Impact of Key Physical and Chemical Parameters on the Health and Growth of Three Native Coral Species of the UAE Under Controlled Conditions

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Abstract- Coral reefs are among the most productive and ecologically important marine ecosystems, yet they are increasingly threatened by climate change and local environmental stressors. Restoration efforts under controlled laboratory conditions provide a valuable approach to support coral growth and resilience. This study assessed the influence of key physical and chemical water parameters on coral growth in controlled tanks. Native coral species collected from the coast of Umm Al Quwain, United Arab Emirates, were acclimatized and monitored under controlled laboratory conditions. Physical parameters - temperature, salinity, dissolved oxygen, pH, alkalinity, and chemical parameters- including calcium, phosphate, nitrate, nitrite, and ammonia-were regularly measured. Optimal coral growth was observed within the following ranges: temperature 23–32.5 °C, salinity 35–41 ppt, pH 7.8–8.5, dissolved oxygen 4.9–5.2 mg/L, alkalinity 7–11 dKH, calcium 400–450 ppm, phosphate <0.03 ppm, nitrate <0.2 ppm, nitrite <10 ppm, and ammonia <0.1 ppm. The findings highlight the critical importance of maintaining these parameters within specific ranges to support coral health and growth under controlled conditions, thereby informing best practices for coral cultivation and restoration in arid marine environments such as the Arabian Gulf.

Index Terms- Coral reefs; micro-fragmentation; controlled environment; restoration; Arabian Gulf; climate change adaptation

I. Introduction

Coral reefs are highly diverse marine ecosystems that provide essential ecological services, including habitat for a wide range of marine species, support for fisheries, and protection of coastlines from erosion. Despite their ecological importance, coral reefs worldwide are increasingly threatened by climate change, ocean acidification, and local stressors such as pollution and habitat degradation. One of the most significant consequences of climate change is the rise in sea surface temperature, which contributes to mass coral bleaching events and impairs coral growth and reproduction (Boström-Einarsson et al., 2020).

In regions such as the Arabian Gulf, corals are exposed to additional environmental stress due to extreme seasonal variations in temperature and salinity. Native coral species—including *Acropora*, *Porites*, and *Stylophora*—have demonstrated resilience to these conditions, making them suitable candidates for restoration initiatives. Successful coral growth and restoration efforts rely heavily on maintaining optimal physical and chemical water parameters, particularly under controlled cultivation conditions.

This study evaluates the critical physical and chemical parameters influencing coral growth under controlled laboratory tank conditions. By identifying the optimal environmental ranges that promote healthy coral development, the research aims to refine coral cultivation protocols and enhance restoration outcomes in the United Arab Emirates and other arid marine environments.

II. METHODOLOGY

Coral Species Covered, Collection and Quarantine

The Marine Environment Research Center cultivated coral species commonly found along the coast of the United Arab Emirates (UAE). These species were selected for their ecological importance and their tolerance to the region's elevated temperature and salinity conditions. The coral groups included: *Stylophora* spp., Brain corals**:** *Platygyra* spp., *Favites* spp. and Cauliflower corals: *Tubinaria*

spp , *Coscinaraea* spp., and *Cyphastraea* spp. Corals were collected from the Umm Al Quwain (UAQ) lagoon, a shallow-water habitat characterized by environmental conditions similar to those found across the Arabian Gulf.
Upon arrival at the Marine Environment Research Center (MERD) facility, corals were placed in holding and quarantine tanks for 2 to 4 weeks. The water quality on the holding tanks was maintained within the optimal range(Table 1). The quarantine process was essential to:

1. Allow physiological acclimatization to laboratory conditions
2. Minimize stress responses
3. Prevent the Introduction of external parasites, pathogens, or algal overgrowth into the main cultivation system

Table 1. Quarantine Tank Water Condition

Parameter	Target Range
Temperature	26–28 °C (stable)
Dissolved Oxygen	≥ 5.0 mg/L
Salinity	39–40 ppt
pH	8.0–8.3
Lighting	Low-intensity (50–80 µmol/m²/s PAR)

Note: Ranges are based on internal observations from MOCCAE/MERC- controlled trials

Maintaining stable salinity and pH within natural reef conditions was essential during the quarantine phase, as even small fluctuations can trigger stress responses in coral tissues. Lowlight levels were maintained using dimmable LED reef lights to reduce coral metabolic demands during initial acclimation. Corals were visually inspected daily for tissue retraction, color changes, or signs of disease. Filtered seawater was used and adjusted to match the tank's temperature, salinity, and pH prior to introduction. All equipment and hoses used during water changes were disinfected to prevent cross-contamination between tanks.

Experimental Tank Setup, Water Quality Monitoring and Maintenance

The experimental aquarium system was designed to maintain stable and controlled conditions suitable for the propagation and monitoring of native coral species under laboratory settings. Following the quarantine period to ensure coral health and acclimation, specimens were transferred to a glass aquarium tank measuring 100 × 200 × 37 cm, with a total volume of approximately 740 liters. During the rearing phase, room temperature was maintained between 23 °C and 24 °C. Light intensity was set at 50–80 µmol m^{-2} s^{-1} and gradually increased to simulate natural light variations. Water circulation was achieved using a submersible powerhead pump to enhance gas exchange and nutrient distribution. Water levels were maintained through periodic top-offs, and water changes were performed, as necessary. Routine maintenance, including filter and tank cleaning, was conducted to ensure uninterrupted system operation.

Water quality parameters were monitored using electronic meters and coral-specific nutrient test kits. Temperature (26–28 °C), salinity (39–40 ppt), and pH (8.0–8.3) were measured daily, while dissolved oxygen was monitored two to three times per week and maintained at ≥ 5.0 mg/L. These parameters are critical for supporting coral metabolic function, symbiont stability, and homeostasis. Temperature and salinity fluctuations can induce stress or bleaching, while deviations in pH affect carbonate availability for calcification. Adequate dissolved oxygen supports respiration and prevents hypoxic conditions that may impair coral health.

Additional nutrient parameters were kept within optimal ranges for coral health: ammonia (NH_3/NH_4^+) < 0.1 ppm, nitrite (NO_2^-) < 0.1 ppm, nitrate (NO_3^-) < 1.0 ppm, phosphate (PO_4^{3-}) < 0.03 ppm, alkalinity (dKH) 7–11, calcium 400–450 ppm, and magnesium 1250–1350 ppm (optional). These values were regularly monitored to support coral growth and physiological stability (see Table 2). Maintaining these ranges is essential for promoting coral calcification, photosynthetic performance, and overall resilience, while preventing stress responses due to nutrient toxicity or imbalance.

Table 2 Water Quality Range, Monitoring Frequency and Maintenance

Parameter	**Target Range**	**Monitoring Frequency**	**Notes**
Temperature (°C)	26–28	Daily	Use digital thermometer or temperature controller
Salinity (ppt)	39–40	Daily	Monitor with refractometer or salinity probe
pH	8.0–8.3	Daily	Use calibrated pH meter
Dissolved Oxygen (mg/L)	≥ 5.0	2–3 times per week	Measure with DO meter; aeration may be used to stabilize

Ammonia (NH_3/NH_4^+)	< 0.1 ppm	2–3 times per week	Critical for coral health; test more frequently if in new system
Nitrite (NO_2^-)	< 0.1 ppm	Weekly	Indicates nitrogen cycle progression
Nitrate (NO_3^-)	< 1.0 ppm	Weekly	High nitrate can stress corals and promote algal growth
Phosphate (PO_4^{3-})	< 0.03 ppm	Weekly	Elevated levels affect coral calcification
Alkalinity (dKH)	7–11	Weekly	Supports pH stability and skeleton formation
Calcium (ppm)	400–450	Weekly	Essential for coral calcification
Magnesium (ppm)	1250–1350 *(optional)*	Bi-weekly	Helps stabilize alkalinity and calcium
Light Intensity (PAR)	50–80 µmol/m²/s *(quarantine)*	Weekly or as needed	Use PAR meter at coral level; increase during grow-out phase

Propagation Methods

Successful coral propagation in controlled aquarium systems requires careful selection of fragmentation techniques to optimize growth rates and survival. Two common approaches are **micro-fragmentation** and **traditional fragmentation**, each with specific protocols and advantages.

1. **Micro-fragmentation**

Micro-fragmentation involves cutting coral colonies into small fragments, typically less than 2.5 cm². This technique accelerates growth by stimulating rapid tissue regeneration and colony fusion.

The advantages of this method include faster relative growth, efficient use of donor colonies and suitability for slow-growing massive corals.

The procedure involves using sterilized diamond band saws or precision cutting tools to section the coral into micro-fragments. Theses fragments are then attached to ceramic or cement plugs using cyanoacrylate glue or epoxy. For healing process, the fragments are kept under low light and moderate flow conditions for 1–2 weeks to reduce stress and encourage tissue regeneration.

2. **Traditional Fragmentation**

Traditional fragmentation involves breaking or cutting larger coral pieces (>2.5 cm) from donor colonies. The advantage of this method includes easier and faster preparation, and suitable for branching coral species.

The procedure includes coral branches or sections are cut with cutters, shears, or saws. Fragments are affixed to substrates similar to micro-fragments. And it will be placed in moderate flow and light, with monitoring to ensure healing and minimize tissue recession.

III. RESULTS

Coral Growth and the Influence of Water Quality Parameters Under Controlled Conditions

Over the 10-month experimental period, both micro-fragmentation and traditional fragmentation techniques supported measurable coral growth within controlled aquarium systems. Micro-fragments had an initial average size of 1.66 cm, growing to a final mean length of 2.38 cm, whereas traditional fragments started larger at 4.2 cm and reached 5.2 cm by the end of the study. Monthly growth rates averaged 0.072 cm/month for micro-fragmentation and 0.10 cm/month for traditional fragmentation, corresponding to relative growth rates of 4.34% and 2.38% per month, respectively. These results confirm the effectiveness of both fragmentation methods under stable water quality conditions, with micro-fragmentation yielding accelerated relative growth, while traditional fragmentation produced faster absolute growth. Substrate type and coral genotype further influenced growth, consistent with findings from previous studies (Papke et al., 2021; Broquet, 2019).

Combined Growth and Temperature Patterns

Water temperature in the aquaria was programmed to simulate seasonal fluctuation over the 10-month period, ranging from approximately 23.5°C to 32.5°C. These values reflect the natural temperature conditions experienced by corals in the Arabian Gulf. Coral growth showed a positive correlation with temperature, with growth rates increasing during the warmer months. Nonetheless, both fragmentation methods supported consistent growth throughout the tolerated temperature range.

Thermal Tolerance and Bleaching Response of UAE Coral Species

Several coral species native to the UAE were exposed to controlled seawater temperature increases to assess thermal tolerance and bleaching thresholds. *Stylophora* spp., maintained at a baseline temperature of 23.0°C, exhibited no visible stress or bleaching up to 34°C, indicating high thermal resilience. Bleaching was observed only at 35–36°C, signaling the onset of thermal stress.

Cyphastrea spp. and *Favites* spp., initially exposed to 24.8°C, showed no bleaching up to 30.1°C. Bleaching in *Cyphastrea* commenced at 30.5°C and intensified at 31.1°C. In contrast, *Favites* remained stable until 31.1°C, with bleaching at 32.4°C. These results suggest that *Cyphastrea* spp. have slightly lower thermal tolerance than *Favites* spp., and both are more sensitive to elevated temperatures than *Stylophora* spp.

These bleaching patterns correspond with established effects of key physical parameters on coral health (Table 3). Elevated temperatures can induce bleaching, impair reproduction, and promote harmful algal growth, while suboptimal temperature restrict growth and cause physiological stress. similarly, deviations in salinity, pH, alkalinity, and dissolved oxygen negatively affect processes critical to coral survival. Maintaining these parameters within optimal ranges is essential to preserve coral resilience under environmental stress.

Table 3. Effects of Physical Properties on Coral Health

Physical Property	**High Parameter Effects**	**Low Parameter Effects**
Temperature	Coral bleaching; reduce reproduction; increased growth of harmful algae	Coral stress; restricted growth; impaired reproduction
Salinity	Coral stress; impaired respiration and nutrient absorption; negative reproductive effects	Coral stress; coral bleaching; impaired reproduction
pH	Coral stress; poor calcium absorption; reduced photosynthesis	Reduced nutrient uptake efficiency; potential toxic buildup
Alkalinity	Reduced nutrient uptake efficiency; potential toxic buildup	Coral stress; poor growth; reduced photosynthesis
Dissolved Oxygen	Increased metabolism enhancing growth and health; stress from excess oxygen	Impaired respiration and photosynthesis; reduced algal photosynthesis

To maintain optimal coral health, specific management strategies were implemented to regulate key physical parameters (Table 4). Temperature fluctuations were minimized using laboratory air conditioning whenever temperatures deviated from the optimal range. Salinity was adjusted by adding freshwater when levels rose or seawater when levels fell, maintaining stable osmotic conditions. Both pH and alkalinity were controlled through biweekly water changes, stabilizing the chemical environment necessary for coral calcification and metabolic functions. Dissolved oxygen was primarily maintained via regular water changes; with supplemental oxygen pumps employed if concentrations dropped below optimal levels, ensuring adequate oxygenation for coral respiration and photosynthesis.

Table 4. Methods for Controlling Physical Parameters

Physical Property	**If increased**	**If decreased**
Temperature	Laboratory air conditioning	Laboratory air conditioning
Salinity	Add freshwater	Add seawater
pH	Change tank water every two weeks	Change tank water every two weeks
Alkalinity	Change tank water every two weeks	Change tank water every two weeks
Dissolved Oxygen	Change tank water every two weeks	Use oxygen pumps

Chemical water parameters are critical for coral growth and health, influencing numerous physiological and ecological processes (Table 5). Slight increases in calcium concentrations enhance skeletal formation; however, excessive calcium can cause harmful water calcification, impairing coral development. Elevated phosphate levels promote algal overgrowth, reducing light penetration and limiting photosynthesis, while low phosphate concentrations restrict energy production by symbiotic algae. Elevated levels of nitrates, nitrites, and ammonia induce cellular damage, biological stress, and potential coral toxicity, whereas maintaining these nutrients at low concentrations fosters a stable and conducive environment for coral health.

Table 5. Effects of Chemical Properties on Coral Health

Chemical Property	**High Level Effects**	**Low Level Effects**
Calcium	Improved skeleton formation at slight elevation; excessive levels cause water calcification	Poor skeletal formation; weak coral growth
Phosphates	Excessive algal growth, reducing light penetration	Reduced algal photosynthesis and energy production
Nitrates, Nitrites, Ammonia	Cellular damage; biological stress; potential coral poisoning	Improved water quality and stability

To mitigate the adverse effects of chemical imbalances on coral health, monthly tank cleaning and water changes were routinely performed, alongside regular checks to ensure proper pump function. These maintenance practices were applied consistently across key chemical parameters—including calcium, phosphates, nitrates, nitrites, and ammonia—regardless of whether their levels were elevated or reduced (Table 6). This approach underscores the importance of proactive intervention, as fluctuations in either direction can disrupt coral physiological processes. For example, both excessive and insufficient calcium levels can impair skeletal formation, while imbalances in nitrogenous compounds such as nitrates and ammonia can induce biological stress or degrade water quality. Consistent system maintenance is therefore essential to prevent accumulation or depletion of critical nutrients and to promote optimal coral growth conditions.

Table 6. Methods for Controlling Chemical Parameters

Chemical Property	**If increased**	**If decreased**
Calcium	Monthly tank cleaning and water change; ensure pump operation	Monthly tank cleaning and water change; ensure pump operation
Phosphates	Monthly tank cleaning and water change; ensure pump operation	Monthly tank cleaning and water change; ensure pump operation
Nitrates and Nitrites	Monthly tank cleaning and water change; ensure pump operation	Monthly tank cleaning and water change; ensure pump operation
Ammonia	Monthly tank cleaning and water change; ensure pump operation	Monthly tank cleaning and water change; ensure pump operation

Overall, these results highlight the critical influence of water temperature, along with other physical and chemical parameters, on coral growth, physiological stress responses, and resilience. Elevated temperatures were identified as a primary driver of bleaching, while imbalances in salinity, pH, alkalinity, dissolved oxygen, calcium, phosphates, and nitrogenous compounds further modulated coral health by affecting metabolic processes, skeletal formation, and symbiotic relationships (Tables 3–6). Effective management strategies—including precise temperature control, regular water changes, routine tank maintenance, and continuous monitoring of water quality—are therefore essential to maintain these parameters within optimal ranges. Such integrated environmental regulation is vital to enhancing coral aquaculture success and supporting reef restoration efforts amid increasing environmental stressors.

IV. CONCLUSION

This study demonstrated that controlled aquarium systems can provide optimal environments for coral growth when physical and chemical parameters are precisely regulated. Native coral species from the Arabian Gulf exhibited broad tolerance to temperature and salinity fluctuation; however, stringent management of nutrient concentrations—including calcium, phosphates, nitrates, and ammonia—was essential to mitigate physiological stress and prevent adverse effects such as bleaching, impaired skeletal formation, and algal overgrowth (Tables 3–6). The micro-fragmentation technique proved highly effective, nearly doubling coral growth compared to traditional fragmentation methods, consistent with previous findings that highlight its value for restoring massive corals on degraded reefs (Page & Vaughan, 2014).

In line with Knapp et al. (2022), this study confirms that micro-fragmentation accelerates coral growth and enhances restoration success under controlled conditions. Moreover, maintaining critical physical parameters—such as temperature, salinity, pH, alkalinity, and dissolved oxygen—within optimal ranges was vital for supporting coral resilience, minimizing stress responses, and facilitating physiological stability (Table 3). The integrated application of monthly tank maintenance, water changes, and pump operation ensured stable chemical water quality, preventing the accumulation and depletion of key nutrients (Tables 4 and 6). These results advocate for the expanded use of micro-fragmentation combined with meticulous environmental regulation in coral restoration initiatives — particularly in regions facing escalating environmental stressors.

Future research should evaluate the long-term survival, reproductive capacity, and ecological integration of fragmented corals, while considering factors such as physical protection, colony size, and genotype effects on outplant success (Rivas et al., 2021). Additionally, studies examining the influence of varied light regimes and water flow rates may further optimize growth conditions. Scaling these methodologies to field applications holds significant potential for improving conservation outcomes in threatened coral reef ecosystems worldwide.

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