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Exploring the Relationship between Coral Mortality, Growth Trends, and Seawater Temperature

Zhiyu Cheng

Sendelta International Academy, Shenzhen, Guangdong, China
cheng5490@outlook.com

Abstract: *Coral reef ecosystems are increasingly threatened by accelerating ocean warming, which has intensified the frequency and magnitude of bleaching and mortality events. This study quantified species-specific thermal tolerance by exposing four ecologically significant coral taxa — Acropora digitifera, Acropora pruinosa, Porites spp., and Goniopora spp. — to five controlled temperature treatments (23°C, 26°C, 29°C, 32°C, and 35°C). Pronounced interspecific variation was observed. All taxa experienced complete mortality at 35°C. At 32°C, Porites spp. and Goniopora spp. maintained partial survival (33.3%) and exhibited limited tissue regeneration, while both Acropora species suffered total mortality. Moderate stress occurred at 29°C, where Acropora species exhibited selective mortality but Porites and Goniopora maintained full survival. These findings demonstrate substantial species-dependent thermal tolerance and highlight the role of resilient taxa in future reef assemblages. The results also emphasize the importance of integrating experimental physiological evidence into adaptive coral conservation strategies.*

Keywords: *Coral Bleaching; Thermal Stress; Porites; Acropora; Thermal Tolerance; Reef Conservation*

1. Introduction

Coral reef ecosystems represent one of the most biologically diverse and ecologically valuable marine environments on Earth. Despite occupying less than 0.1% of the ocean floor, they support an estimated 25% of marine species and provide essential ecological functions, including nutrient cycling, shoreline protection, and structural habitat for numerous fish and invertebrate taxa. Their aragonite frameworks also underpin human economic activities such as fisheries and coastal tourism, supporting the livelihoods of millions globally. However, the accelerating impacts of anthropogenic climate change—particularly ocean warming—have placed coral reefs under unprecedented stress.

Rising seawater temperatures directly threaten the obligate symbiosis between coral hosts and intracellular dinoflagellates of the family Symbiodiniaceae. Thermal stress impairs photosystem II (PSII), causing the generation of reactive oxygen species (ROS) and the subsequent expulsion or degradation of algal symbionts. This bleaching process severely reduces photosynthate supply, compromising coral energy budgets and increasing susceptibility to tissue necrosis, reduced calcification, and mortality. Large-scale bleaching events have intensified in frequency and severity over recent decades. During the 2016–2017 Great Barrier Reef heatwaves, approximately 30% of corals died, with losses exceeding 50% in northern regions [1]. These events signal an ongoing global restructuring of coral assemblages in response to warming seas.

Thermal tolerance is governed by both symbiont identity and host-level physiological mechanisms. Corals hosting thermotolerant symbionts such as Durusdinium trenchii often maintain higher photochemical stability at elevated temperatures, whereas those associated with Cladocopium spp. display rapid photoinhibition [2–4]. Host responses — including heat shock protein (HSP70, HSP90) expression, antioxidant enzyme activity, and metabolic plasticity — further influence survival under thermal stress [5–7]. Short-term acclimation and epigenetic modifications may also raise thermal thresholds, as demonstrated in corals preconditioned to sublethal warming [8–10]. Despite these advances, controlled comparisons across key coral taxa remain limited. Understanding differences in thermal tolerance is essential for predicting future reef trajectories and guiding restoration, assisted evolution, and climate adaptation strategies.

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2. Materials and Methods

2.1 Experimental Design

A controlled laboratory experiment was conducted to quantify coral thermal tolerance under five temperature treatments: 23°C, 26°C, 29°C, 32°C, and 35°C. Temperature was the sole manipulated variable, and each treatment was maintained in an independent aquarium system to prevent cross-exposure. Water temperature was regulated using a digital thermostatic heater with ±0.5°C accuracy. All environmental parameters unrelated to temperature — light, salinity, pH, and flow — were standardized to eliminate confounding effects.

Lighting was supplied by a full-spectrum LED system programmed on a 10:00–16:00 photoperiod using a sunrise–sunset ramp model. Deep-blue and ultraviolet wavelengths constituted approximately 85% of total output (Figure 1). Salinity was maintained at 35 ± 0.5‰ using calibrated instruments, and pH was kept between 8.1 and 8.3. Water flow was maintained at 5–10 cm s^{-1} using circulation pumps to simulate shallow-reef hydrodynamic conditions (Figure 2).

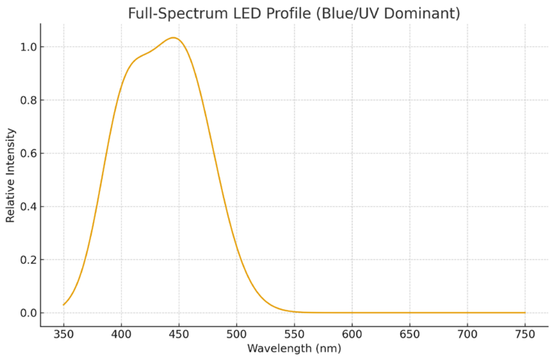

Figure 1 Full-Spectrum LED Light Schematic

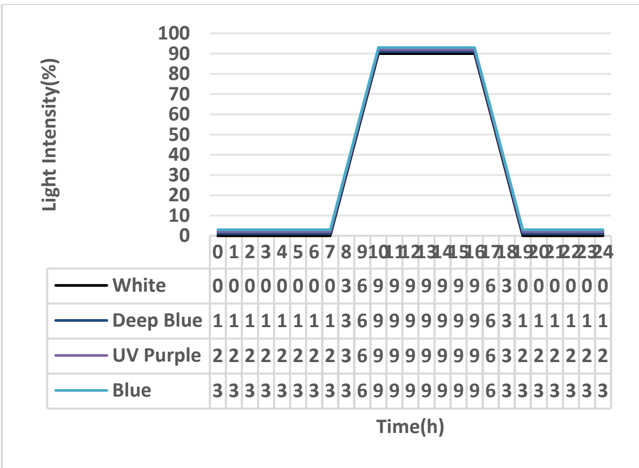

Figure 2 Daily Light Intensity Schedule for White, Deep Blue, UV Purple, and Blue Channels

2.2 Coral Material and Sample Allocation

Four coral taxa commonly found in Indo-Pacific reef ecosystems were selected for the experiment: Acropora digitifera, Acropora pruinosa, Porites spp., and Goniopora spp. Three fragments of each species were assigned to each of the five temperature treatments (n = 60). Fragments were sourced from healthy parent colonies provided by Haiyue Marine Technology Co. (Shenzhen, China). Each fragment measured approximately 1.5 × 1.5 cm and was mounted on standardized ceramic plugs using underwater epoxy. All fragments were acclimated at 26°C for 48 hours before experimental heating began to minimize handling stress [11–13].

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2.3 Environmental Control and Equipment

All aquaria were equipped with identical hardware, including a VASTOCEAN HL30hb aquarium system, HL-311 circulation pump, Red Starfish SQ-50 PRO protein skimmer, and H-40W full-spectrum LED light (Sun Geometry Co.). Water chemistry was monitored daily. Alkalinity was maintained between 7.3 and 7.7 dKH using Salifert test kits. To ensure stable water quality, 10% water changes were conducted every 48 hours using pre-treated synthetic seawater (Table 1).

Table 1 Instruments and Equipment

Equipment	Model
Aquarium	VASTOCEAN HL30hb
Circulation Pump	HL-311
Protein Skimmer	Red Starfish SQ-50 PRO
Full-Spectrum LED Light	H-40W (Sun Geometry Co.)
Salinometer	Delixi Electric
kH Test Kit	Salifert
Thermostatic Heater	Sunsun GW-100B

2.4 Health and Physiological Indicators

Coral responses were evaluated using the following indicators:

• Bleaching intensity — assessed visually and confirmed through calibrated image analysis;

• Symbiont density — inferred from bleaching indices and observed tissue pigmentation;

• Mortality rate — defined as complete tissue loss or detachment from the skeleton;

• Regenerative growth — evaluated qualitatively in surviving fragments exposed to 32°C.

2.5 Data Handling and Interpretation

Data interpretation focused on survival patterns, bleaching severity, and species-specific performance across temperature treatments. Because the experimental goal was to identify thermal thresholds rather than test hypothesis-driven statistical relationships, emphasis was placed on comparative physiological patterns rather than inferential statistics.

3. Results

3.1 Overall Effects of Temperature on Coral Survival

The experiment revealed a strong negative relationship between seawater temperature and coral survival across all four taxa. Mortality increased markedly with rising temperature, and distinct interspecific differences were observed at intermediate and high treatment levels. Complete mortality occurred for all corals at 35°C, confirming this temperature as a universal lethal threshold.

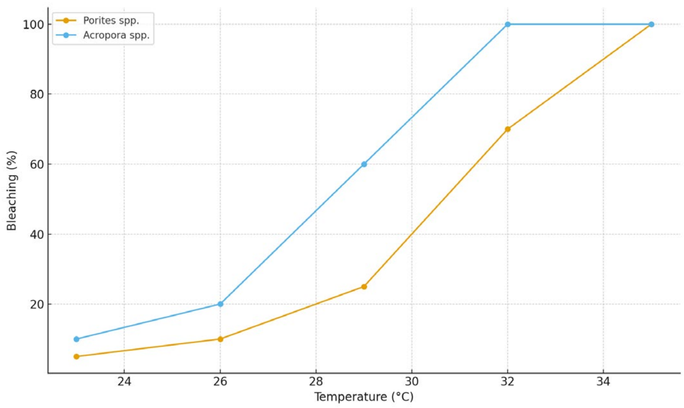

Figure 3 Bleaching Severity under Temperature Stress

Under 35°C exposure, full bleaching was observed within the first 48–72 hours, followed by rapid tissue loss and complete detachment from the skeleton by Day 7. Symbiodiniaceae densities approached zero, indicating total symbiont expulsion (Figure 3).

3.2 Divergent Species Responses at 32°C

Pronounced differences in thermal tolerance emerged at 32°C. Both Acropora digitifera and Acropora pruinosa experienced complete mortality within 14 days. Bleaching was rapid, progressing from paling to total tissue disintegration.

In contrast, Porites spp. and Goniopora spp. exhibited partial survival (33.3%). Surviving Porites fragments showed visible tissue regeneration along skeletal margins, suggesting limited acclimation capacity. Goniopora survivors retained partial polyp extension and displayed moderate bleaching intensity.

3.3 Selective Mortality at 29°C

At 29°C, selective mortality occurred exclusively among the Acropora species. Two of three fragments of both Acropora digitifera and Acropora pruinosa died (33.3% survival). Bleaching symptoms developed more slowly than at 32°C, with progressive paling observed between Days 5 and 7.

Porites spp. and Goniopora spp. maintained full survival at 29°C and showed no evidence of significant bleaching. These results indicate that 29°C lies within the tolerable thermal range for both taxa.

3.4 Responses at 23°C and 26°C

At benign temperatures (23°C and 26°C), all species showed high survival, although Acropora digitifera exhibited isolated mortality (one fragment per treatment). No bleaching was detected among Porites spp., Goniopora spp., or Acropora pruinosa. This pattern suggests that Acropora digitifera is more sensitive to minor environmental fluctuations than the other taxa [14–15].

3.5 Comparative Thermal Tolerance

Thermal tolerance rankings across all treatments were as follows:

• Highest tolerance: Porites spp. and Goniopora spp.

• Lowest tolerance: Acropora digitifera and Acropora pruinosa.

These findings demonstrate substantial species-dependent variation in coral responses to thermal stress (Figure 4).

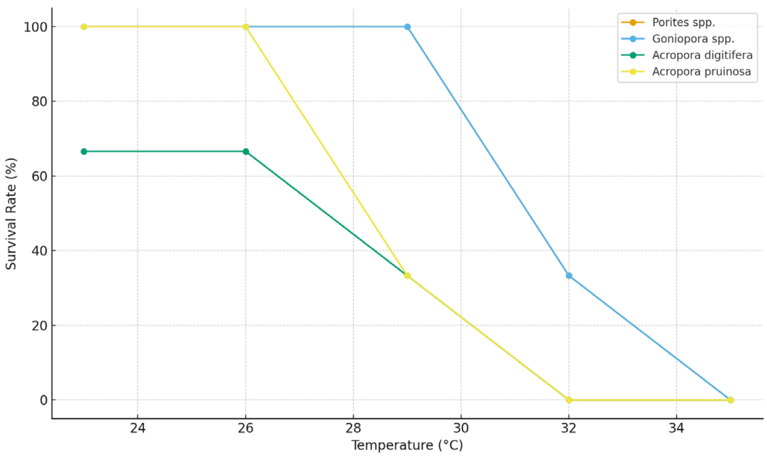

Figure 4 Coral Survival Rates under Temperature Stress

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4. Discussion

This study provides a comparative evaluation of thermal tolerance among four ecologically important coral taxa under controlled laboratory conditions. The results clearly demonstrate substantial interspecific variation in bleaching severity, survival patterns, and regenerative potential, reflecting distinct physiological and life-history strategies. Such species-dependent responses underscore the complexity of coral thermal resilience and have significant implications for predicting future reef community dynamics in an era of accelerating ocean warming.

4.1 Differential Mortality Reflects Life-History Strategies

The complete mortality of all taxa at 35°C confirms this temperature as a universal upper lethal limit. However, at 32°C, striking differences emerged. Both Acropora digitifera and Acropora pruinosa, representing fast-growing branching corals, displayed rapid bleaching and total mortality. These species typically possess higher metabolic rates and thinner tissues, which reduce their capacity to withstand and buffer thermal stress. Their narrow physiological tolerance ranges make them particularly vulnerable during marine heatwaves.

In contrast, Porites spp. and Goniopora spp. demonstrated partial survival at 32°C. Massive corals such as Porites are characterized by slower metabolism, thicker tissues, and greater energy reserves, which collectively enhance thermal stability. Their symbionts also tend to exhibit higher resistance to photoinhibition. The observed tissue regeneration in surviving Porites fragments further suggests a capacity for sublethal acclimation, allowing limited recovery despite ongoing stress. These findings align with field observations in which Porites populations persist following recurrent bleaching events while Acropora populations decline.

4.2 Mechanistic Basis for Thermal Tolerance Differences

The contrasting responses among taxa can be attributed to the interplay between symbiont thermal sensitivity and host-level physiological buffering. Corals hosting thermotolerant symbionts such as Durusdinium trenchii maintain relatively stable photosynthetic performance at elevated temperatures, allowing them to avoid rapid ROS accumulation. In contrast, Cladocopium-dominated Acropora species experience photodamage at comparatively mild temperature elevations, initiating bleaching more rapidly.

Host stress-response pathways also influence survival outcomes. Massive and encrusting corals often express higher baseline concentrations of heat shock proteins (HSP70 and HSP90) and antioxidant enzymes that protect cellular structures from oxidative damage. Their elevated lipid reserves provide alternative metabolic energy during periods of reduced photosynthate availability. Conversely, Acropora species have limited antioxidant capacity and lower tissue biomass, leaving them less equipped to withstand prolonged stress.

4.3 Implications for Future Reef Assemblages

The thermal thresholds identified in this study are consistent with observed ecological trends across the Indo-Pacific. As marine heatwaves intensify under global climate change, branching Acropora species are likely to suffer increased mortality and population declines. Their loss may result in reduced structural complexity, affecting biodiversity and ecosystem function. In contrast, Porites and Goniopora may assume greater ecological prominence due to their relative thermal resilience.

Such shifts toward dominance by thermally tolerant taxa may stabilize some ecological functions but will alter community composition and reduce the architectural complexity characteristic of Acropora-dominated reefs. Understanding these trajectories is critical for forecasting reef futures and developing effective conservation strategies.

4.4 Applications for Reef Restoration and Assisted Evolution

The identification of Porites spp. and Goniopora spp. as thermally resilient taxa highlights their potential suitability for restoration initiatives. Their demonstrated ability to withstand moderate to high temperatures suggests that they may persist under future climate scenarios. These taxa may also serve as candidates for selective breeding, assisted gene flow, or microbiome optimization aimed at increasing coral thermal tolerance.

Thermal preconditioning—exposing corals to sublethal heat stress—has also been shown to elevate tolerance thresholds by modulating host gene expression and altering symbiont community composition. Integrating such approaches with the resilient taxa identified here may enhance long-term reef restoration success.

4.5 Limitations and Future Research

Several limitations should be acknowledged. First, the 14-day duration may not capture longer-term acclimation processes, including symbiont shuffling or host epigenetic responses. Second, small sample sizes limited statistical inference, though comparative physiological patterns remain clear. Third, the absence of molecular assays prevented direct measurement of oxidative stress markers, gene expression profiles, or symbiont communities. Finally, real reef environments expose corals to multiple interacting stressors—acidification, eutrophication, pollutants — that may alter thermal tolerance dynamics.

Future work should incorporate extended experimental durations, multi-stressor designs, and molecular-scale analyses to further elucidate mechanisms underlying coral resilience. Integrating these approaches will enhance predictive models and inform adaptive reef management strategies.

5. Conclusion

This study demonstrates clear species-specific differences in coral thermal tolerance under controlled temperature treatments. All four taxa experienced complete mortality at 35°C, confirming this temperature as a universal lethal threshold. At 32°C, Porites spp. and Goniopora spp. displayed partial survival and limited tissue regeneration, whereas Acropora digitifera and Acropora pruinosa suffered rapid bleaching and total mortality. Moderate thermal stress at 29°C resulted in selective mortality only in Acropora species, while Porites and Goniopora maintained full survival. These patterns reflect fundamental physiological differences across taxa, with massive and encrusting corals exhibiting greater resilience than branching Acropora.

The findings highlight the likelihood of future reef assemblages becoming increasingly dominated by thermally tolerant taxa as ocean warming intensifies. Such ecological shifts may stabilize certain functions but could reduce structural complexity historically provided by Acropora species. The identification of Porites and Goniopora as resilient taxa also provides actionable insights for coral restoration, selective breeding, and thermal preconditioning strategies aimed at enhancing reef resilience under climate change.

Overall, integrating physiological experiments such as this with adaptive management approaches and global emissions mitigation will be essential for safeguarding coral reef ecosystems in a warming ocean.

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