

Thermal, Salinity, and pH Tolerance of Arabian Gulf Corals: Insights for Assisted Evolution and Reef Restoration

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Abstract- Coral reefs worldwide are increasingly threatened by the combined impacts of climate change, ocean acidification, and salinity fluctuations, resulting in widespread bleaching and habitat degradation. To address these challenges, the Creating Super Corals project (2016–2021), initiated by the Ministry of Climate Change and Environment (MOCCAE), United Arab Emirates, aimed to enhance coral resilience through assisted evolution. The study exposed corals to controlled thermal, salinity, and pH stressors to stimulate adaptive tolerance mechanisms. Over six years, seven coral genera commonly found in UAE waters—*Acropora*, *Stylophora*, *Porites*, *Platygyra*, *Cyphastraea*, *Favites*, and *Turbinaria*—were systematically examined under both laboratory and field conditions. Physiological indicators, such as photosynthetic efficiency, calcification rate, and tissue survival, were monitored to assess adaptive responses (Anthony et al., 2008; Radice et al., 2024; Tanvet et al., 2023). Results revealed substantial interspecific variability in stress tolerance, with *Porites* and *Stylophora* exhibiting superior resilience to elevated temperatures (up to 36°C) and high salinity (up to 42 PSU). These genera maintained stable symbiotic relationships with heat-tolerant *Symbiodiniaceae* clades and exhibited faster post-stress recovery compared to other taxa. The findings provide valuable insights into the natural adaptive capacity of UAE corals and underscore their potential for assisted evolution and restoration initiatives. This study enhances understanding coral adaptation in extreme environments and supports the development of targeted conservation strategies under future climate change scenarios (Anthony et al., 2008; Radice et al., 2024; Tanvet et al., 2023).

Index Terms- Coral resilience, Climate change adaptation, UAE corals, Marine conservation, Coral restoration.

I. INTRODUCTION

Coral reefs are among the most biologically diverse and productive ecosystems on Earth, yet they remain highly susceptible to climate-induced stressors such as ocean warming, acidification, and salinity fluctuations. The Arabian Gulf, characterized by its extreme temperature and salinity variations, represents one of the most challenging environments for coral survival. To better understand coral resilience under such conditions, the Marine Environment Research Center Department (MERD) at the Ministry of Climate Change and Environment (MOCCAE), UAE, launched a long-term project to assess the tolerance limits of native coral species. Through controlled laboratory exposures to varying stress conditions, the study aimed to determine threshold levels for coral survival and recovery (Burt et al., 2008; Camp et al., 2018b).

The primary objectives were to evaluate the effects of key water quality parameters—including temperature, salinity, dissolved oxygen (DO), and pH—on common coral species inhabiting the Arabian Gulf and to develop protocols to induce tolerance by exposing corals to extreme conditions. Furthermore, the project evaluated coral survival and recovery potential following normally lethal exposures typically deemed lethal. The findings provide valuable insights into coral adaptation mechanisms and contribute to the development of targeted conservation strategies to sustain reef ecosystems under future climate change scenarios (Anthony et al., 2008; Radice et al., 2024; Tanvet et al., 2023).

II. METHODOLOGY

Study Overview

This study investigated the tolerance and adaptive responses of Arabian Gulf corals to key environmental stressors—controlled laboratory experiments were conducted on coral fragments collected from the UAE lagoon. The study focused on three primary stressors—temperature, salinity, and pH—to mimic extreme environmental conditions observed in the Arabian Gulf. The experiments aimed to

determine physiological limits and assess stress recovery capacity for selected coral species (Anthony et al., 2008; Radice et al., 2024; Tanvet et al., 2023).

Study Site and Coral Collection

Experiments were conducted at MERD in Umm Al Quwain, UAE, between 2016 and 2021. Coral colonies representing seven genera—*Stylophora* sp., *Acropora*, *Porites*, *Platygyra*, *Favites*, *Cyphastrea*, and *Turbinaria*—were collected from the Umm Al Quwain lagoon (25°34'N, 55°36'E). Fragments were taken from healthy parent colonies and affixed to ceramic bases for experimental use. Water quality parameters, including temperature, salinity, pH, and DO, were continuously monitored to maintain stable conditions throughout the experiments.

All stress trials were conducted in indoor, static tanks to enable precise control of individual environmental variables and minimize confounding effects.

Temperature Stress

Temperature tolerance experiments were designed to determine both the upper and lower thermal limits of selected coral species, simulating potential climate-induced fluctuations within the Arabian Gulf. Coral fragments were exposed to controlled temperatures ranging from 20°C to 35°C. Experiments were performed periodically between 2016 and 2021 to account for seasonal variability and ensure reproducibility (Coles & Riegl, 2013; Riegl & Purkis, 2012).

DO, salinity, and pH were measured at the beginning and end of each experimental run and mean $\pm$ standard deviation (SD) values were calculated to verify the stability of experimental conditions (Table 1).

Table 1. Temperature Experiment Conditions and Water Quality Parameters of UAE Corals (2016–2021)

Period	DO (Start–End, mg L ⁻¹)	Salinity (Start–End, ppt)	pH (Start–End)
May–Jul 2016	6.06–5.45 (5.75 $\pm$ 0.32)	39.6–40.11 (39.98 $\pm$ 0.15)	8.18–8.16 (8.15 $\pm$ 0.03)
Jun–Sep 2019	5.60–5.40 (5.53 $\pm$ 0.06)	39.0–40.1 (39.57 $\pm$ 0.41)	7.90–7.80 (7.85 $\pm$ 0.05)
Mar–May 2020	5.20–5.30 (5.24 $\pm$ 0.05)	40.0–40.2 (40.08 $\pm$ 0.07)	7.83–8.04 (7.94 $\pm$ 0.07)
Jun–Oct 2021	5.20–5.40 (5.28 $\pm$ 0.08)	40.0–40.0 (40.00 $\pm$ 0.00)	7.98–7.91 (7.94 $\pm$ 0.04)

Salinity Stress

Salinity tolerance experiments were conducted to replicate extreme hypersaline conditions, increasingly observed in the Arabian Gulf as a consequence of evaporation rates. Coral fragments were subjected to a salinity gradient ranging from 34 to 55 ppt, while temperature and pH were maintained within ranges representative natural lagoon conditions. This experimental design enabled the isolation and quantification of coral physiological and stress responses attributable specifically to variation in salinity.

DO, temperature, and pH were continuously monitored throughout the experimental period to ensure environmental stability and consistency across treatments (Table 2).

Table 2. Salinity Experiment Conditions and Water Quality Parameters of UAE Corals (2016–2021)

Period	DO (Start–End, mg L ⁻¹)	Temperature (Start–End, °C)	pH (Start–End)	Salinity (ppt)
Apr–Jun 2016	6.14–5.40 (5.84 $\pm$ 0.37)	29.38–28.35 (29.73 $\pm$ 0.60)	8.01–8.18 (8.13 $\pm$ 0.04)	34–55
Jun–Sep 2019	5.60–5.40 (5.51 $\pm$ 0.07)	25.20–25.20 (25.19 $\pm$ 0.06)	7.90–7.80 (7.84 $\pm$ 0.05)	34–55
Sep–Oct 2020	5.10–5.20 (5.15 $\pm$ 0.05)	25.20–25.00 (25.19 $\pm$ 0.08)	7.90–7.80 (7.89 $\pm$ 0.04)	34–55
Jun–Jul 2021	5.10–5.20 (5.15 $\pm$ 0.05)	24.20–24.20 (24.28 $\pm$ 0.10)	7.90–7.90 (7.90 $\pm$ 0.00)	34–55

pH (Acidification) Stress

To simulate ocean acidification, controlled infusions of CO₂ gas were applied to experimental tanks to systematically reduce pH, generating conditions ranging from 8.1 to 4.5 (Table 3). These experiments were designed to assess the tolerance of UAE corals species to rapid alternations in in carbonate chemistry.

Temperature and salinity were maintained within ranges representative of natural lagoon environments to ensure that pH served as the primary experimental stressor. DO, temperature, and salinity were continuously monitored throughout the experimental duration to verify environmental stability.

Table 3. pH (Acidification) Experimental Conditions and Water Quality Parameters of UAE Corals (2018 and 2021)

Period	Temperature (°C)	DO (mg L ⁻¹)	Salinity (ppt)	pH
Mar–May 2018	23.74–24.15 (24.25 ± 0.37)	5.41–5.46 (5.36 ± 0.28)	38.04–40.18 (39.47 ± 0.85)	8.1–4.5
Oct–Nov 2021	24.20–23.80 (23.94 ± 0.18)	5.10–5.20 (5.14 ± 0.05)	42.00–42.00 (42.00 ± 0.00)	8.1–4.5

III. RESULTS

Environmental Conditions

Environmental parameters measured during the experimental periods are summarized in Tables 1–3. Dissolved oxygen (DO) ranged from 5.1 to 6.14 mg L⁻¹, salinity from 38.04 to 42 ppt, and pH from 7.8 to 8.18. Temperature in the salinity and pH experiments varied between 23.74 to 29.73°C, whereas thermal tolerance experiments exposed corals to elevated temperatures exceeding ambient conditions. These measurements indicate that Arabian Gulf corals naturally experience high salinity, slightly alkaline pH, and moderate DO levels, consistent with prior observations of extreme environmental conditions in the region (Riegl & Purkis, 2012; Coles, 2003).

Temperature Tolerance

Thermal tolerance experiments on *Acropora downingi* and *Stylophora pistillata* revealed species-specific bleaching thresholds. *Acropora* tolerated temperatures up to 33°C, whereas *Stylophora* survived up to 34.01°C, showing slower onset of bleaching and higher recovery (Figure 1). These observations suggest that *Stylophora* possesses physiological or symbiotic traits that allow it to better withstand elevated thermal stress compared to *Acropora*, which tends to exhibit earlier bleaching responses under similar conditions.

Among seven coral genera tested, *Porites* demonstrated the highest thermal resilience, tolerating up to 35°C and achieving an 83% recovery after eight weeks. In contrast, bleaching in *Cyphastrea microphthalma* and *Favites pentagona* occurred at 31.1°C and 32.4°C, with respective recovery rates of 66% and 33%. *Turbinaria* bleached at 32.1°C recovering 42% of its original condition, while *Platygyra* bleached at 33.2°C, with a 72% recovery rate.

Taken together, these findings demonstrate pronounced interspecific variation in the susceptibility and resilience of Gulf coral species to thermal stress. The capacity of *Porites* and *Stylophora* to withstand and recover from elevated temperatures highlights their potential ecological significance as foundational taxa contributing to the persistence and stability of reef assemblages under increasingly variable thermal regimes. These results align with previously documented species-specific bleaching and mortality thresholds for Arabian Gulf corals, wherein *Acropora*, *Stylophora*, and *Porites* exhibit some of the highest recorded thermal tolerances globally (Riegl et al., 2012).

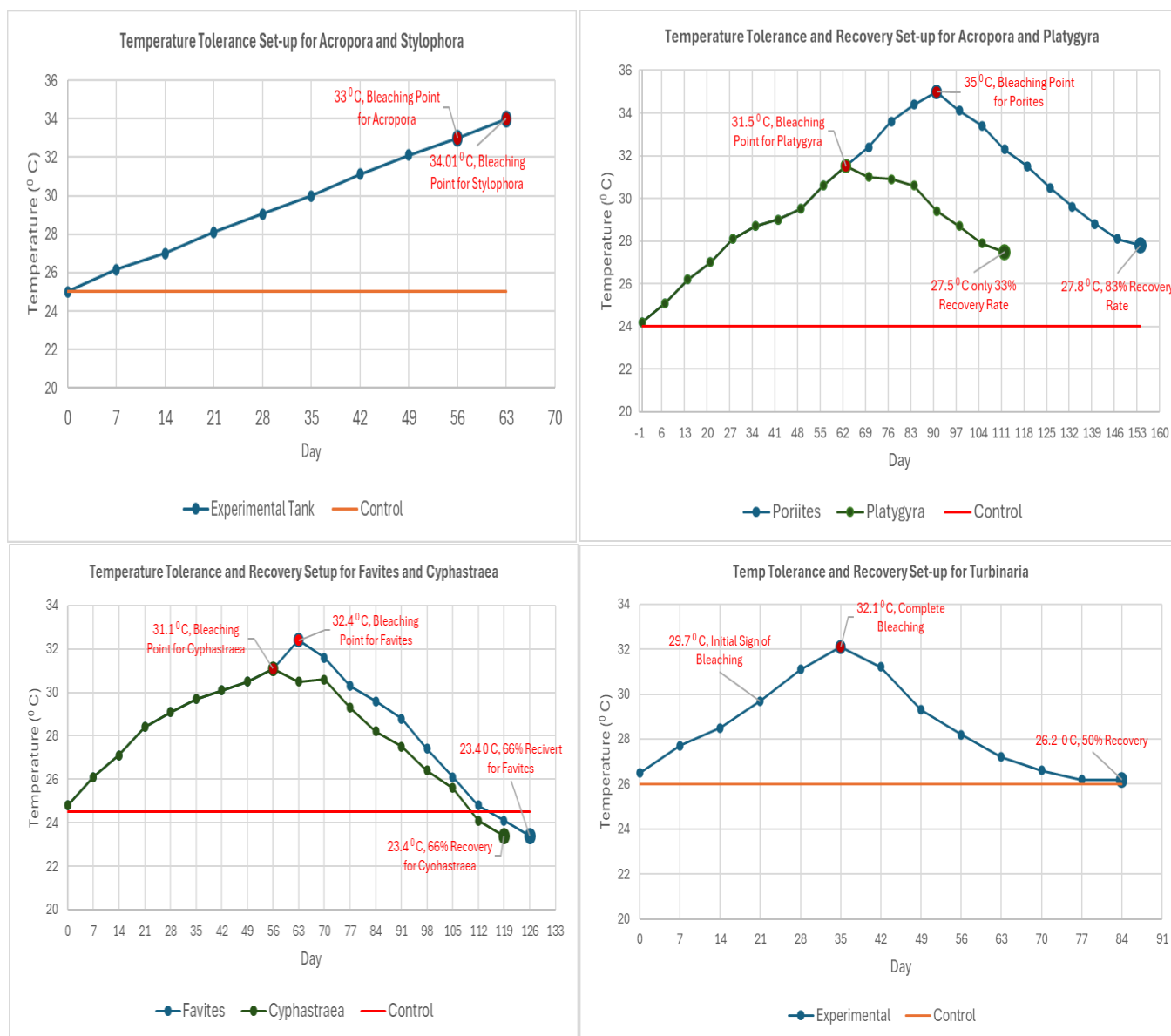


Figure 1 shows the results of thermal tolerance and recovery experiments for several coral genera, *Acropora*, *Stylophora*, *Porites*, *Platygyra*, *Favites*, *Cyphastrea*, *Turbinaria*, with bleaching points ranging from about 31°C to 35°C and various recovery percentages once temperature returned to normal.

Salinity Tolerance

The salinity manipulation experiments (Figure 2) revealed distinct bleaching thresholds and recovery responses among the studied coral species, highlighting species-specific tolerance to elevated salinity levels. *Acropora* exhibited bleaching at a salinity of 51 ppt, while *Stylophora* bleached at a higher salinity of 55.12 ppt, indicating a comparatively greater tolerance to hypersaline conditions. Among the massive corals, *Porites* and *Platygyra* bleached at 55 ppt and 51.3 ppt, respectively, with recovery rates reaching 70% for *Platygyra* and 50% for *Porites* after salinity returned to baseline levels. In contrast, *Cyphastrea* and *Favites* showed bleaching at 46.5 ppt and 44.9 ppt, respectively, with *Cyphastrea* demonstrating a higher recovery of 70% compared to 50% for *Favites*. The branching coral *Turbinaria* bleached at 45 ppt, but exhibited substantial recovery (80%) upon normalization of salinity.

These findings underscore a clear variation in salinity tolerance among Gulf coral taxa, with *Stylophora* and *Porites* showing the greatest resilience to extreme salinity stress, which is consistent with their ecological prominence in hypersaline reef environments. Recovery percentages varied widely, suggesting differential capacities for physiological repair and acclimatization after stress cessation. The data provide critical insight into how salinity extremes influence coral health and highlight the importance of species-specific tolerance in predicting reef persistence under changing environmental conditions. These results align with previously reported environmental tolerance thresholds for corals in the Arabian Gulf, where species such as *Acropora*, *Stylophora*, and *Porites* have demonstrated high resilience to multiple environmental stressors (Riegl et al., 2012).

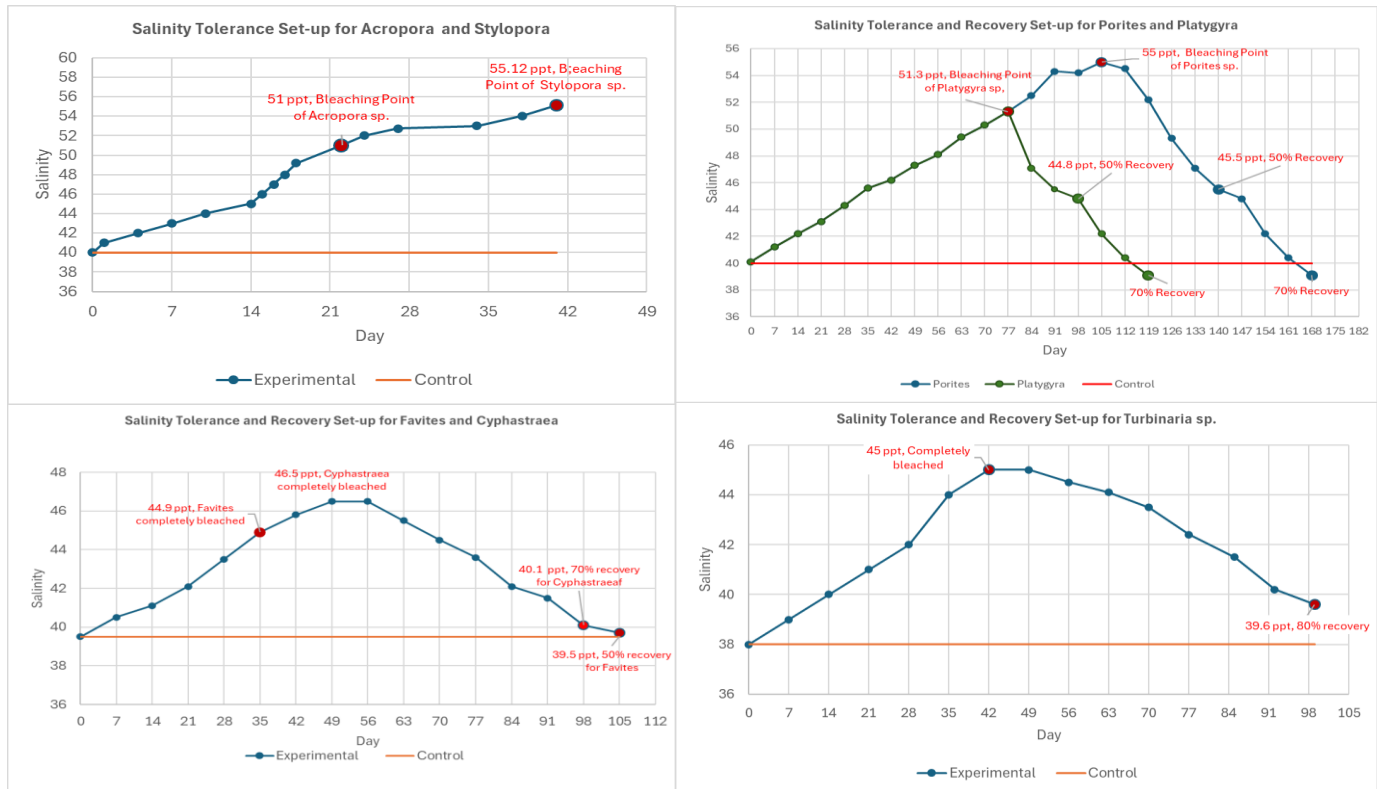


Figure 2. Results of the four salinity manipulation experiments showing the bleaching points of each coral type under study and the recovery percentages after the parameter was being back to normal.

pH Stress Exposure

The pH manipulation experiments subjected corals to progressively acidified conditions, reaching extreme low pH levels of 4.5, to assess species-specific tolerance and resilience under acidification stress. These experiments revealed substantial variation among coral taxa in their capacity to maintain physiological function under challenging conditions. *Porites* and *Stylophora* demonstrated remarkable resistance, preserving both symbiont density and tissue integrity for prolonged periods despite the severe acidification. In contrast, *Acropora*, *Favites*, and *Turbinaria* exhibited rapid bleaching when exposed to the lowest pH levels, reflecting heightened susceptibility to disruptions in carbonate chemistry that affect photosynthesis, calcification, and overall coral health (Riegl et al., 2012). Following the return to ambient pH conditions, recovery responses varied considerably among genera. While most species exhibited only partial restoration of tissue and symbiont condition, *Porites* displayed near-complete recovery, underscoring its exceptional capacity to withstand and recover from acidification stress. These findings highlight the critical role of species-specific tolerance mechanisms in shaping coral community resilience and suggest that taxa like *Porites* and *Stylophora* may serve as foundational species capable of sustaining reef ecosystems under future scenarios of ocean acidification (Figure 3).

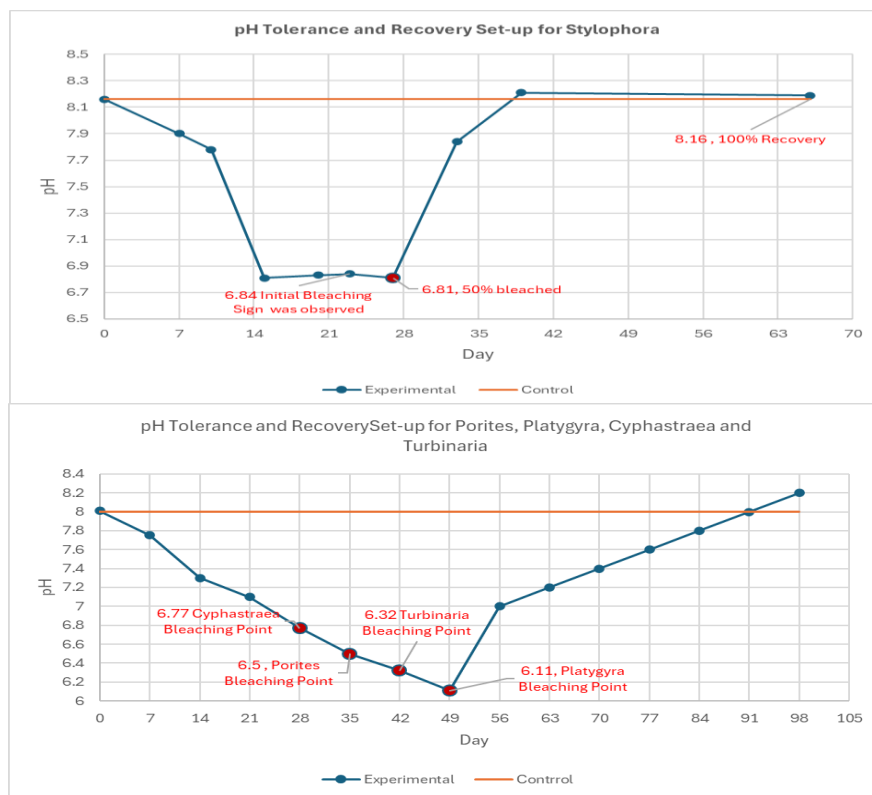


Figure 3. Results of the pH manipulation experiments showing the bleaching points of 5 coral types.

The experimental assessment of UAE corals reveals marked variability in species-species tolerance to thermal, salinity, and acidification stressors. Notably, *Porites* and *Stylophora* consistently exhibited superior resilience under multiple stress conditions, emphasizing their potential as focal species for restoration programs, assisted evolution initiatives and broader climate resilience strategies (Riegl et al., 2012; Howells et al., 2020; Anthony et al., 2008).

These results highlight the critical need for species-specific conservation approaches, particularly in extreme environments such as the Arabian Gulf, where corals are naturally exposed to high temperature and salinity fluctuations (West & Salm, 2003; Coles & Brown, 2003). The observed recovery rates suggest that even more sensitive species may regain physiological stability if stress events are brief, underscoring the potential effectiveness of targeted interventions, such as temperature shading, selective breeding or managed relocation (Burt et al., 2011a; Camp et al., 2018). By integrating knowledge of species-specific tolerance and recovery patterns, conservation strategies can be optimized to enhance reef resilience and ensure long-term sustainability.

Overall, these findings provide a strong rational for integrating resilient species into conservation planning while continuing to monitor and manage environmental stressors, thereby enhancing the adaptive capacity of coral communities in the UAE under ongoing climate change. Furthermore, the data contribute to a growing body of evidence emphasizing the importance of understanding species-level responses for predicting reef futures in other thermally extreme or rapidly changing marine environments globally (Riegl et al., 2012; Howells et al., 2020; Anthony et al., 2008).

V. CONCLUSION

The study establishes critical tolerance thresholds for common coral species in the identifying those most likely to endure climate-related stressors. *Porites* and *Stylophora* stand out as prime candidates for targeted conservation and restoration initiatives, given their exceptional resilience to elevated temperatures, high salinity, and acidification (Riegl et al., 2012; Howells et al., 2020; Anthony et al., 2008). By providing species-specific insights into tolerance and recovery potential, this research offers a robust scientific foundation for coral restoration and assisted evolution programs in the Arabian Gulf, thereby supporting the long-term preservation of these ecologically and economically vital reef ecosystems under changing global conditions (West & Salm, 2003; Camp et al., 2018).

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