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Thermal photo-physiological responses of massive heat-resistant coral *Porites lutea* under fish predated versus non-predated conditions

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Abstract. *Ricot M, Jeetun S, Joggee S, Kaullysing D, Taleb-Hossenkhan N, Bhagooli R. 2023. Thermal photo-physiological responses of massive heat-resistant coral* Porites lutea *under fish predated versus non-predated conditions. Indo Pac J Ocean Life 7: 38-47.* Fish predation on corals leading to polyp and tissue loss has been identified as a significant stressor to corals and is often associated with reduced growth, reproduction, and even mortality. However, how climate change-driven ocean warming may impact such a biological stressor is yet to be thoroughly understood. This study aimed to assess elevated temperature's effects on the photo-physiology of fish-predated and non-predated parts of the thermally resistant coral *Porites lutea* (Quoy & Gaimard, 1833). The objectives were to assess the photo-physiological parameters such as effective quantum yield at photosystem II (FPSII), relative maximum electron transport rate ($rETR_{max}$), maximum photo-chemical quenching (NPQ_{max}), photosynthetic efficiency (α), photoinhibition (β) and Ik at fish bite-affected (BA) and non-affected (NA) coral parts at temperatures of 28°C and 32°C under low-light (10 µmol quanta $m^{-2}s^{-1}$) and moderate-light (110 µmol quanta $m^{-2}s^{-1}$) conditions for a duration of 48hr. FPSII, $rETR_{max}$ and NPQ_{max} were not negatively affected by fish predation conditions. Under moderate light, the $rETR_{max}$ increased in the non-predated condition at 28°C but not at 32°C while the NPQ_{max} exhibited a more pronounced increase at 32°C compared to the 28°C treatment. The absence of significant declines in FPSII and $rETR_{max}$ accompanied by a significant increase in NPQ_{max} at 32°C is indicative of a lack of photo-inhibition and an active quenching of energy in a non-harmful way at PSII. No significant interactions of temperature and predation condition and light and predation condition were found, indicating that short-term exposure of 2 days to an elevated temperature of 32°C and moderate light intensity of 110 µmol quanta $m^{-2}s^{-1}$ did not result in any exacerbated negative photo-physiological impacts of fish predation in *P. lutea*. These findings suggest that both fish-predated and non-predated conditions in *P. lutea* are equally tolerant to the tested elevated temperature level. Thus, ocean warming events may not differentially impact their photosynthetic activities.

Keywords: Elevated temperature, photo-physiology, *Porites*, predation, stress

INTRODUCTION

Coral reefs support an array of ecosystem goods and services that contribute to the well-being of millions of people (Woodhead et al. 2019). However, the coral reefs have endured disturbances of such broad scale and severity in the past decade, that changes in the coral assemblages, and composition and physical appearance were observed (Hughes et al. 2017, 2018). Coral reefs throughout the tropics have been severely impacted by climate change through tropical storms and coral bleaching (Hughes et al. 2018). Extensive loss of coral cover owing to coral mortality following temperature-induced bleaching has been reported globally (Monroe et al. 2018; Sully et al. 2019) and around Mauritius (Bhagooli and Klaus 2014; Bhagooli and Kaullysing 2019; Bhagooli et al. 2021a; McClanahan and Muthiga 2021). Moreover, the uneven susceptibility of corals of different taxa to stressors has led to broad changes in the coral community (Huertas et al. 2021). The species such as the massive *Porites*, which are bleaching-resistant, often survive bleaching episodes that are capable of killing other corals which are more susceptible (McClanahan et al. 2007; Prachett et al. 2013). For instance, on the Great Barrier Reef, a rise in the proportion of massive *Porites* compared with the remaining coral cover has been reported (Hughes et al. 2018).

The changes in coral cover resulting from acute disturbances are rapidly noticeable (Hughes et al. 2018) and aftermaths of coral loss has domino effects throughout the whole ecosystem (Prachett et al. 2011). Hence, the probable loss of biodiversity in these systems has put forward the crucial need to comprehend the main factors sustaining the diversity of the reef and upholding coral reef resilience (Bellwood et al. 2004), which is important as the effect of climate change on coral reef is expected to escalate (Bonaldo and Bellwood 2011; Hughes et al. 2017). In this line, coral predation by reef fishes has been investigated (Rotjan and Lewis 2008; Mumby 2009; Rotjan and Lewis 2009), exhibiting the significance of predation as one of the major natural factors influencing the distribution and abundance of corals on coral reefs (Littler et al. 1989; Rotjan and Lewis 2005).

Even though parrotfishes mostly feed on substratum covered by algal turf, they scrape the surface of live corals as well (Rotjan and Lewis 2005; Bonaldo and Bellwood 2011; Bruckner and Bruckner 2015). Under particular conditions, parrotfish corallivory may compromise the coral survival and henceforth regulate their abundances and distribution (Rotjan and Lewis 2005; Rotjan et al. 2006; Mumby 2009; Bonaldo and Bellwood 2011).

Colonies of hermatypic corals have proven to be very sensitive to thermal stress (Marshall and Baird 2000; Hoegh-Guldberg 2011) and the magnitude of predation can cause further ripple-effects on the corals (Kayal et al. 2012). Lacerations to tissues and wounds to the aragonite skeleton caused by predation require substantial energetic, molecular and cellular supplies in order to restore (Rice et al. 2019). Even small injuries on the skeletal or tissue structures can induce disturbances in growth and cause fitness consequences (Rotjan and Lewis 2008). Additionally, recurrent corallivory can become a source of chronic stress (Madeira et al. 2022).

Eco-physiological studies brought about insights into mechanisms used by corals while coping through thermal stress challenges (Madeira et al. 2022). Chlorophyll a fluorescence is being employed to a greater extent as a fast, non-intrusive, accurate, and practical measure of photosynthetic activity in marine photosynthetic organisms. This method has been used extensively in research to identify stress, resistance and acclimation/adaptation to stress in marine autotrophic organisms, particularly in the context of a globally changing marine climate (Bhagooli et al. 2021b)

As coral reefs cope with warming oceans and other anthropogenic stress, it is important to understand how these stressors will impact important interactions such as coral predation and their influence on the ecosystem structure and function of the coral reef. Therefore, this study aimed at investigating the short-term combined effects of elevated sea temperature and predation on massive *P. lutea*. We assessed the photo-physiological parameters of coral parts affected by fish bites (BA) and those that were not affected (NA) at temperatures of 28°C and 32°C under low-light (10 µmol quanta $m^{-2}s^{-1}$) and moderate-light (110 µmol quanta $m^{-2}s^{-1}$) conditions.

MATERIALS AND METHODS

Collection sites and sample collection

Collection of massive *Porites* samples were carried out at the backreef at Albion (20.2081°S, 57.4090°E), which is located on the west coast of Mauritius Island (Figure 1). The site was selected according to the ease of access and high occurrence of massive *Porites*.

Porites lutea (Quoy & Gaimard, 1833) was identified in situ according to Veron (2000). The *P. lutea* with visible parrotfish scars were identified as per the description in Benaldo et al. (2011) and were sampled (Figure 2). A total of 12 fragments (4 from each of the 3 colonies) of *P. lutea* having both fish bite-affected (BA) and non-affected (NA) parts were collected by using a hammer and chisel during snorkelling. The coral samples were transported in an isotherm box and kept under shade to the laboratory for experimentation.

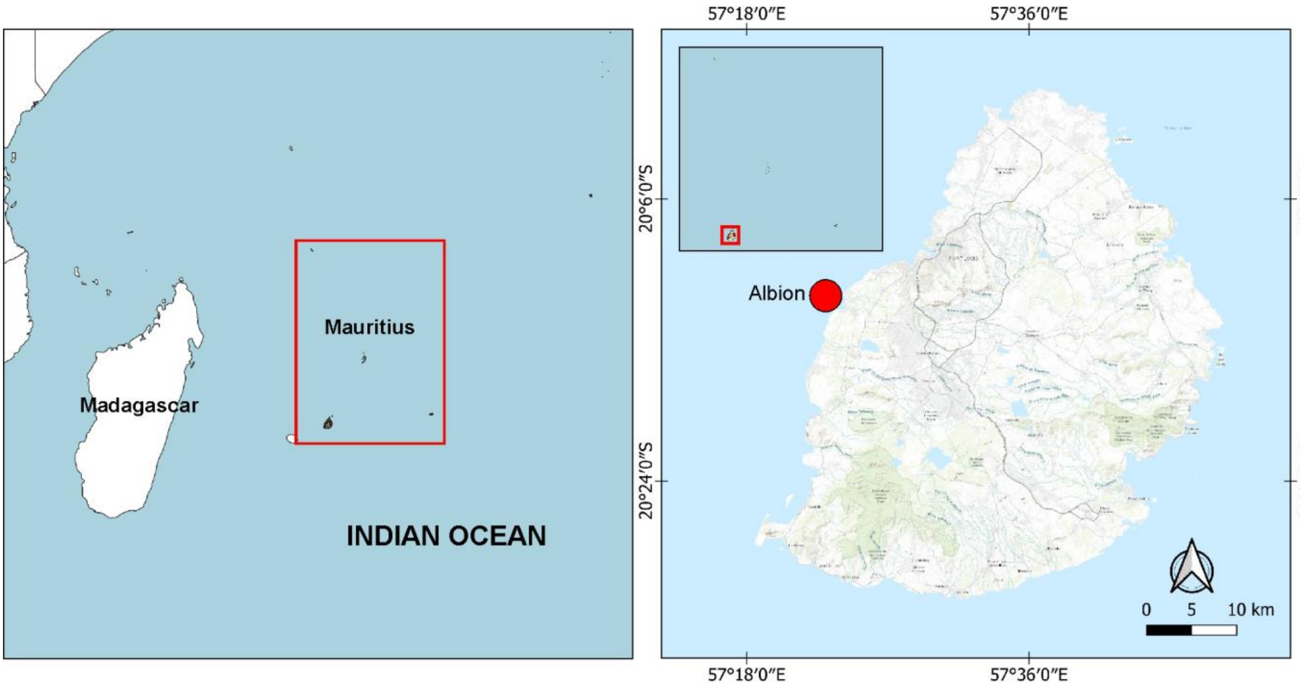


Figure 1. Location of Mauritius Island in the Indian Ocean (*left*). Map showing Albion, the collection site (*right*)

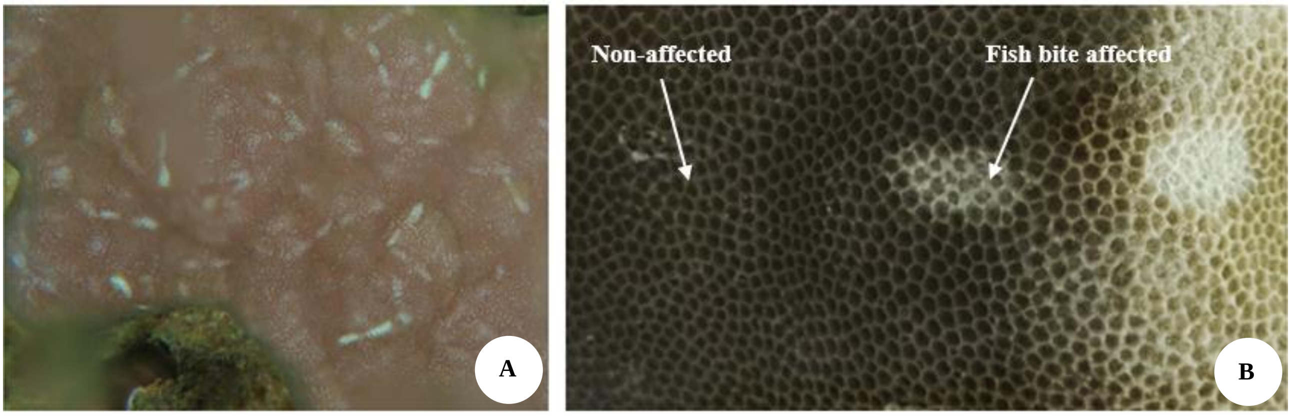


Figure 2. The *P. lutea* in-situ. A. Fish predation scars; B. Close-up of non-affected and fish-bite affected coral parts

Experimental design and procedures

Coral samples were exposed to temperatures ramped up within 2 hr to 28°C and 32°C from 6 a.m. to noon and allowed to recover at 27°C in the afternoon, in order to mimic field-like daily thermal variations. The samples were also exposed to two light conditions (approximately 110 µmol quanta $m^{-2}s^{-1}$ and 10 µmol quanta $m^{-2}s^{-1}$) for 12 hr, followed by 12 hr of no light (dark). The Hobo pendant data loggers were used to track the changes in temperature. The Chlorophyll *a* fluorescence was measured at both the non-affected and the fish-bite affected coral parts whereby the measurement of chlorophyll *a* fluorescence, using the Imaging Pulse Amplitude Modulated fluorometer (Model: IMAG-K7) (Bhagooli et al. 2021b), commence by the switching on a weak measuring light (<1 µmol quanta $m^{-2}s^{-1}$) that yields a measure of the minimal level of fluorescence (F_0) (Figure 3). A saturating white light flash is then applied to the coral parts to obtain the measurement of F_m, the maximum fluorescence value, when all the photosynthetic reaction centres are closed. Hence, the maximum quantum yield at PSII (F_v/F_m) for the BA and NA parts were recorded using a diving Pulse-Amplitude-Modulated fluorometer (D-PAM) before the exposure to temperatures of 28°C and 32°C and during subsequent recovery period (evening). The effective quantum yield at PSII was recorded just before noon; when exposure to temperature was expected to be the highest, and just after noon; at the beginning of the recovery period, using D-PAM and Imaging Pulse-Amplitude-Modulated fluorometer (I-PAM), respectively. The relative electron transport rate (rETR) and the non-photochemical quenching (NPQ) were also determined through the rapid light curves (RLCs) using I-PAM. During the rapid light curve, the corals were illuminated from 0 to 1325 µmol photon $m^{-2}s^{-1}$ in 8 phases of 10 seconds each. A double exponential decay function (Platt et al. 1980) was used to fit curves to the RLCs and quantitatively compare descriptive parameters, namely $rETR_{max}$, the onset of saturation (α), the onset photo-inhibition (ß) and the minimum saturating irradiance (I_k). The photosynthetic parameters were calculated as follows:

Effective Quantum Yield (ϕ PSII) = $(F'_m - F_t)/F'_m$, where F'_m is the light-adapted maximum fluorescence and F_t is the fluorescence before a saturating pulse (Genty et al. 1989).

Maximum Quantum Yield $(F_v/F_m) = (F_m - F_o)/F_m$

Non-Photochemical Quenching (NPQ) = $(F_o - F'_m)/F'_m$

Relative Electron Transport Rate (rETR) = ϕ PSII x PAR x 0.5, where 0.5 is the factor for light partitioning between PSII and PSI.

$I_k = {}_{r}ETR_{max}/$ ß

Statistical analyses

The absolute values were arsine-square root transformed where necessary to meet the assumptions of normality and equal variances for the use of parametric statistical tests. A three-way ANOVA test was used to test for differences in the photo-physiological parameters (F_v/F_m, ${}_{r}ETR_{max}$, NPQ_{max}, α, ß, and I_k) in the NA and BA parts of the coral samples exposed to temperatures of 28°C and 32°C under light intensities of 10 µmol quanta m^{-2} s^{-1} and 110 µmol quanta m^{-2} s^{-1}.

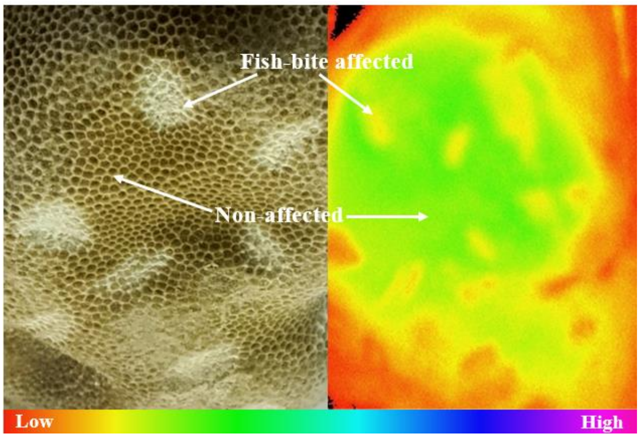


Figure 3. Fluorescence (F_o) at fish-predated and non-predated areas on *P. lutea* as seen normally (*left*) and using the Imaging-PAM fluorometer (*right*)

RESULTS AND DISCUSSION

Temperature and light intensity variations during the experimental trial

The temperature recorded using the data loggers during the experimental trials indicated that the tanks were maintained at 28°C or so during the day and 24 to 25°C during the night in tanks labeled 28°C and at 32°C or so during the day and 25 to 26°C during the night in tanks labeled 32°C (Figure 4 and Table 1). Light conditions were maintained at approximately 110 µmol quanta $m^{-2}s^{-1}$ of ML and 10 µmol quanta $m^{-2}s^{-1}$ for LL labeled tanks for 12 hr, followed by 12 hr of no light (dark).

Photo-physiological responses of *Porites lutea*

The three-way ANOVA (Table 2) revealed that there was no negative effect on all the measured photo-physiological responses of the *P. lutea* irrespective of bite-affected or non-affected conditions. Additionally, the maximum electron transport rate and the non-photochemical quenching were found to be also affected by the light (ETR_{max}, $P = 0.031$ and NPQ, $P = 0.011$) and temperature (ETR_{max} and NPQ, $P < 0.001$) conditions. α, ß and I_K were significantly affected by the light.

At the low light treatment, the effective quantum yield for the BA and NA parts exposed to 28°C increased ($p<0.05$) from 0.45±0.01 to 0.53±0.03 and, 0.50±0.01 to 0.63±0.04, respectively (Figure 5). However, following the 48hr treatment the corals exposed to 32°C conditions, showed almost no change in the effective quantum yield, both for the bite-affected and non-affected parts. Additionally, at the moderate light treatment, the effective quantum yield of the BA and NA parts exposed to 28°C increased by approximately 12% ($p<0.05$) from 0.47±0.03 to 0.52±0.04 and, 0.48±0.05 to 0.61±0.01, respectively, while at the 32°C treatment, a minor decrease was noted for the bite-affected part. However, no significant difference was found in the effective quantum yield for the coral parts exposed at 32°C.

An increase of 15%, however not significant, was noted in the maximum electron transport rate of the coral parts exposed to the low light treatment, except for the BA exposed at 32°C which remained almost unchanged (Figure 6). At the moderate light treatment, the $rETR_{max}$ recorded for the BA and NA parts, both 28°C and 32°C increased by approximately 20%. However, only the NA parts showed significant increase in $rETR_{max}$ ($P<0.05$). The highest increased in the maximum electron transport rate was observed for the NA parts at 32°C temperature treatment (10.13±2.98 vs 20.13±1.04).

Moreover, the NPQ of the BA and NA parts showed a trend of elevation for both temperature conditions, at both the low light and moderate light treatments (Figure 7). However, the increase in NPQ was not significant, except for the NA part exposed at 28°C. The highest increase in the NPQ (25%) was observed for the moderate light treatment for the BA parts at 32°C.

A significant increase in α ($p<0.05$) was noted for the NA parts exposed to low light at 28°C and, the BA parts exposed to moderate light at 28°C (Figure 8) However the corals exposed to 28°C and 32°C under both low light and moderate light conditions, exhibited no significant change in ß (Figure 9) and I_k (Figure 10).

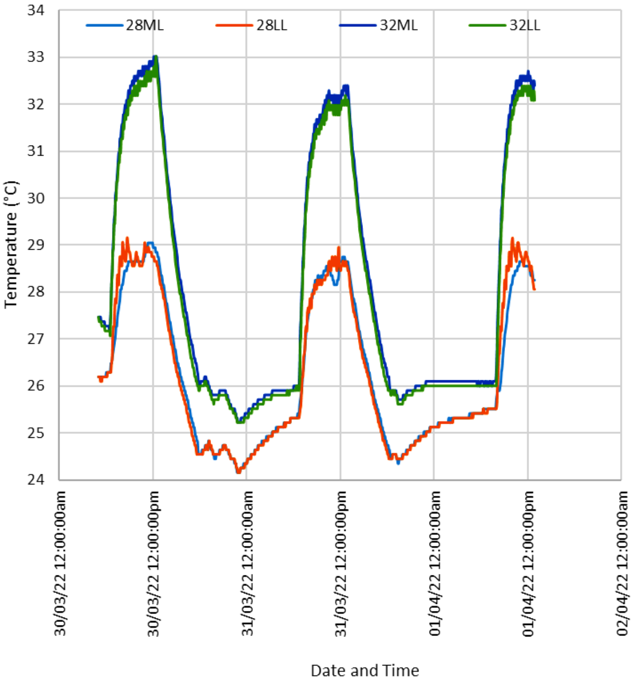
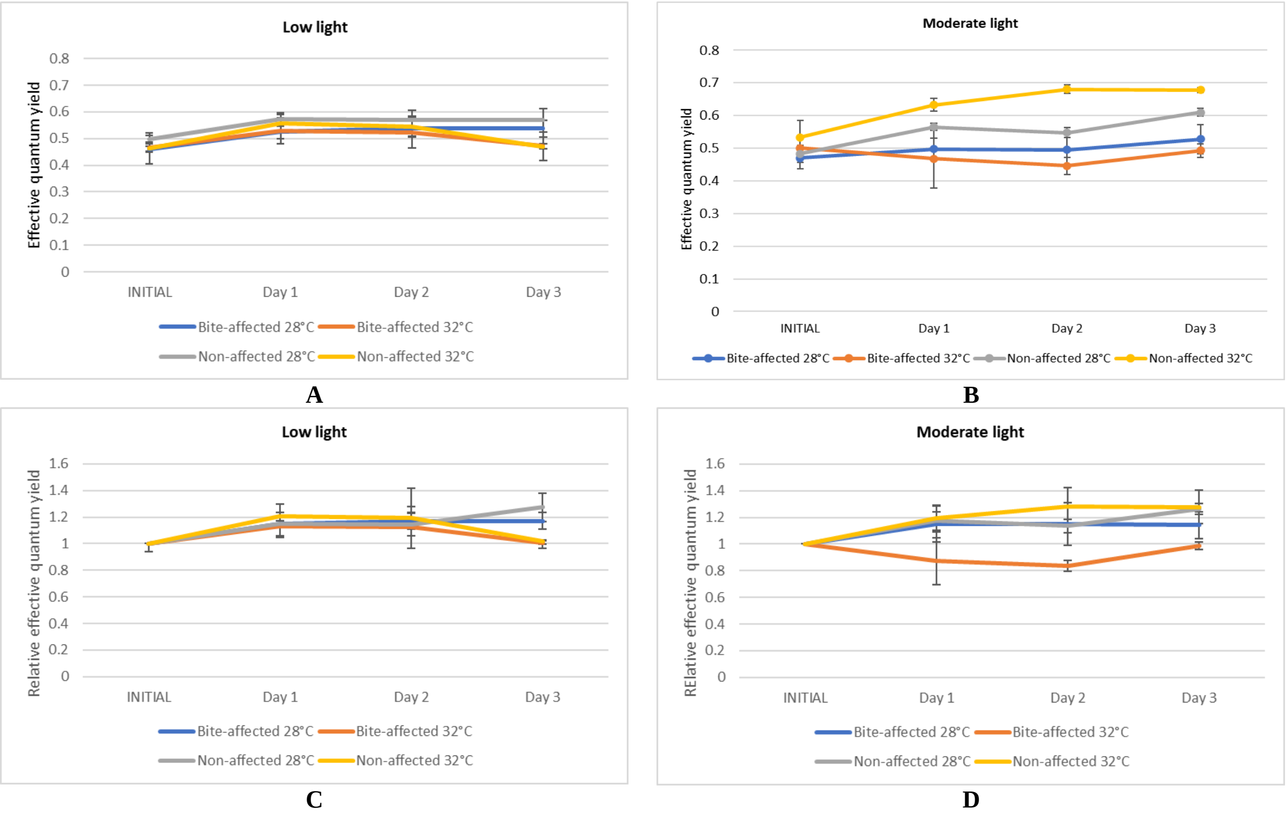


Figure 4. Temperature (°C) variation during the experimental trial. The different coloured lines represent different treatment (light blue: moderate light -28°C (28ML), orange: low light -28°C (28LL), dark blue: moderate light -32°C (32ML) and, green: low light -32°C (32LL))

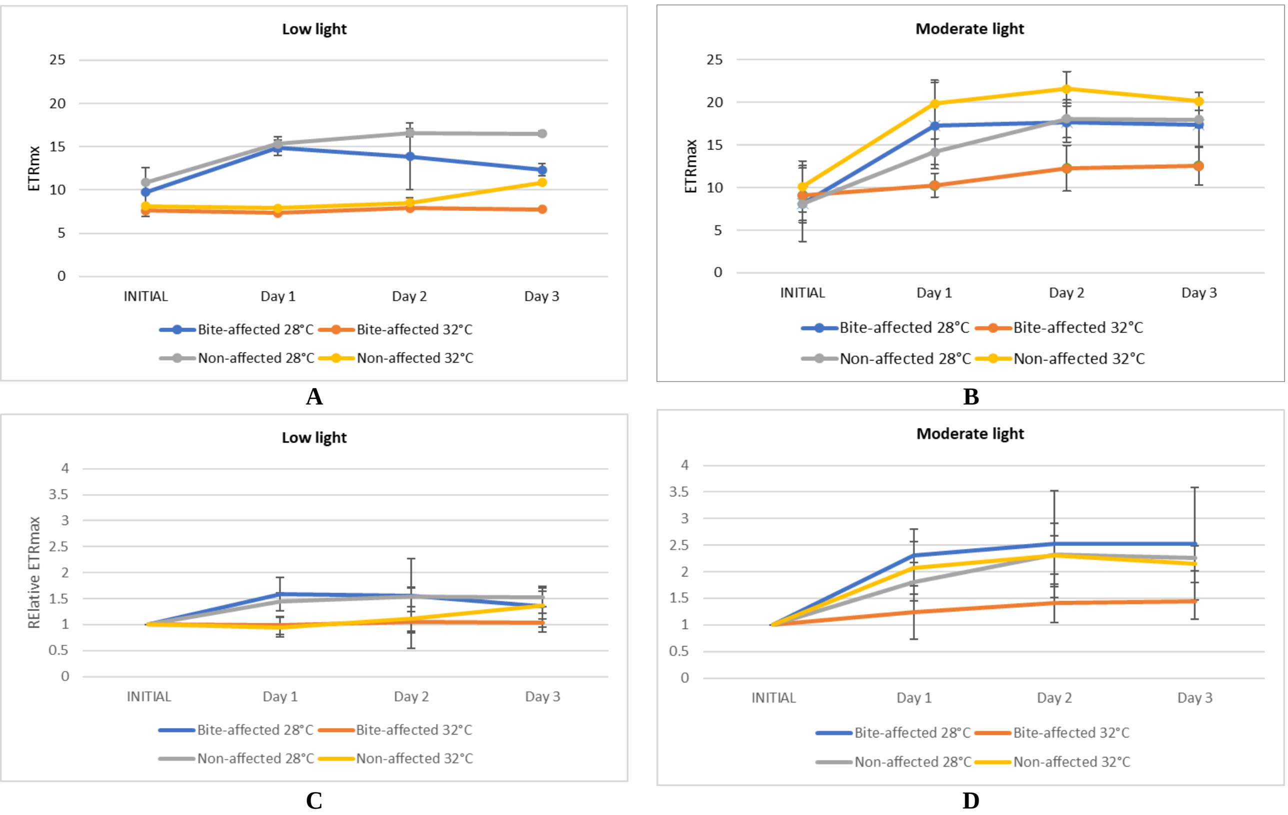
Table 1. Summary of thermal exposures during the day following the ramping up of temperature within 2hr and night time experimental trials

Day	Time of the day	Temperature and light conditions			
		28LL: 28°C + 10 µmol quanta m^{-2} s^{-1}	**28ML: 28°C + 110 µmol quanta m^{-2} s^{-1}**	**32LL: 32°C + 10 µmol quanta m^{-2} s^{-1}**	**32ML: 32°C + 110 µmol quanta m^{-2} s^{-1}**
1	Day time	28.77 ± 0.17	28.71 ± 0.18	32.65 ± 0.24	32.41 ± 0.26
	Night time	24.53 ± 0.17	24.53 ± 0.17	25.67 ± 0.26	25.60 ± 0.25
2	Day time	28.48 ± 0.21	28.86 ± 0.09	32.18 ± 0.13	32.00 ± 0.11
	Night time	25.13 ± 0.33	25.11 ± 0.33	26.03 ± 0.11	25.94 ± 0.11
3	Day time	28.50 ± 0.12	28.67 ± 0.26	32.47 ± 0.12	32.22 ± 0.12



A B C D

Figure 5. Effective Quantum Yield of BA and NA parts at 28°C and 32°C at: A. Low light treatment, B. Moderate light treatment, and the relative effective quantum yield of the BA and NA parts at 28°C and 32°C at: C. Low light treatment; D. Moderate light treatment. Data represents mean ± SD (n=3)



A B C D

Figure 6. Maximum electron transport rate ($rETR_{max}$) of BA and NA parts at 28°C and 32°C at: A. Low light treatment, B. Moderate light treatment, and the relative maximum electron transport rate of the BA and NA parts at 28°C and 32°C at: C. Low light treatment; D. Moderate light treatment. Data represents mean ± SD (n=3)

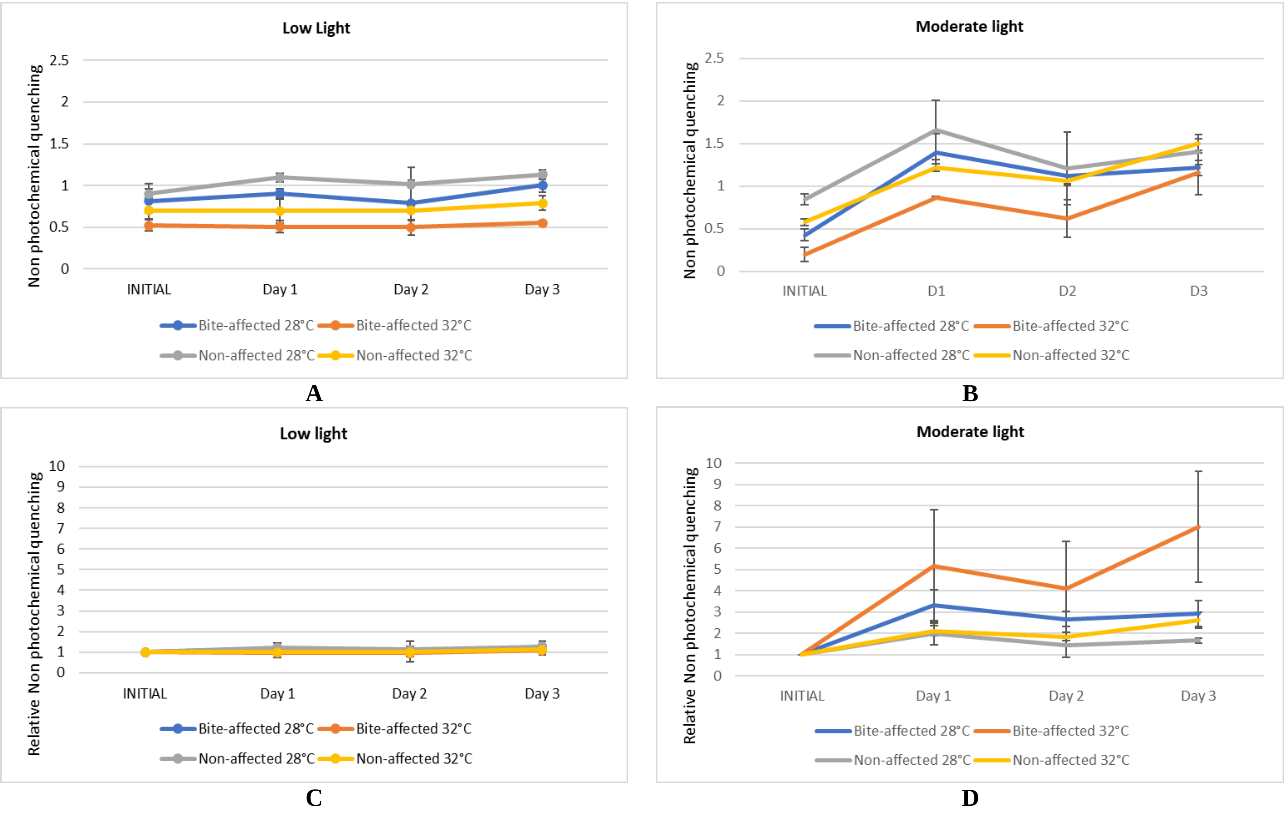


Figure 7. Non photochemical quenching (NPQ) of BA and NA parts at 28°C and 32°C at: A. Low light treatment; B. Moderate light treatment, and the relative NPQ of the BA and NA parts at 28°C and 32°C at: C. Low light treatment; D. Moderate light treatment. Data represents mean ± SD (n=3)

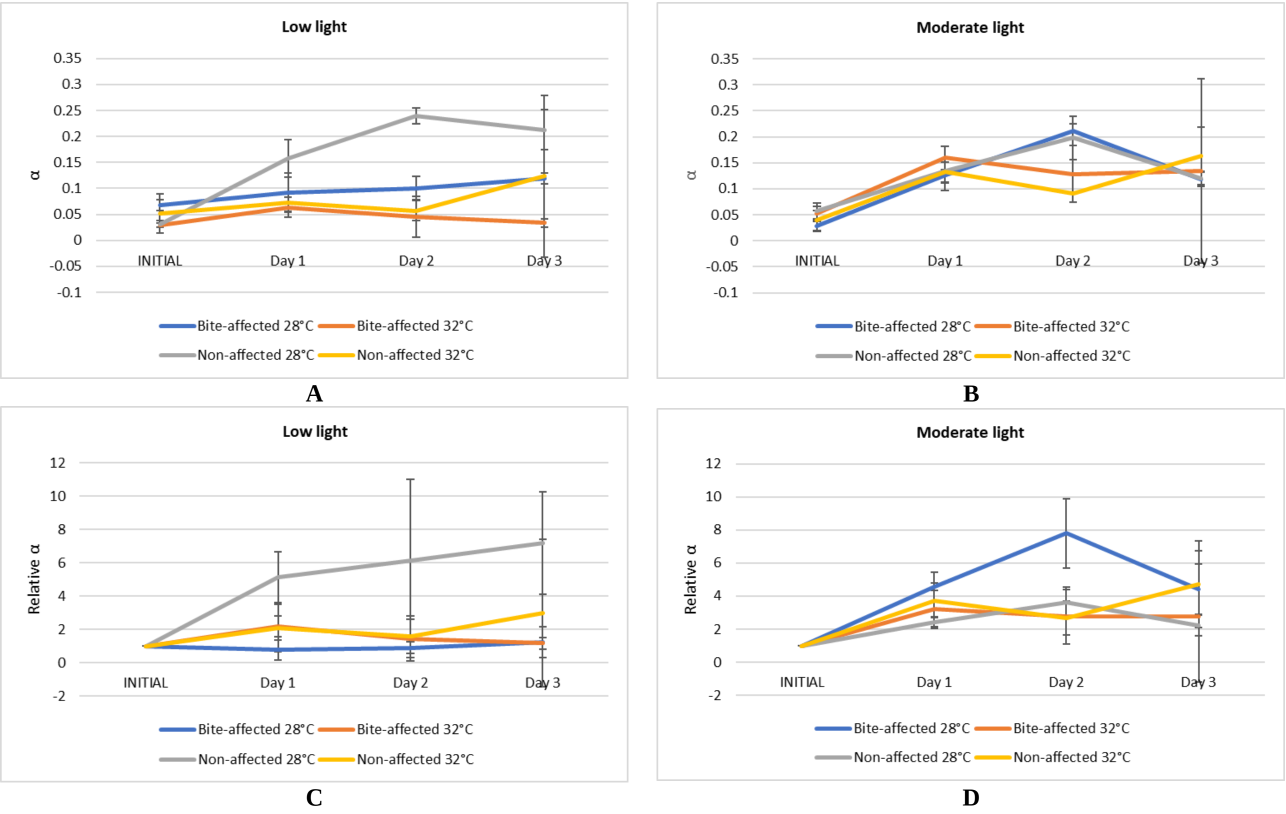
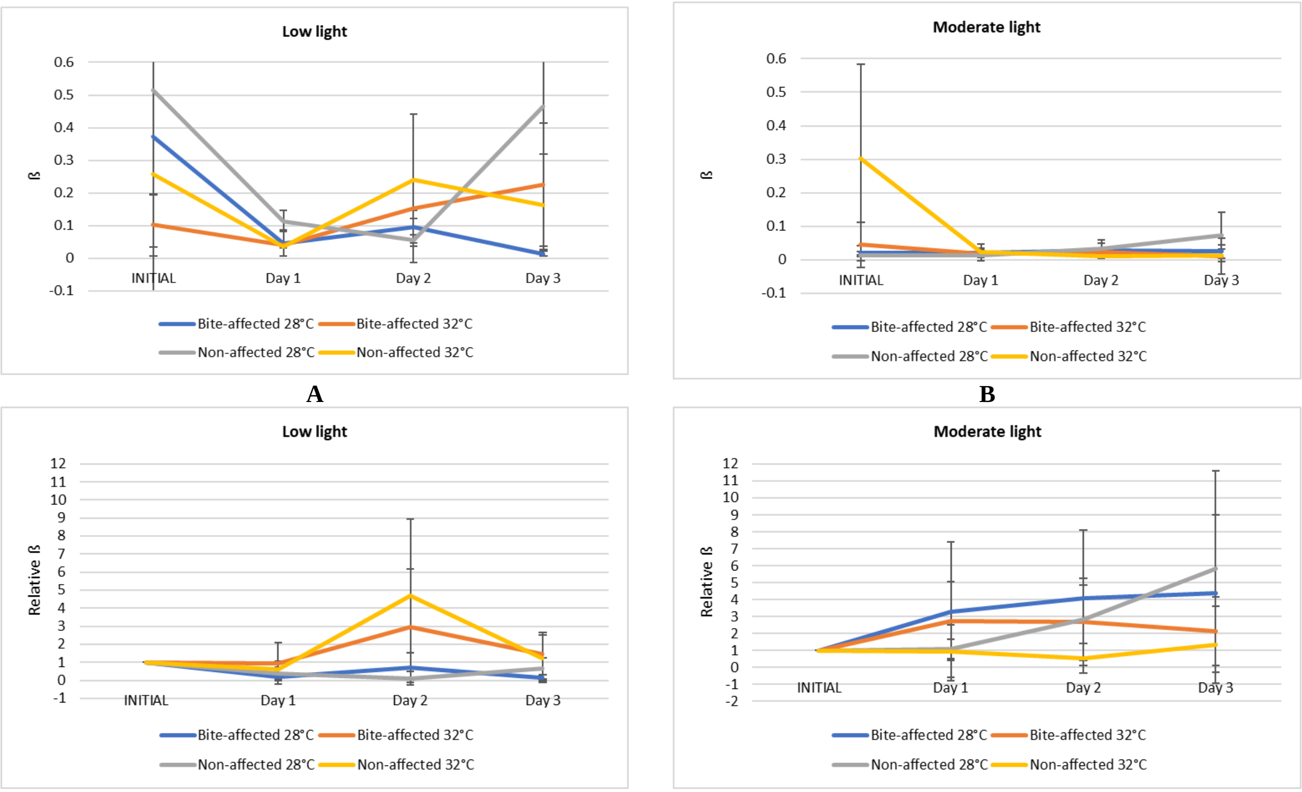


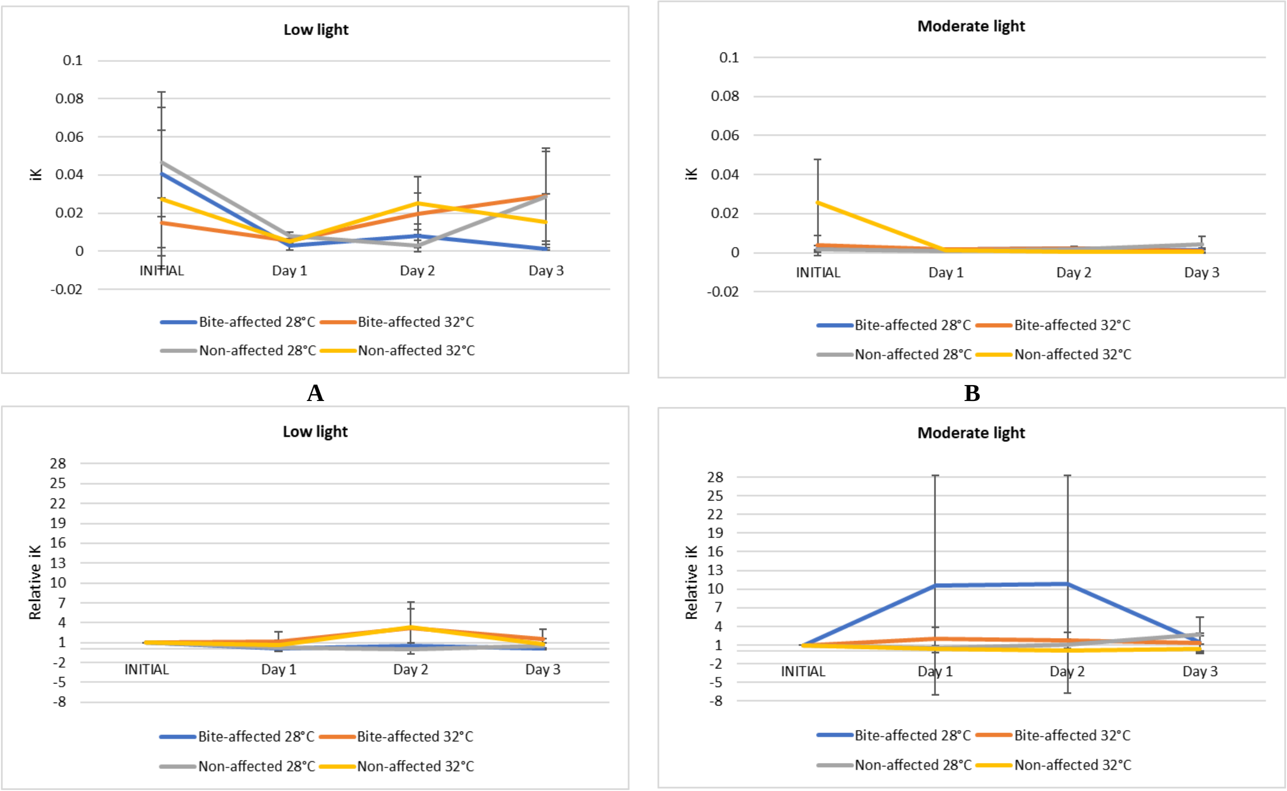
Figure 8. Alpha (α) of BA and NA parts at 28°C and 32°C at: A. Low light treatment; B. Moderate light treatment, and the relative α of the BA and NA parts at 28°C and 32°C at: C. Low light treatment; D. Moderate light treatment. Data represents mean ± SD (n=3)



A B

C D

Figure 9. Beta (ß) of BA and NA parts at 28°C and 32°C at: A. Low light treatment; B. Moderate light treatment, and the relative ß of the BA and NA parts at 28°C and 32°C at: C. Low light treatment; D. Moderate light treatment. Data represents mean ± SD (n=3)



A B

C D

Figure 10. I_K of BA and NA parts at 28°C and 32°C at: A. Low light treatment; B. Moderate light treatment, and the relative I_k of the BA and NA parts at 28°C and 32°C at: C. Low light treatment; D. Moderate light treatment. Data represents mean ± SD (n=3)

Table 2. Three-way ANOVA for effects of different light treatments (Low light and Moderate light), temperature (28°C and 32°C) and conditions (BA and NA) on photo-physiology (F_v/F_m, $rETR_{max}$, NPQ_{max}, α, ß and I_k). $P < 0.05$ - *, $P < 0.01$ - **, $P < 0.001$ - ***

Dependent variables	Source of variation	*Df*	*Ms*	*F*	*P value*	
F_v/f_m	Light	1	1.01E-06	0.000	0.986	
	Temperature	1	0.011	3.416	0.068	
	conditions	1	0.037	11.793	0.001	**
	Light * Temperature	1	0.011	3.678	0.058	
	Light * conditions	1	0.009	2.765	0.100	
	Temperature * conditions	1	0.001	0.357	0.552	
	Light * Temperature * conditions	1	0.013	4.137	0.045	*
$rETR_{max}$	Light	1	2.694	4.808	0.031	*
	Temperature	1	14.596	26.053	< 0.001	***
	conditions	1	3.794	6.772	0.011	*
	Light * Temperature	1	12.439	22.203	< 0.001	***
	Light * conditions	1	0.615	1.098	0.298	
	Temperature * conditions	1	1.151	2.054	0.155	
	Light * Temperature * conditions	1	0.503	0.898	0.346	
NPQ_{max}	Light	1	0.232	6.685	0.011	*
	Temperature	1	1.763	50.834	< 0.001	***
	conditions	1	0.565	16.286	< 0.001	***
	Light* Temperature	1	0.122	3.528	0.064	
	Light * conditions	1	0.025	0.713	0.401	
	Temperature * conditions	1	0.006	0.180	0.673	
	Light* Temperature * conditions	1	0.059	1.693	0.197	
α	Light	1	0.007	1.052	0.308	
	Temperature	1	0.053	7.590	0.007	**
	conditions	1	0.001	0.202	0.654	
	Light * Temperature	1	0.030	4.291	0.041	*
	Light * conditions	1	0.003	0.402	0.528	
	Temperature * conditions	1	0.000	0.034	0.855	
	Light * Temperature * conditions	1	0.003	0.498	0.482	
ß	Light	1	0.356	11.427	0.001	**
	Temperature	1	0.000	0.007	0.936	
	conditions	1	0.060	1.930	0.168	
	Light * Temperature	1	0.072	2.312	0.132	
	Light * conditions	1	0.057	1.840	0.178	
	Temperature * conditions	1	0.017	0.549	0.461	
	Light * Temperature * conditions	1	0.021	0.663	0.418	
I_k	Light	1	0.005	18.193	< 0.001	***
	Temperature	1	5.14E-05	0.196	0.659	
	conditions	1	0.000	1.043	0.310	
	Light * Temperature	1	3.65E-05	0.139	0.710	
	Light * conditions	1	3.88E-05	0.148	0.701	
	Temperature * conditions	1	1.53E-05	0.058	0.810	
	Light * Temperature * conditions	1	0.000	0.814	0.369	

Discussion

This study tested the effects of light conditions (moderate and low light) and temperatures on the massive *P. lutea* to investigate the combined effects of ocean warming and fish predation. The results indicate no compounded effect of high temperature on predation conditions in the massive heat-tolerant coral *P. lutea.*

Following 48 hours of exposure, the BA and NA coral fragments exposed to low light and 28°C exhibited a rise in the effective quantum yield. Acclimatization most likely influenced the reactions of the massive *Porites* (Edmunds and Gates 2008). According to Denis et al. (2011), lesion healing in predation-affected *Porites* was highest during the cooling and cool periods, when radiation from the sun was lower, and sea surface temperature was moderate. This could explain how the bite-affected and non-affected coral segments responded to 28°C and low light.

The exposure to moderate light and high temperature (32°C) for 48 hours had significant effects on the BA and NA parts of the *P. lutea*. These conditions significantly affected the effective quantum yield at photosystem II, with the mean values showing a decrease. It is common to note a decrease in effective quantum yield at high temperatures (Jones et al. 1998), with the reductions induced by brief exposures to sub-lethal temperatures due to alterable photoprotective pathways (Jones et al. 1998). However, longer exposure to more severe or sub-lethal temperatures, principally at high light intensities, can cause significant biological changes and permanent decreases (Jones et al. 1998; Warner et al. 1999). This aspect may need further investigation.

Both the BA and NA parts of the *P. lutea* were affected by the exposure to moderate light and high temperature (32°C). These conditions impacted the effective quantum yield, which exhibited a decline in the mean values. Effective quantum yield reductions caused by short exposures to sub-lethal temperatures are frequently observed at high temperatures (Jones et al. 1998). Reductions in the effective quantum yield result from adjustable photoprotective mechanisms (Jones et al. 1998). However, prolonged exposure to higher or sub-lethal temperatures, particularly at high light intensities, might result in major biological alterations and long-term reductions (Jones et al. 1998). The decrease in effective quantum yield for the BA and NA components subjected to moderate light level and high temperature (32°C) indicated that these conditions did not constitute a significant threat to the photo-physiology of the *P. lutea*, and the reductions indicated alterable photoprotection. Photo-physiological processes in corals are generally affected by temperature in a curvilinear fashion which can be characterized by an abrupt positive threshold followed by a quick decay (Edmunds 2005), and alterations in temperature may produce quick responses. Jones et al. (1998) reported stress responses exhibited by corals within hours of exposure to a severe thermal episode. Additionally, when exposed to less acute chronic conditions, corals can exhibit a stress response within days or weeks (Jokiel and Coles 1990). Different coral species could show different levels of tolerance to bleaching and susceptibilities to heat stress (Marshall and Baird 2000). For instance, Hongo and Yamano (2013) demonstrated that few branching coral colonies occurring in reefs with clear water are unable to withstand severe thermal stress, while massive coral colonies generally display more tolerance, which may be explained due to the coral host having a thick tissue and/or the coral harboring a thermally robust symbiont. Additionally, Morikawa and Palumbi (2019) found that *Porites cylindrica*, a reef-building coral species had the highest tolerance compared to *Acropora hyacinthus* and *Acropora gemmifera*. Moreover, previous studies reported a decrease in the health conditions of corals when exposed to high temperatures for a longer time (Fujise et al. 2014; Zinke et al. 2015; Madeira et al. 2022), hence 48 hours of exposure to the different treatments could be insufficient to detect changes in the photo-physiology of the corals.

Predation upon corals results in damage and/or loss in the coral tissue, adversely affecting the growth and survival of coral colonies (Rotjan et al. 2006). Furthermore, physical damage caused by predation also resulted in zooxanthellae loss (Van Veghel and Bak 1993), and the reduced symbiont densities and physical damage could also interact (Rotjan et al. 2006). Moreover, when there is damage, coral colonies initiate regeneration and repair as a response mechanism, which is very energy intensive for adjacent polyps (Meesters et al. 1994). Hence these findings could explain the significant difference in Fv/Fm, rETRmax and NPQmax exhibited by the BA and NA coral pars.

The findings revealed the generalized effects of light, temperature, and predation on the photo-physiological responses of *P. lutea*; when subjected to various conditions. Similar patterns in the photo-physiology under BA and NA conditions were evident. Hence, our findings suggest that predation by fish on coral would have little negative influence on the photo-physiological susceptibility of *P. lutea* to an increase in the sea temperature. It is evident that reef fish assemblages are undergoing a rapid shift (Nystrom et al. 2000), especially when coral cover is declining worldwide and the oceans of the world are getting warmer (Hughes et al. 2003). As a result, it is essential to comprehend the synergistic effects of multiple stressors, including chronic fish grazing, rising sea surface temperature, and ocean acidification, among others, on coral survival and recovery.

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