate increased significantly with increased temperature in *A. taxiformis*, for both the 30°C ($p < 0.05$ Tukey HSD) and the 34°C treatment group ($p < 0.001$ Tukey HSD) (Fig. 2).

A different result was found in *Sargassum sp.*, where the gross production rates decreased in the 34°C treatment group compared to the control, however this was not significant compared to the controls ($p = 0.053$ Tukey HSD). However, the 34°C treatment group had a lower gross production rate compared to the 30°C treatment group ($p < 0.01$ Tukey HSD) (Fig. 2).

P. lutea showed a lower gross production rate in the 34°C exposure compared to the controls, however, this was not significant ($p = 0.058$ Tukey HSD).

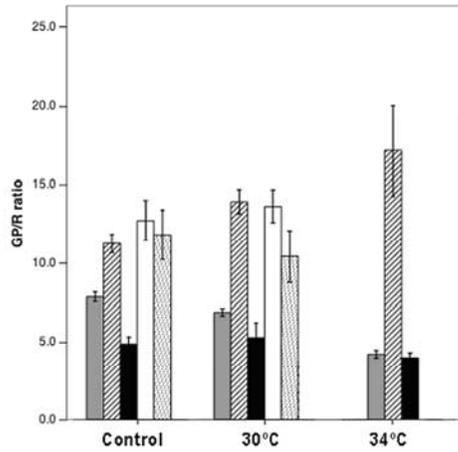


Figure 1: GP/R ratio. *Sargassum sp.* (grey): Control vs. 30°C *, Control vs. 34°C ***. *Gracilaria asiatica* (striped): Control vs. 34°C trend $p=0.071$. *Asparagopsis taxiformis* (black), *Ulva torta* (white), *Ulva compressa* (dotted): ns. $n=7$. Error bars: SE. * $p<0.05$, *** $p<0.001$, ns= non significant.

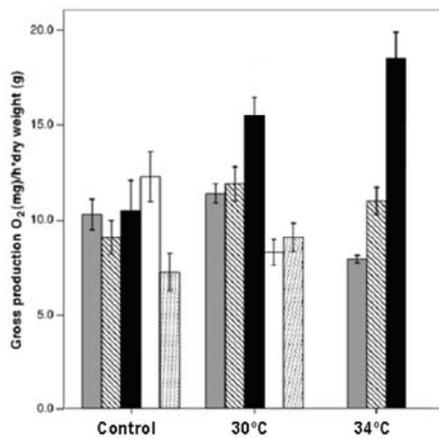


Figure 2: Gross primary production rates. *Asparagopsis taxiformis* (black): Control vs. 30°C *. Control vs. 34°C ***. *Sargassum sp.* (grey): Control vs. 34°C trend $p=0.053$. 30°C vs. 34°C **. *Gracilaria asiatica* (striped), *Ulva torta* (white), *Ulva compressa* (dotted): ns. $n=7$. Error bars: SE. * $p<0.05$, ** $p<0.01$, *** $p<0.001$, ns= non significant.

Furthermore, there was a significant difference between the higher gross production rate in the 30°C exposure compared to the 34°C exposure group ($p<0.01$ Tukey HSD) (Fig. 4). There were no significant results in gross production rates for *U. torta*, *U. compressa* or *G. asiatica* (Fig. 2).

Respiration rates

Sargassum sp. showed an increase in respiration rate as a reaction to increased temperatures, with a significant difference between the control and the 34°C exposure group ($p<0.01$) (Fig. 3).

The respiration rates increased in *A. taxiformis* with temperature and showed a significant difference between the control and the higher respiration value in the 34°C treatment group ($p<0.001$), there was also a trend for an increase in respiration in the 30°C treatment compared to the control ($p=0.051$) (Fig. 3).

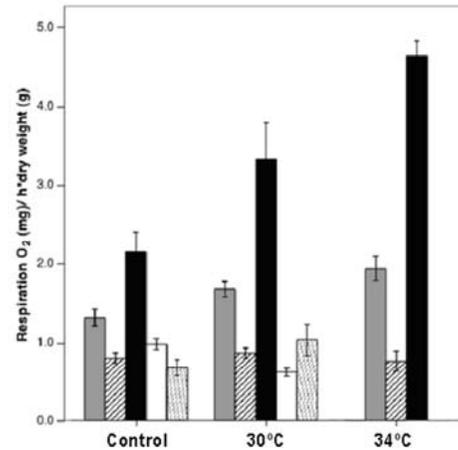


Figure 3: Respiration rates. *Sargassum sp.* (grey): Control vs. 34°C **. *Asparagopsis taxiformis* (black): Control vs. 30°C trend $p=0.051$. Control vs. 34°C ***. 30°C vs. 34°C *. *Ulva torta* (white): Control vs. 30°C **. *Gracilaria asiatica* (striped), *Ulva compressa* (dotted): ns. $n=7$. Error bars: SE. * $p<0.05$, ** $p<0.01$, *** $p<0.001$, ns= non significant.

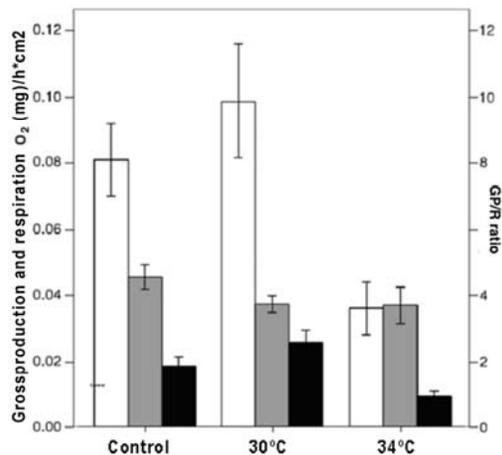


Figure 4: GP/R ratio, gross primary production and respiration rates for *Porites lutea*. Gross primary production (white): Control vs. 34°C trend $p=0.058$. 30°C vs. 34°C **. Respiration (black): Control vs. 34°C trend $p=0.082$. 30°C vs. 34°C **. GP/R ratio (grey): ns. $n=7$. Error bars: SE. ** $p<0.01$, ns= non significant.

Furthermore, the 34°C treatment had a higher respiration compared to the 30°C treatment ($p<0.05$) (Fig. 3). *U. torta* showed a decrease in respiration rates between the control and the 30°C treatment group ($p<0.01$) (Fig. 3).

The respiration rate for *P. lutea* in the 34°C treatment group was lower than both the control ($p=0.082$) and the 30°C treatment group ($p<0.01$) (Fig. 4).

No significant differences could be found in *G. asiatica* or *U. compressa* (Fig. 3).

Discussion

Several authors have reported that increased temperature may have a negative effect on corals (Coles and Jokiel 1977; Fitt and Warner 1995; Hoegh-Guldberg and Smith 1989; Nyström et al. 2001). However, studies have shown a positive correlation between increased temperature and GP/R ratio in algae (Elwing and Tedengren 2000) and increased algae biomass (Tsai et al. 2005).

The results from the study showed dissimilar responses in GP/R ratio to elevated temperature for the algae species. *Sargassum sp.* was negatively affected by increased temperature, which was reflected in a decrease in GP/R ratio. In the field, Ateweberhan et al. (2005) showed that the highest growth rate for *Sargassum sp.* occurred at 28-30°C, while the growth rate was below zero when the temperature reached 33-36°C. Furthermore, *Sargassum sp.* has shown to be a late succession species (Hughes et al. 2007), which establish after green filamentous algae (Kokita and Nakazono, 2001), such as *Enteromorpha* (McClanahan 1997). Our results showed that neither *U. torta* nor *U. compressa* was negatively affected by a high increase in temperature. This suggests that increased sea water temperature may have a limited effect on early succession algae species, which may or may not be followed by a succession of brown frondous algae.

In contrast to *Sargassum sp.*, *G. asiatica* was positively affected with an increase in GP/R ratio, in response to elevated temperature. A decrease in gross production rate together with an increase in respiration rate explained the changes in GP/R ratio for *Sargassum sp.*, while the result for *G. asiatica* was explained by a stimulated gross production rate whereas no change in respiration was noted. A positive relationship between temperature and growth rate for *Gracilaria coronopifolia* has been found by other authors (Tsai et al. 2005). Furthermore the results showed that *A. taxiformis* increased both gross production and respiration rates due to the temperature treatment, however the GP/R ratio was not affected. This in turn might indicate higher metabolic requirements and energetic costs due to thermal stress (Bayne et al. 1985). On disturbed coral reefs, *Asparagopsis taxiformis* may completely dominate the reef and form large canopy (Diaz-Pulido and McCook 2002), which, especially in the absence

of herbivores, may prevent corals to re-establish after disturbances (Hughes et al 2007).

In this study *P. lutea* did not show any changes in GP/R ratio due to heat treatment. Nevertheless, both gross production and respiration rates were affected, indicating that increased temperature had an effect on the coral's metabolism, at least to some extent.

A possible explanation to these results may be that the corals in the region may be adapted to large variation in seasonal temperature, as has been noted in other regions (Kemp et al. 2006), since the water temperature may fluctuate between 16°C and 31°C in the Halong Bay area during the year (Nguyen 2004; Latypov 2005). Upper thermal limits have been shown to vary between the same coral species in different regions (Hughes et al. 2003), suggesting that local adaptation may occur (Cook et al. 1990).

Furthermore, *P. lutea* has been shown to be tolerant to elevated temperatures and has been known to prevail during bleaching events (Loya et al. 2001; Baker et al. 2004; McClanahan et al. 2007). Nevertheless, our results suggest that since increased temperature in fact benefited several of the algae species, but had a limited effect on *P. lutea*, this may alter the competition between the species.

The results from this experiment demonstrate that coral reef organisms' physiological responses to increased temperatures vary between species, even within the same phylum. This in turn suggests that the consequences of global warming may be severe, since it not only will affect coral reef organisms directly, by reduced metabolism/growth rate and increasing mortality, but also indirectly by altering their relative competitive ability, which in turn may lead to decreased biodiversity and an increase in coral reef vulnerability to further anthropogenic or natural disturbances.

In addition, during periods of elevated temperatures, this could have further implications. If several species of algae may in fact be positively affected by elevated temperatures this may lead to a more rapid overgrowth of algae after e.g. bleaching events, and thereby contribute to a phase shift, especially in areas where herbivore fish and invertebrates are more or less absent, due to over-exploiting of marine resources.

Acknowledgement

This research project was sponsored by Sida. We would also like to thank the staff at Tram Bien Research Station in Do Son, for all their help!

References

- Ateweberhan M, Bruggemann JH, Breeman AM (2005) Seasonal dynamics of *Sargassum ilicifolium* (Phaeophyta) on a shallow reef flat in the southern Red Sea (Eritrea). *Mar Ecol Progr Ser* 292:159-171

- Baker AC, Starger CJ, McClanahan TR, Glynn PW (2004) Corals' adaptive response to climate change. *Nature* 430:741
- Bayne BL, Brown DA, Burns K, Dixon DR, Ivanovici A, Livingstone DR, Lowe DM, Moore MN, Stebbing ARD, Widdows J (1985) The effect of stress and pollution on marine animals. Praeger Publishers, New York
- Bellwood DR, Hughes TP, Folke C, Nyström M (2004) Confronting the coral reef crisis. *Nature* 429:827-833
- Berkes F, Hughes TP, Steneck RS, Wilson JA, Bellwood DR, Crona B, Folke C, Gunderson LH, Leslie HM, Norberg J, Nyström M, Olsson P, Österblom H, Scheffer M, Worm B (2006) Globalization, roving bandits, and marine resources. *Science* 311(5767):1557-1558
- Coles SL, Jokiel PL (1977) Effects of temperature on photosynthesis and respiration in hermatypic corals. *Mar Biol* 43:209-216
- Cook CB, Alan L, Ward J, Luckhurst B, Berg CJ (1990) Elevated temperatures and bleaching on a high latitude coral reef: the 1988 Bermuda event. *Coral Reefs* 9:45-49
- Diaz-Pulido G, McCook LJ (2002) The fate of bleached corals: patterns and dynamics of algal recruitment. *Mar Ecol Prog Ser* 232:115-128
- Done TJ (1992) Phase shifts in coral reef communities and their ecological significance. *Hydrobiologia* 247:121-132
- Elfwing T, Tedengren M (2000) A comparison of production effects between corals and macroalgae at increased seawater temperature. *Proc 9th Int Coral Reef Symp* 2:1139-1142
- Fabricius KE (2005) Effects of terrestrial runoff on the ecology of corals and coral reefs: review and synthesis. *Mar Pollut Bull* 50:125-146
- Fitt WK, Warner ME (1995) Bleaching patterns in four species of Caribbean reef corals. *Biol Bull* 189:298-307
- Gardner TA, Côte IM, Gill JA, Grant A, Watkinson AR (2003) Long-term region-wide declines in Caribbean corals. *Science* 301:958-960
- Hoegh-Guldberg O (1999) Climate change, coral bleaching and the future of the world's coral reefs. *J Mar Freshwater Res* 50:839-866
- Hoegh-Guldberg O, Smith JG (1989) The effect of sudden changes in temperature, light and salinity on the population density and export of zooxanthellae from the reef corals *Stylophora pistillata* Esper and *Seriatopora hystrix* Dana. *J Exp Mar Biol Ecol* 129:279-303
- Hughes TP, Baird AH, Bellwood DR, Card M, Connolly SR, Folke C, Grosberg R, Hoegh-Guldberg O, Jackson JBC, Kleypas J, Lough JM, Marshall P, Nyström M, Palumbi SR, Pandolfi JM, Rosen B, Roughgarden J (2003) Climate change, human impacts, and the resilience of coral reefs. *Science* 301:929-933
- Hughes TP, Rodrigues MJ, Bellwood DR, Ceccarelli D, Hoegh-Guldberg O, McCook L, Moltschanivskyj N, Pratchett MS, Steneck RS, Willis B (2007) Phase shifts, herbivory, and the resilience of coral reefs to climate change. *Curr Biol* 17:360-365
- Jackson JBC, Kirby MX, Berger, WH, Bjorndal KA, Botsford LW, Borque BJ, Bradbury RH, Cooke R, Erlandson J, Estes JA, Hughes TP, Kidwell S, Lange CB, Lenihan HS, Pandolfi JM, Peterson CH, Steneck RS, Tegner MJ, Warner RR (2001) Historical overfishing and the recent collapse of coastal ecosystems. *Science* 293:629-638
- Kemp DW, Cook CB, LaJeunesse TC, Brooks WR (2006) A comparison of the thermal bleaching responses of the zoanthid *Palythoa caribaeorum* from three geographically different regions in south Florida. *J Exp Mar Biol Ecol* 335:266-276
- Kokita T, Nakazono A (2001) Rapid response of an obligately corallivorous filefish *Oxymonacanthus longirostris* (Monacanthidae) to a mass coral bleaching event. *Coral Reefs* 20:155-158
- Latypov YY (2005) Reef-building corals of Vietnam as a part of the Indo-Pacific reef ecosystem. *Russian J Mar Biol* 31:34-40
- Loya Y, Sakai K, Yamazato K, Nakano Y, Sambali H, van Woesik R (2001) Coral bleaching: the winners and the losers. *Ecol Lett* 4:122-131
- March JA (1970) Primary productivity of reef-building calcareous red algae. *Ecology* 51:255-263
- McClanahan TR (1997) Primary succession of coral-reef algae: Differing patterns of fished versus unfished reefs. *J Exp Mar Biol Ecol* 218:77-102
- McClanahan TR, Muthiga NA, Mangi S (2001) Coral and algal changes after the 1998 coral bleaching: interaction with reef management and herbivores on Kenyan reefs. *Coral reefs* 19:380-391
- McClanahan TR, Ateweberhan M, Graham NAJ, Wilson SK, Ruiz Sebastián C, Guillaume MM, Bruggemann JH (2007) Western Indian Ocean coral communities: bleaching responses and susceptibility to extinction. *Mar Ecol Prog Ser* 337:1-13
- McCulloch M, Fallon S, Wyndham T, Hendy E, Lough J, Barnes D (2003) Coral record of increased sediment flux to the inner Great Barrier Reef since European settlement. *Nature* 421:727-730
- Moberg F, Nyström M, Kautsky N, Tedengren M, Jarayabhand P (1997) Effects of reduced salinity on the rates of photosynthesis and respiration in the hermatypic corals *Porites lutea* and *Pocillopora damicornis*. *Mar Ecol Prog Ser* 157:53-59
- Nguyen DN (2004) Causes of coral degradation and solutions for the protection and rehabilitation of coral reefs in Ha Long – Cat Ba. in: Thanh TD (ed) Marine resources and environment, TOME XI (2004) Vietnamese academy of science and technology, Institute of Marine environment and resources, Haiphong, Vietnam, pp 194-212
- Nordemar I, Nyström M, Dizon R (2003) Effects of elevated seawater temperature and nitrate enrichment on the branching coral *Porites cylindrica* in the absence of particulate food. *Mar Biol* 142:669-677
- Nyström M, Folke C, Moberg F (2000) Coral reef disturbance and resilience in a human-dominated environment. *TREE* 15:413-417
- Nyström M, Nordemar I, Tedengren M (2001) Simultaneous and sequential stress from increased temperature and copper on the metabolism of the hermatypic coral *Porites cylindrica*. *Mar Biol* 138:1225-1231
- Porter JW, Fitt WK, Spero HJ, Rogers CS, White MW (1989) Bleaching in reef corals: physiological and stable isotopic responses. *Proc Natl Acad Sci USA*. 86:9342-9346
- Tsai C-C, Chang J-S, Sheu F, Shyu Y-T, Yu A Y-C, Wong S-I, Dai C-F, Lee T-M (2005) Seasonal growth dynamics of *Laurencia papillosa* and *Gracilaria coroniofolia* from a highly eutrophic reef in southern Taiwan: temperature limitation and nutrient availability. *J Exp Mar Biol Ecol* 315:49-69
- Wilkinson C (2000) Status of coral reefs of the world: 2000. Australian Institute of Marine Science, Townsville, Queensland, Australia
- Wilkinson C (2004) Status of coral reefs of the world: 2004. Australian Institute of Marine Science, Townsville, Queensland, Australia