Assessing The Impact of Tourism Ban on Ecosystem Recovery in Saint Martin Marine Protected Area, Bangladesh

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Abstract: Situated in the north-eastern Bay of Bengal, Saint Martin's Island is a small sedimentary island. It hosts the only coral ecosystem in Bangladesh and is popularly (but wrongly) called 'coral island'. Since 2004, uncontrolled tourism and unsustainable practices, along with global warming and marine pollution have considerably degraded island's ecosystems and threatened its very existence. To mitigate this substantial threat, in January 2022, Bangladesh Government declared Saint Martin Marine Protected Area and in October 2024, imposed strict tourism regulations including a 'nine months' tourism ban' on the island, generating mixed reactions. Amid opposing demands from environmental and hospitality stakeholders, the first-ever 'tourism ban' (February to October 2025) has come to an end, providing a unique opportunity to assess the health status of the marine ecosystem and eventual recovery. For this purpose, temperature, salinity, pH, dissolved oxygen, total dissolved solids and turbidity were measured from November 2022 to October 2025, using multi-parameter oceanographic instruments. While the assessment of temperature and salinity showed distinct seasonal variability, the comparison of other bio-geochemical parameters, before and during the 'nine months' tourism ban', demonstrated considerable ecological improvement (DO improved from 6.0-6.6 to 7.1-7.4 mg/L and pH improved from 7.0-8.14 to 8.13-8.21). As one of the first in-situ assessments in the Bay of Bengal region, linking 'tourism ban' with ecosystem recovery, this research has the potential to generate valuable insights for sustainable development in Saint Martin's Island and similar places across the globe.

Keywords: anthropogenic stressors; biodiversity; coral ecosystem; ecological recovery; marine protected area.

JEL Classification: Q57; Z32; Q28.

Introduction

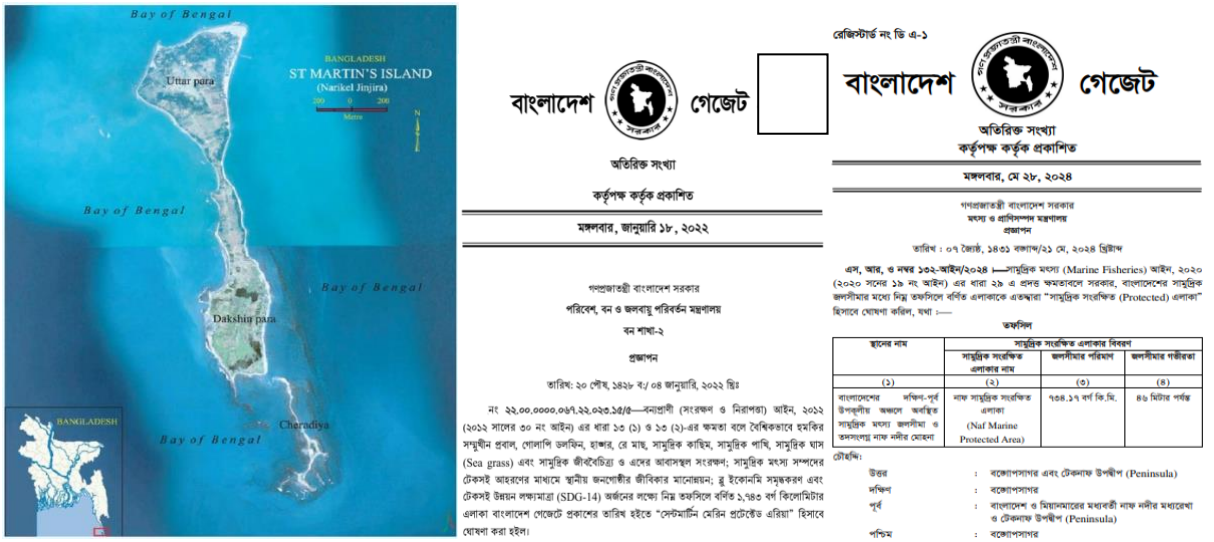
Bangladesh is part of the Bay of Bengal Large Marine Ecosystem (one of the largest ecosystems in the world), endowed with mangroves, coral reefs, estuaries, marine animals and fish breeding areas (Bay of Bengal Large Marine Ecosystem, 2015). Situated at the north-eastern Bay of Bengal, Saint Martin's Island (SMI) is the only island in Bangladesh that sustains coral ecosystem, one of the country's most biologically diverse and ecologically sensitive marine environments. To preserve its unique biodiversity, in 1999, Bangladesh's Department of Environment (DoE) declared the island an Ecologically Critical Area (ECA) (Ahmed, 2025).

Since 2004, tourist ferries from mainland started transporting regularly, making SMI the preferred domestic tourist destination (Saif, 2010). During winter season, roughly 3,000-8,000 tourists were recorded every day to visit the island, generating considerable economic activities for its 7,000 residents (Rahman, 2024). As SMI's estimated carrying capacity is 500-900 visitors/day, such mass tourism was beyond the hosting capacity of this 8 km² tiny island (SMI Master Plan, 2025). The growing number of tourist ferries/boats with associated water, air

and sound pollution posed considerable challenges for SMI's marine ecosystems (IUCN, 2010). Furthermore, repeated coral breakage from anchoring of tourist ships/boats and increasing oil spill, along with sewage discharge have been threatening the survival of SMI's coral ecosystem (Chowdhury *et al.*, 2021).

Corals are animals and host symbiotic zooxanthellae algae for food and color. Due to the slow process of reef generation, corals are unable to adapt in rapidly changing marine environment. Marine pollution, destructive fishing, disease, predation along with global warming, ocean acidification and natural calamities are globally degrading the health of coral ecosystems, threatening millions of species they host and half a billion people they feed (National Geographic, 2017). Considering the threats to fragile coral colonies and endangered wildlife, in January 2022, Bangladesh Forest Department declared 1,743 km² area around the island, as Saint Martin Marine Protected Area (MPA) and in May 2024, Bangladesh's Department of Fisheries declared 734 km² adjacent area as Naf MPA (MoEF, 2024). Though Bangladesh Navy and Coast Guard have been conducting regular patrols for compliance of declared MPA, the degradation of marine biodiversity could not be slowed down (Haque & Karim, 2022). Uncontrolled tourism and tourism-related unsustainable practices have not only endangered the coral reef-based ecosystem, but also island's very existence (Rahman, 2024).

Figure 1. Saint Martin's Island and Official Gazette Notification for Marine Protected Areas



Source: Bangladesh Legislative & Parliamentary Affairs Division, 2025

Realising this emerging threat, in October 2024, Bangladesh's Ministry of Environment, Forest & Climate Change (MoEF) banned single-use plastic and imposed compulsory pre-registration before tourists' arrival on SMI with the following temporal restriction to their access on the island: maximum 2,000 tourists/day; no overnight stay in November; possibility to stay overnight in December-January; no tourists allowed during February-October. These strict tourism regulations were aimed to facilitate natural regeneration of SMI's coral colonies and preservation of fragile biodiversity. Although a complete 'tourism ban' for the protection of coral ecosystem is something rare, localized restrictions on tourism activities for protection of globally endangered species have several precedents. In 2018, Thailand indefinitely banned tourists in Phuket's popular Maya Bay for coral regeneration; which was later reopened only for strictly monitored ecotourism in 2021. Ras Mohamed National Park in Egypt, Quintana Roo in Mexico and Boracay Bay in the Philippines have similar examples of 'tourism ban' for ecological recovery (Andaman, 2025).

Banning all sorts of tourism on SMI for nine months generated mixed reactions across Bangladesh (MoEF, 2024). Amid such contrasting opinions among environmental and hospitality stakeholders, this 'first-year's tourism ban' (February to October 2025) came to an end, providing a unique opportunity to analyze the changes in bio-geochemical parameters and assess the expected marine ecosystem recovery. Several researches have been conducted on the degradation of SMI's coral reefs, highlighting the adverse impact of anthropogenic stressors (Tomascik *et al.* 2021, Gazi et al. 2020). In addition, Norway's Research Vessel (RV) Fridtjof Nansen and USA's Research Vessel Thomas G. Thompson conducted oceanographic survey off SMI in 2025. However, decades of studies and concerns could do little to protect SMI's marine ecosystems (Doropoulos *et al.* 2025).

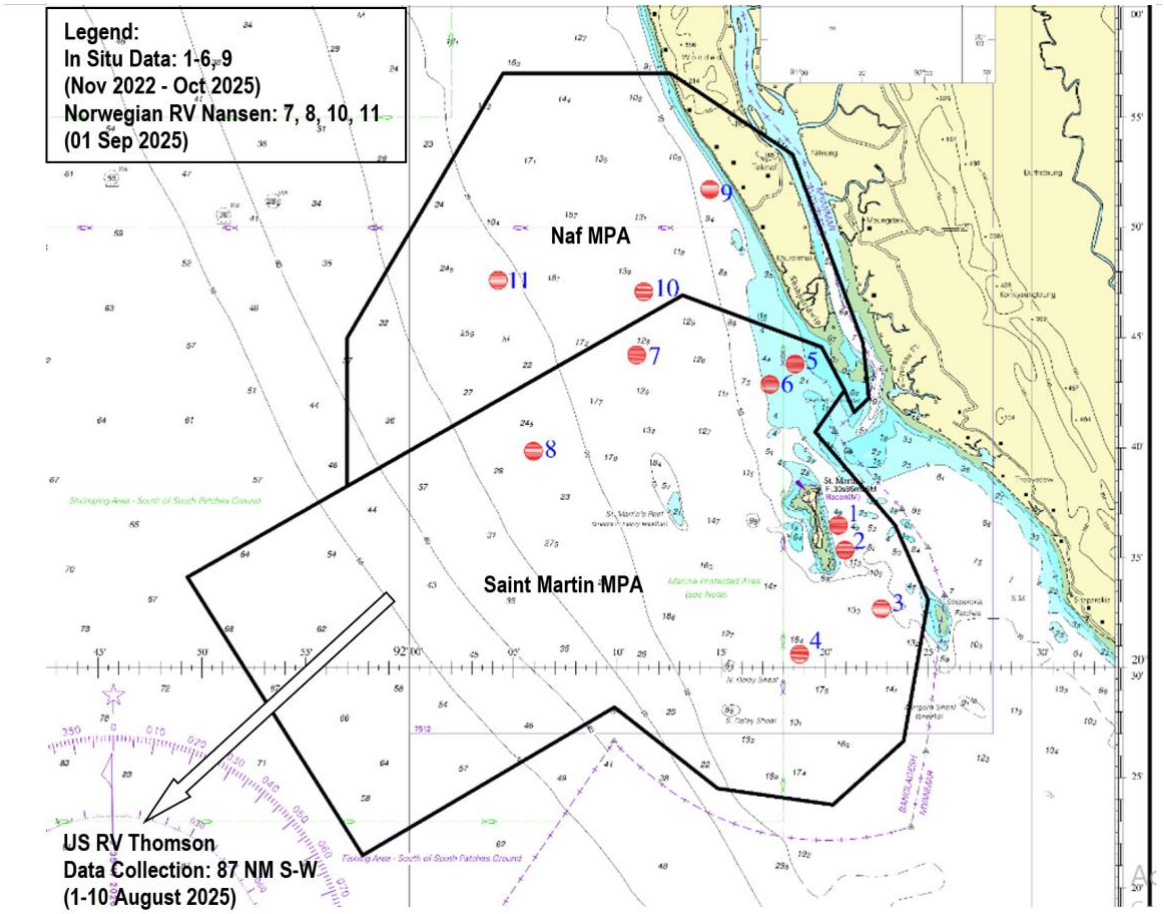
Though temperature (T), salinity (S), potential of hydrogen (pH), dissolved oxygen (DO), total dissolved solids (TDS) and turbidity are essential indicators of coral, plankton, fish productivity (Ahmed *et al.* 2020), their in-situ measurement has never been previously conducted in order to assess the health of SMI's coral ecosystem.

To statistically corroborate the results obtained from the analysis of in-situ data, 'the compliance of nine months' tourism ban did not have significant impact on ecosystem recovery of Saint Martin MPA' was considered as the null hypothesis (H_0) and 'the compliance of nine months' tourism ban had significant impact on ecosystem recovery of Saint Martin MPA' was considered as alternative hypothesis (H_1). Being the first scientific effort of in-situ assessments in the Bay of Bengal region, this research highlights the findings of the baseline study conducted to measure key ecosystem parameters in Saint Martin MPA before and during 'tourism ban' and assess its impact on coral ecosystem recovery. By proposing nature-based solutions, this research has the potential to generate valuable insights for sustainable development options to balance between conservation and livelihood needs of Saint Martin's Island and similar places across the globe.

1. Study Area

For the purpose of this research, Saint Martin MPA has been considered as the main study area and the recently declared Naf MPA has also been studied for broader understanding of ecosystem dynamics.

Figure 2. Ecosystem Parameter Collection Points in Saint Martin and Naf MPA



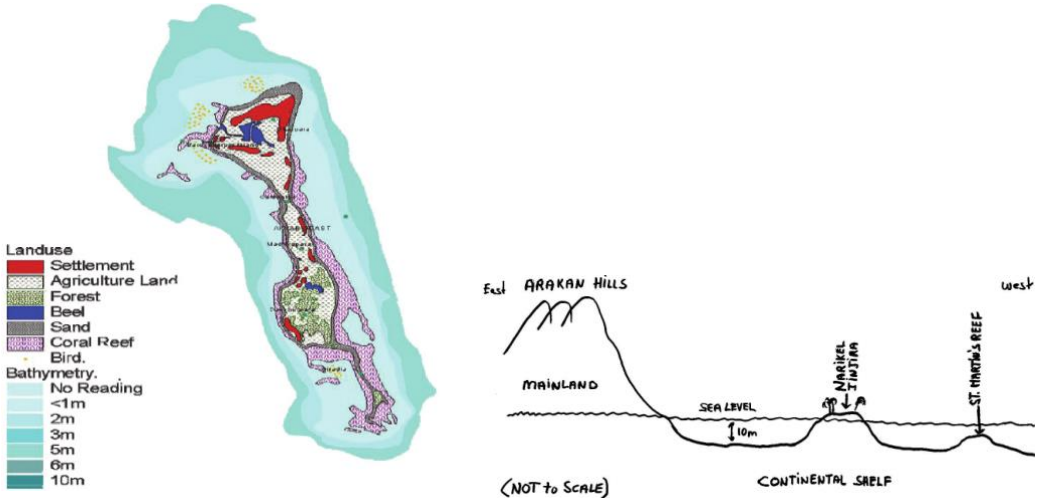
Source: Author's Construct from Bangladesh Navy Chart 30002

Being a small sedimentary island and hosting the only coral ecosystem in Bangladesh, SMI is popularly (though wrongly) called 'the coral island'. In 1997, detailed underwater survey found the island to be surrounded by rocky reefs, instead of corals, consisting of moderately hard/soft sandstones and covered by conglomerate boulders, calcareous concretions that provide a suitable substrate for coral settlement (Tomascik, 1997). This particular sedimentary geology facilitates the availability of highly selective coral larvae to attach and thrive (Ruano *et al.* 2025).

According to a national environmental survey, SMI hosts various ecologically sensitive and environmentally critical species (corals: 68, marine fish: 234, algae: 151, reptiles: 20, dolphins: 5, amphibians: 4, crabs: 40, mollusks: 191, etc.) (DoE, 2021). SMI had an abundance of forest which had gradually been cleared to meet the growing demands of cultivable land and tourism activities. Keya trees are prevalent along its eastern coast and limited mangrove patch may still be found in the south-western coast (Rahman, 2024). However,

uncontrolled tourism and unsustainable practices have threatened the very existence for many of these species. The destruction of biodiversity-rich coral ecosystem has particularly alarmed not only the environmentalists, but also the general population across the country (Tazvir, 2021).

Figure 3. Saint Martin's Island is sedimentary (not coral) island



Source: Tomascik, 1997

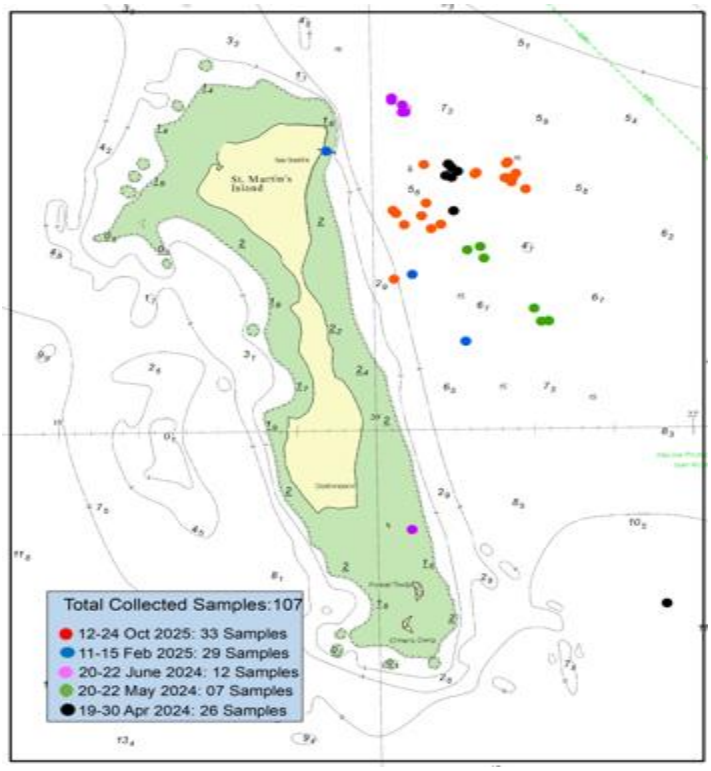
Figure 4. Revival of Saint Martin's biodiversity after 'nine months' tourism ban'

2. Materials and Methods

To assess the impact of 'nine months' tourism ban' on SMI's ecosystem recovery, the bio-geochemical parameters were collected from 107 sampling points before (November 2022 to June 2024) and during (February to October 2025) 'tourism ban'. Considering the limited accessibility, in-situ data (T, S, pH, DO, TDS, turbidity) have been collected primarily from SMI's eastern portion and during winter season. As offshore in-situ data samples were limited, secondary offshore data were collected from the National Oceanic & Atmospheric Administration (NOAA), Norwegian Research Vessel Nansen, and US Research Vessel Thomson for broader oceanographic understanding and cross-checking of the results.

Data were collected by portable multi-parameter oceanographic instruments (Hanna Instruments HI98494), Conductivity, Temperature, Depth (Ocean Seven 310) and Sound Velocity Profiler (Valeport MIDAS SVX2). These sensors were checked and calibrated before every deployment. To compare statistical significance, single-factor Analysis of Variance (ANOVA) across two temporal groups was used: pre-ban period and during-ban period. The analysis quantified the 'variance within groups' and 'variance between groups' at 95% confidence level (α=0.05). Following extreme heatwave and heavy rainfall, occasional localized spikes in the upper layers' ocean temperature, salinity and turbidity were identified. However, these natural variability and seasonal monsoon effects could not be quantified separately from impact of 'tourism ban', due to their complex interaction and lack of sufficient, relevant datasets.

Figure 5. Ecosystem Parameter Collection Points near Saint Martin's Island



Source: Author's Construct from Bangladesh Navy Chart 3501

3. Analysis of Collected Data

3.1. Sea Surface Temperature (SST)

SST refers to the temperature of ocean's upper layer. Satellite measurements typically refer to top few millimeters from sea surface, drifting buoys 0.2-1.5 m and ships 0-10 m depths. In this study, SST was measured at 0-2 m depth. Reef-building corals thrive in 23°-29°C water temperature (NOAA, 2022). The persistent temperature of 30° and above is likely to stress coral colonies.

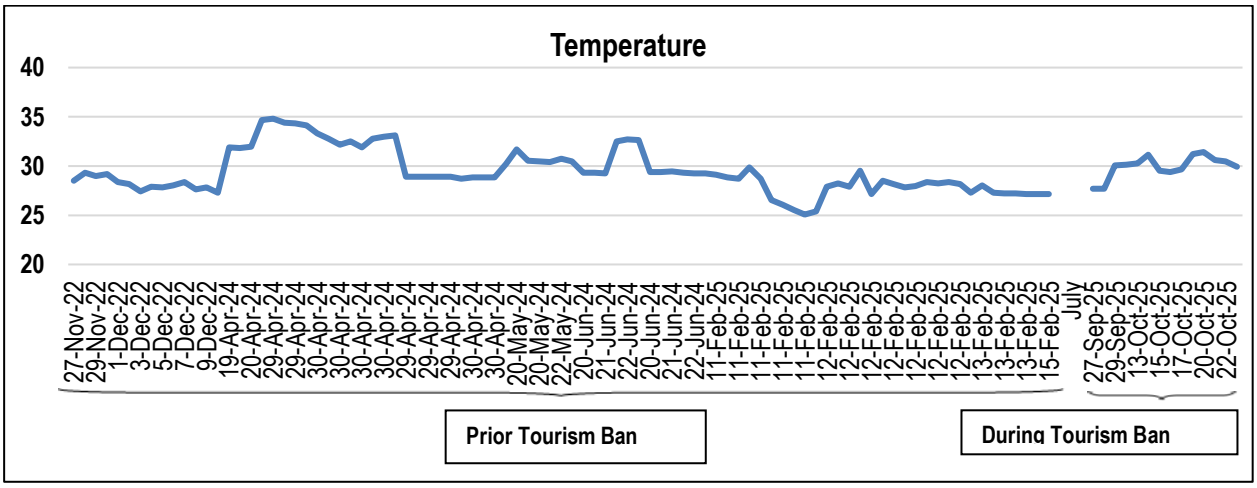
- **February**: SST ranged 25.07-29.85°C, representing the lowest values due to relatively colder winter and reduced incoming solar radiation, currents, etc.
- **April**: SST ranged 27.29-34.81°C due to hot and dry spring. The upper value (34.81°C) was very unusual, but likely due to severe record-breaking heatwaves across Bangladesh, occurred in April 2024 (NOAA, 2024).
- **May**: SST ranged 30.21-31.69°C, probably due to pre-monsoon weather pattern.
- **June**: SST varied between 29.28 and 32.48°C. This high range of temperature was threatening the entire ecosystem.
- **September**: SST varied 27.14-30.47°C. The onset of increased cloud cover and rainfall gradually moderated SST.
- **October 2025**: After 'nine months' tourism ban', SST ranged 29.10-31.48°C. Strong solar radiation under clear sky, calm sea and reduced mixing caused surface water to be quickly warmed up.

Table 1. Measured Sea Surface Temperature near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

	Collection Date	Min (°C)	Max (°C)	Average
Secondary Data	**Optimum for Coral Ecosystem**	**26**	**29**	**27.5**
	NOAA ERSSTv5 (1975-2025)	25.5	31.2	28.3
	Norwegian RV Fridtjof Nansen (01 Sep 2025)	29.06	29.29	29.18
	US RV Thomas Thompson (1-10 Aug 2025)	28	30.06	28.84
Prior Tourism Ban	**27-30 Nov 2022**	28.5	29.3	28.9
	01-09 Dec 2022	27.4	28.4	27.9
	19-30 Apr 2024	27.29	34.81	**31.41**
	20-22 May 2024	30.21	31.69	**30.64**
	20-22 Jun 2024	29.28	32.48	**30.15**
During Tourism Ban	**11-15 Feb 2025**	25.07	29.85	27.69
	27-30 Sep 2025	27.14	30.47	28.81
	13-18 Oct 2025	29.38	31.48	30.43
	20-23 Oct 2025	29.1	30.58	29.84

Figure 6: Measured Sea Surface Temperature near Saint Martin's Island



3.2. Sea Surface Salinity

Coral reefs generally thrive in salinity ranging 32-36 parts per thousand (ppt) and can tolerate 28-40 ppt (Kleypas *et al.* 2006). Maintaining stable salinity is vital for sustaining coral ecosystem. In this study, surface salinity was measured at 2-5 m depth. Freshwater influx from nearby Naf River caused seasonal variation with damage and decline of SMI's coral reef.

- **February**: Salinity ranged 30-38 ppt, due to lack of precipitation, low freshwater discharge from Naf River and high evaporation rate.
- **April**: Salinity ranged 30-34 ppt, due to increased temperature, evaporation and reduced freshwater discharge from Naf River.

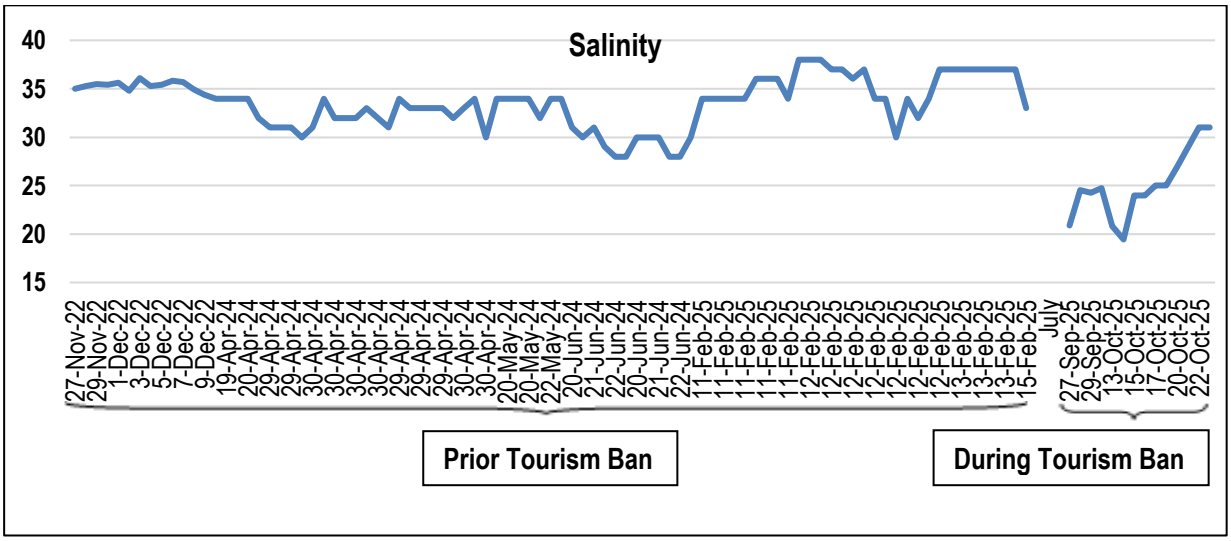
- **May**: Salinity ranged optimally 32-34 ppt, suggesting a balance between temperature, evaporation and freshwater discharge from Naf River.
- **June**: Salinity reduced to 28-31 ppt, reflecting the rainfall and freshwater runoff effects from Naf River.
- **September**: Salinity drastically diluted to 24-25.81 ppt, due to increased rainfall with substantial freshwater influx.
- **October 2025:** After 'nine months' tourism ban', salinity varied 22-31 ppt, due to prolonged monsoon rainfall.

Table 2. Measured Sea Surface Salinity near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, Red: Dangerous)

	Collection Date	Min	Max	Average (ppt)
Secondary Data	Optimum for Coral Ecosystem	28	40	34
	Norwegian RV Fridtjof Nansen (01 Sep 2025)	27.80	30.71	29.26
	US RV Thomas Thompson (1-10 Aug 2025)	21.68	32.61	27.37
Prior Tourism Ban	27-30 Nov 2022	35	35.4	35.2
	01-09 Dec 2022	34.4	36.1	35.25
	19-30 Apr 2024	30	34	32.42
	20-22 May 2024	32	34	33.71
	20-22 Jun 2024	28	31	29.41
During Tourism Ban	11-15 Feb 2025	30	38	35.48
	27-30 Sep 2025	24	25.81	24.91
	13-18 Oct 2025	22	26	24
	20-23 Oct 2025	27	31	29

Figure 7. Measured Sea Surface Salinity near Saint Martin's Island



3.3. Dissolved Oxygen (DO)

DO refers to seawater's oxygen concentration, essential for respiration, metabolism and calcification of coral reef (Nelson *et al.* 2019). Sufficient DO supports the productivity of reef ecosystem while depleted oxygen content

threatens coral biodiversity (Diaz *et al.* 2008). DO≥6 mg/L is considered favorable and DO≤4 mg/L can induce hypoxic stress with possible extinction of species (Vaquer-Sunyer *et al.* 2008).

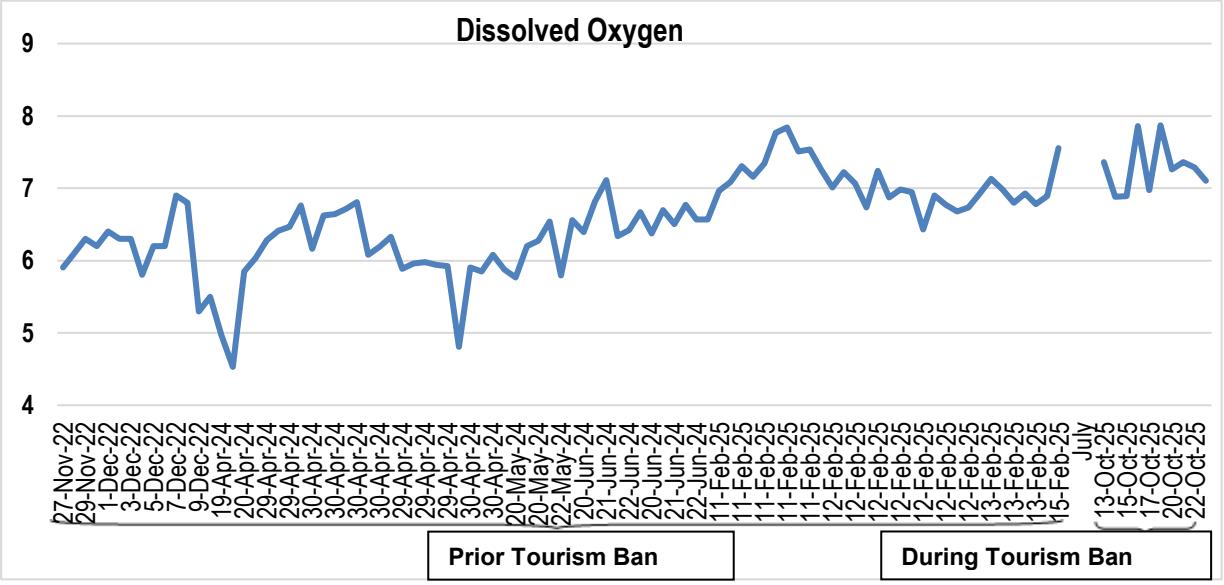
Table 3. Measured Dissolved Oxygen in Seawater near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

	Collection Date	Min	Max	Average (mg/l)
Secondary Data	**Optimum for Coral Ecosystem**	**6**	**8**	**7**
	Norwegian RV Fridtjof Nansen (01 Sep 2025)	4.22 @10m depth	4.45	**4.34**
	US RV Thomas Thompson (1-10 Aug 2025)	4.46 @10m depth	4.75	**4.64**
Prior Tourism Ban	**27-30 Nov 2022**	5.9	6.3	6.1
	01-09 Dec 2022	5.3	6.9	6.1
	19-30 Apr 2024	4.53	6.81	6.02
	20-22 May 2024	5.77	6.56	6.14
	20-22 Jun 2024	6.34	6.82	6.60
During Tourism Ban	**11-15 Feb 2025**	6.43	7.84	7.07
	13-18 Oct 2025	6.82	7.87	7.35
	20-23 Oct 2025	7.02	7.36	7.2

- **February:** DO ranged 6.43-7.84 mg/L, reflecting high oxygen solubility due to cool winter.
- **April:** DO deteriorated to 4.53-6.81 mg/L, due to high temperature and limited water circulation.
- **May:** With the start of monsoon rainfall, DO improved to 5.77-6.56 mg/L.
- **June:** DO stabilized at 6.34-6.82 mg/L**,** consistent with monsoon rainfall and increased mixing.
- **October 2025:** Due to minimal anthropogenic stressors during 'nine months' tourism ban', DO improved to 6.82-7.87 mg/L. This highest recorded DO reduced the risk of hypoxia and increased the pace of coral calcification.

Figure 8. Measured Dissolved Oxygen in Seawater near Saint Martin's Island



3.4. Potential of Hydrogen (pH)

pH indicates acidity (pH<7: acidic) or alkalinity (pH>7: alkaline) (Zeebe *et al.* 2001). pH governs the availability of carbonate ions, necessary for coral calcification and skeleton formation (Plaisance *et al.* 2021). 7.8≤pH≤8.5 is favorable for coral growth (Kleypas *et al.* 2006).

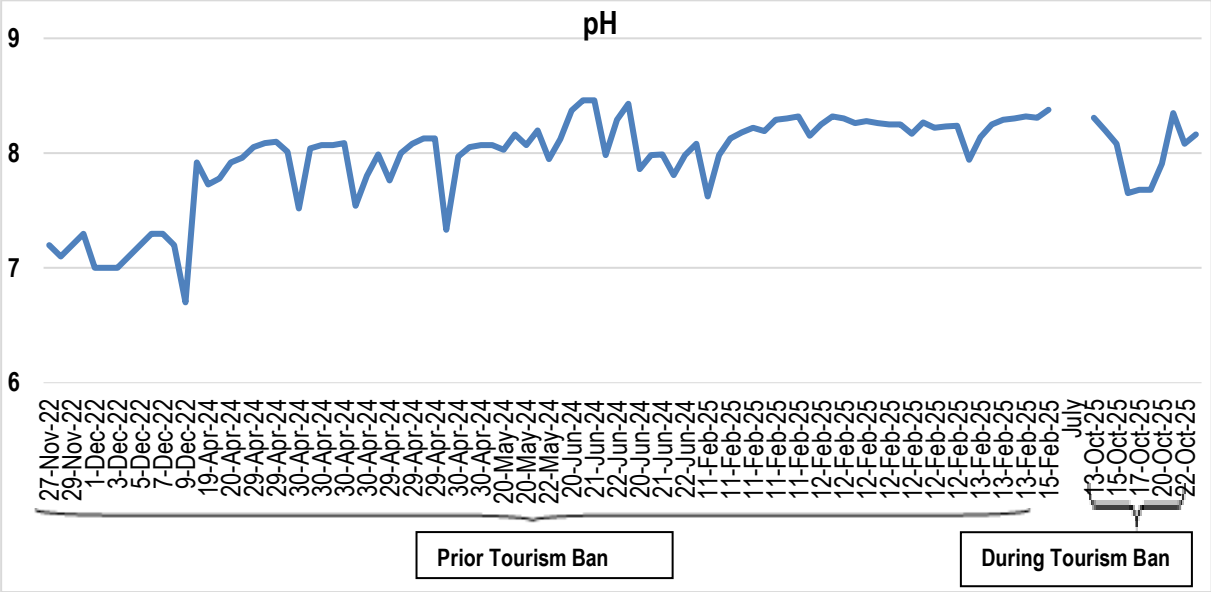
Table 4. Measured pH in Seawater near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

Collection Date	Min		Max	Average
Optimum for Coral Ecosystem	**7.8**		**8.5**	**8.2**
Prior Tourism Ban	**27-30 Nov 2022**	7.1	7.2	**7.15**
	01-09 Dec 2022	6.7	7.3	**7.0**
	19-30 Apr 2024	7.33	8.13	7.93
	20-22 May 2024	8.03	8.16	8.08
	20-22 Jun 2024	7.81	8.43	8.14
During Tourism Ban	**11-15 Feb 2025**	7.62	8.38	8.21
	13-18 Oct 2025	7.65	8.71	8.18
	20-23 Oct 2025	7.91	8.35	8.13

- **February:** pH ranged 7.62-8.38. This lower pH values may have resulted from elevated CO_2 solubility and reduced photosynthesis, causing potential ecological stress.
- **April:** During hot and dry spring, pH reduced to 7.33-8.13. Localized pollution or increased biological activity might have caused this deterioration.
- **May:** pH improved to 8.03-8.16, indicating phytoplankton's enhanced photosynthesis.
- **June:** pH ranged 7.81-8.43, indicating high biological productivity.
- **October 2025:** After nine months' tourism ban, pH remained stable within favorable range (7.65-8.71), probably due to increased photosynthesis in pollution-free clear water.

Figure 9. Measured pH in Seawater near Saint Martin's Island



3.5. TDS

TDS represents the inorganic and organic salts (calcium, sodium, magnesium, potassium, carbonate, chloride, sulfate, nitrate, etc.) present in water solution (WHO, 2016). Healthy coral reefs thrive in stable TDS (32,000-36,000 mg/L) and can tolerate 25,000-40,000 mg/L (Millero *et al.* 2006). Instable TDS can disrupt coral physiology, growth and resilience (Sealife Planet, 2022).

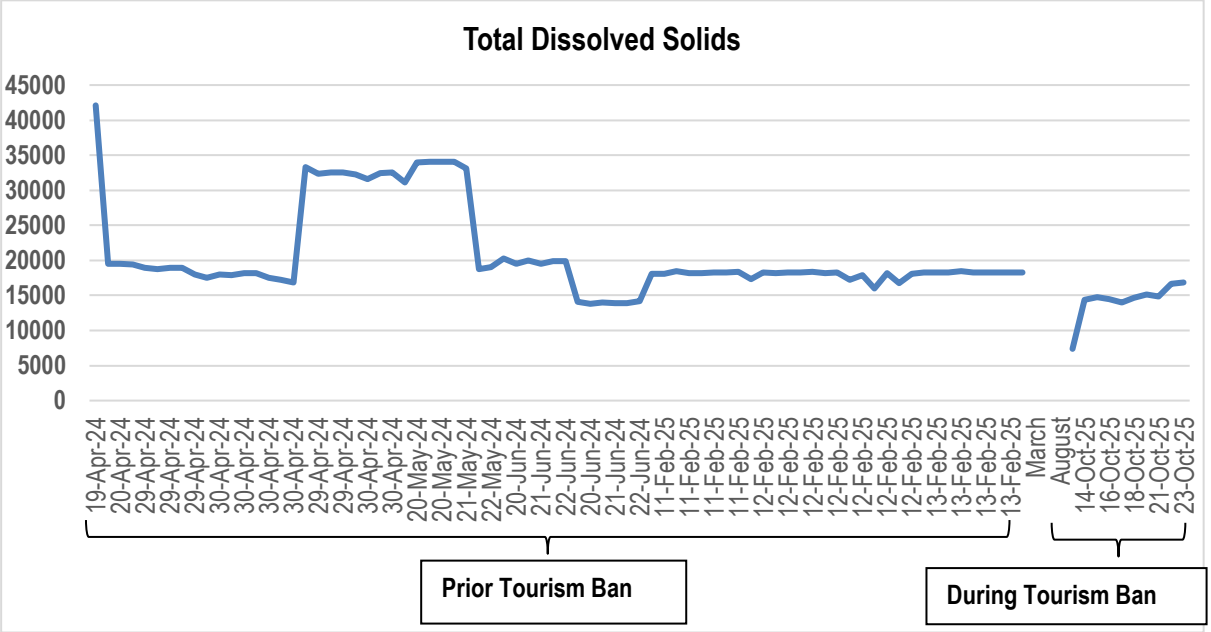
Table 5. Measured Total Dissolved Solids in Seawater near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, Red: Dangerous)

Collection Date		Min (mg/l)	Max (mg/l)	Average
Optimum for Coral Ecosystem		**25,000**	**40,000**	**32,500**
Prior Tourism Ban	**19-30 Apr 2024**	17,230	42,100	**24,080**
	20-22 May 2024	18,790	34,100	29,665
	20-22 Jun 2024	13,760	20,230	**16,995**
During Tourism Ban	**11-15 Feb 2025**	15,970	18,480	**17,225**
	13-15 Oct 2025	13,920	15,820	**14,870**
	20-22 Oct 2025	14,140	16,840	**15,490**

TDS ranged 13,760-42,100 mg/L, showing distinct seasonal variation due to freshwater influence from rainfall and Naf River discharge. Unusually low TDS adversely affected ion availability and coral calcification; while high TDS increased osmotic stress. Maintaining TDS within the tolerable range is vital for coral health and reef resilience.

Figure 10. Measured Dissolved Oxygen in Seawater near Saint Martin's Island



3.6. Turbidity

Turbidity measures water haziness, caused by suspended particles (silt, clay, organic matter, plankton, etc) and is expressed in Formazin Turbidity Units (FTU) (Fabricius *et al.* 2005).

Table 6. Measured Seawater Turbidity near Saint Martin's Island

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

	Collection Date	Min (FTU)	Max (FTU)	Average
Optimum for Coral Ecosystem	**Ideal**	**0.3**	**0.8**	**0.5**
	Moderate	1	3	2
	Stressed	3	5	4
	Harmful	5	15	10
During Tourism Ban	**13 Oct 2025**	1.1	1.2	1.15
	14 Oct 2025	2.9	3.5	**3.2**
	15 Oct 2025	0.4	0.5	0.45
	16 Oct 2025	0.6	0.7	0.65
	17 Oct 2025	0.7	0.8	0.75
	18 Oct 2025	0.7	0.7	0.7

The optimum turbidity for coral colonies is 0.3-0.8 FTU (Fabricius *et al.* 2005). Due to unavailability of suitable instrument, turbidity value could not be measured before 'tourism ban'. However, after 'nine months' tourism ban', it was visually evident that SMI's seawater turbidity reduced and water quality improved. Except abrupt sediment re-suspension due to heavy rainfall on 13-14 October, turbidity remained within the acceptable range (0.45-0.75), suggesting ideal condition for light penetration, photosynthesis and coral-algae symbiosis.

4. Results and Discussion

Teeming with biodiversity, coral reefs are called 'The Rainforest of the Sea'. Despite covering 0.1% of ocean floor, they are home to 25% of global marine creatures (up to 2 million species). Since pre-industrial period, 50%

of global coral reefs have been lost due to 1.2°C warming of the earth. The loss may reach upto 70% and 99%, if average global temperature rises by 1.5°C and 2°C (WWF, 2025). Higher temperature and nutrient enrichment can cause hypoxic DO conditions, jeopardizing the stability of coral ecosystem (Altieri *et al.* 2015). In addition, the ever-growing global carbon emission is causing seawater to absorb more carbon dioxide and increase ocean acidification, posing a serious threat to coral calcification (FAO, 2025).

Despite initial protests from hospitality stakeholders and local communities, SMI's first-ever 'nine months' tourism ban' was successfully implemented due to Bangladesh Government's firm commitment for ecological recovery. Awareness campaigns could convince the local communities that 'tourism ban' may have reduced tourist revenue, but was necessary for island's survival and would gradually usher indirect benefits for the islanders. In the end, local communities realized that SMI's ecological recovery could potentially generate sustainable livelihood (increased fishing, agricultural output, ecotourism, etc.).

Unsustainable tourism activities had caused physiological stress for coral ecosystem through higher temperature, turbidity and lower DO, pH. The 'nine months' tourism ban' (February to October 2025) has reduced anthropogenic pressures, improved water transparency, pH, DO and contributed to SMI's gradual ecosystem recovery. However, anthropogenic drivers from natural and seasonal phenomenon could not be separated due to non-availability of data on climatic effects, Naf river discharge and localized precipitation. Furthermore, the availability of only one year data during 'tourism ban' posed a major challenge to perform further analysis to corroborate these preliminary results.

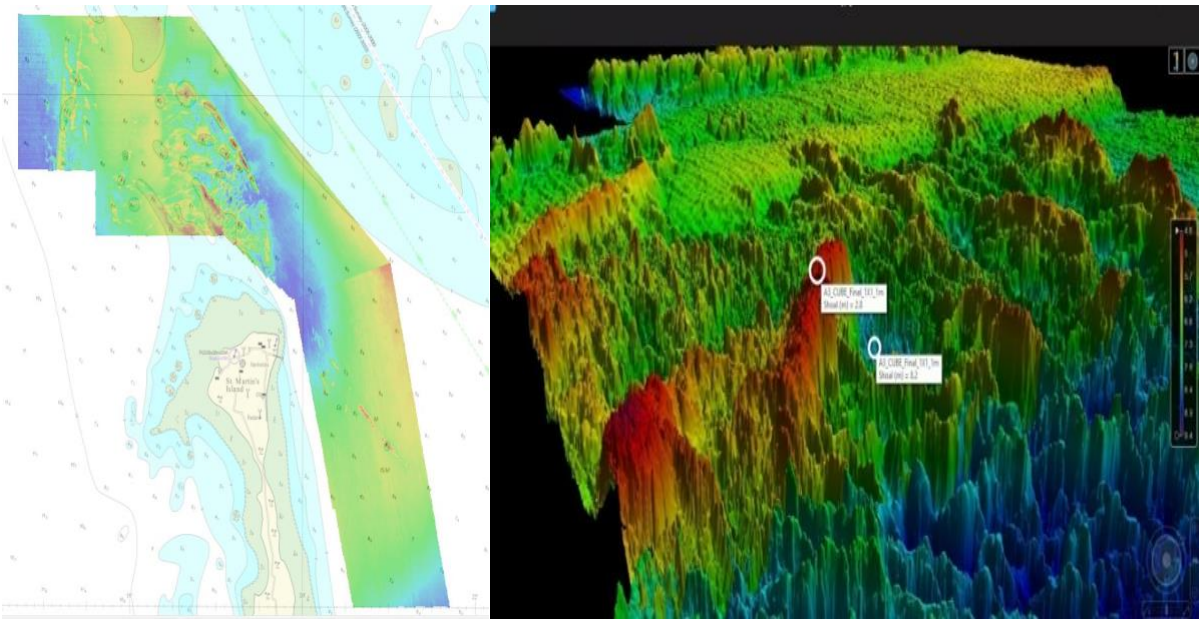
4.1. Temperature

SST measurements displayed clear monsoon-driven seasonal variation. 30°C and above values for extended period may be attributed to strong solar heating, limited cloud cover and stratification. Both global warming and local activities may have caused physiological stress to coral ecosystem, increasing the risk of algae expulsion. The warming trend of SST reduced DO, impaired plankton productivity and accelerated coral bleaching/mortality.

4.2. Salinity

Maintaining stable salinity within acceptable range is vital for sustaining coral ecosystem. Seawater salinity around SMI reflected distinct monsoonal effects. Excessively low salinity (≤28 ppt) reduced coral resilience. While tourism activities alone may have limited impact, associated pollution, sewage runoff and localized Naf freshwater discharge may have caused this variation. After 'nine months' tourism ban', salinity reduced from ≥30 to 24 ppt (later settled at 29 ppt), due to this year's exceptionally heavy rainfall and freshwater discharge.

Figure 11. Mapping Saint Martin's Coral Colonies using Multi Beam Echo Sounder



Source: Author's Construct on Bangladesh Navy Chart 3501

4.3. Dissolved Oxygen

DO around SMI showed clear seasonal variation due to varying SST and biological activity. High temperature reduced gas solubility and corresponded to low DO. After 'nine months' tourism ban', DO improved from 6.0-6.6 to 7.1-7.4 mg/L, suggesting gradual ecosystem recovery. The reduction of human-induced pollution, sewage runoff and sediment influx may have caused such variation.

4.4. pH

Before April 2024, seawater pH<7.8 reduced coral calcification and weakened reef structure. For the rest of the year, pH remained within acceptable range (7.8-8.4) with seasonal fluctuation due to freshwater influx and biological activity. The 'nine months' tourism ban' has reduced anthropogenic pressures and improved pH value from 7.0-8.14 to 8.13-8.21.

4.5. Total Dissolved Solids

TDS around SMI fluctuated widely due to seasonal change, rainfall dilution and Naf river discharge. After 'nine months' tourism ban', the reduction of TDS reflected improved water quality. However, unusually low TDS (during 13-14 October's heavy rainfall) have adversely affected ion availability and coral calcification, being ultimately detrimental to ecological recovery.

4.6. Turbidity

The 'nine months' tourism ban' caused considerable reduction in sediment suspension (or turbidity) and improved water clarity. Though turbidity value could not be measured before tourism ban due to unavailability of suitable instrument, the improvement of SMI's seawater quality was visually evident. Enhanced light penetration is supporting benthic/algae productivity and the overall health of coral ecosystem.

Table 7. Chronological Assessment of Average Ecosystem Parameters in Saint Martin MPA

(Black: Favourable Value, Yellow: Stressed, **Red: Dangerous**)

Date	Temp (°C)	Salinity (ppt)	DO (mg/L)	pH	TDS (mg/L)	Turbidity (FTU)	Remarks
27-30 Nov 2022	28.9	35.2	6.1	**7.15**	-	-	Stable, mild Acidic
1-9 Dec 2022	27.9	35.25	6.1	**7.0**	-	-	Stable, Acidic
19-30 Apr 2024	**31.41**	32.42	6.02	7.93	**24,080**	-	Highest Temp, low TDS & pH **(Coral stressed)**
20-22 May 2024	**30.64**	33.71	6.14	8.08	29,665	-	High Temp **(Coral stressed)**
20-22 Jun 2024	**30.15**	29.41	6.60	8.14	**16,995**	-	High Temp, low TDS **(Coral stressed)**
11-15 Feb 2025	27.69	35.48	7.07	8.00	**17,225**	-	Favorable, low TDS
27-30 Sep 2025	28.81	**24.91**	-	-	-	-	Lowest salinity
13-18 Oct 2025	29.86	**24.0**	7.15	8.18	**14,870**	1.15	High temperature, low salinity, lowest TDS
20-22 Oct 2025	29.84	29.0	7.36	8.13	**15,490**	-	High temperature, low salinity, low TDS

To evaluate the impact of 'tourism ban' on SMI's water quality and coral ecosystem, single-factor ANOVA was used to compare pre-ban and during-ban temporal groups and quantified the following values:

Table 8. Statistical Analysis of Ecosystem Parameters in Saint Martin MPA

Parameter	P	F	F crit	Remarks
Temp (°C)	0.1	1.69	2.5	Alternative hypothesis rejected (P>0.05) Statistically insignificant (F<F crit)
Salinity (ppt)	0.00001	14.63	2.51	Null hypothesis rejected (P<0.05) Statistically significant (F>F crit)
DO (mg/L)	0.04	2.83	2.65	Null hypothesis rejected (P<0.05) Statistically significant (F>F crit)

Parameter	P	F	F crit	Remarks
pH	0.001	6.32	2.65	Null hypothesis rejected (P<0.05) Statistically significant (F>F crit)
TDS (mg/L)	0.14	2.05	3.09	Alternative hypothesis rejected (P>0.05) Statistically insignificant (F<F crit)

Salinity (P=0.00001), pH (P=0.001) and DO (P=0.04) showed statistically significant improvements and thus, null hypothesis (H_0) was rejected. However, temperature (P=0.1) and TDS (P=0.14) were found statistically insignificant, indicating the influence of complex broader issues (global warming, ocean acidification, monsoon, etc.), rather than localized management interventions.

Conclusions

SMI is the only island in Bangladesh that sustains unique coral ecosystem, teeming with biodiversity. Since 2004, uncontrolled tourism along with unsustainable practices beyond island's hosting capacity has severely degraded coral ecosystem and is threatening its very existence. As a result, in January 2022, Bangladesh Government declared Saint Martin MPA and in October 2024, regulated tourists arrival on SMI through pre-registration (November to January, maximum 2,000 tourists/day). While many commended such endeavors to protect the threatened biodiversity, hospitality professionals have organized nationwide protests to lift this tourism ban (Dailystar, 2025). Through awareness campaigns on the necessity of tourism restrictions for island's survival and islanders' long-term benefits, SMI's first-ever 'nine months' tourism ban' was successfully implemented from February to October 2025.

Regular monitoring of bio-geochemical parameters is highly desirable for ensuring healthy coral ecosystem. The enforcement of strict tourism regulations provided unique opportunity to measure ecosystem parameters before and during 'tourism ban' to assess ecological recovery. Due to the limited accessibility, in-situ data (T, S, pH, DO, TDS, turbidity) have been collected primarily from SMI's eastern portion and during winter season. Nevertheless, these restricted samplings have generated an approximate representation and facilitated the broader oceanographic understanding of the entire Saint Martin MPA.

The study revealed distinct environmental benefits of regulated tourism due to decreased anthropogenic stressors. The analysis of temperature and salinity demonstrated significant monsoon-driven variability and freshwater discharge from Naf River. The assessment of DO and pH demonstrated considerable improvement (DO improved from 6.0-6.6 to 7.1-7.4 mg/L and pH improved from 7.0-8.14 to 8.13-8.21). ANOVA test for salinity, pH and DO found the impact of 'tourism ban' on SMI's ecological recovery as statistically significant. However, whether this amelioration can be attributed primarily to 'tourism ban' or a combination of correlated factors could not be verified, due to the lack of longer-term complementary, pertinent dataset on climate and hydro-meteorology.

The valuable insights of this pioneering study to evaluate the impact of 'nine months' tourism ban' on SMI's coral ecosystem recovery may promote coral resilience, environmental preservation and contribute to the blue economic development. This analysis may be regarded as a microcosmic example of the interplay between human activities and marine environment in the entire Bay of Bengal. Therefore, the continuation of 'tourism ban' and measurement of ecosystem parameters should be pursued in the upcoming years. Based upon the findings of this study, the followings are recommended for the preservation of SMI's marine environment and coral ecosystem:

- **Regulated Tourism**: Bangladesh Government may continue with Saint Martin's on-going tourism restrictions for another two years to allow natural regeneration of coral colonies and healing of coral ecosystem. Upon achieving the desired ecological recovery, regulated eco-tourism may be promoted.
- **Awareness Campaign**: Bangladesh's Department of Environment & Forest may conduct awareness campaigns for both locals and tourists on the benefits of environmental preservation to reduce pollution and usher ecological recovery.
- **Underwater Survey**: Bangladesh Oceanographic Research Institute may conduct a detailed underwater survey to ascertain the location and health of coral colonies.
- **Coral Regeneration**: Efforts may be taken to minimize anthropogenic stressors like pollution, sedimentation along with global warming, ocean acidification to facilitate coral regeneration.
- **Coral Gardening**: With international support, Bangladesh's Department of Environment may conduct feasibility study and cost-benefit analysis on climate-resilient coral gardening around SMI.

- **Mangrove Plantation**: To protect the shorelines and minimize water turbidity, Bangladesh's Department of Forest may scientifically conduct mangrove plantation and other nature-based environment-friendly solutions.
- **Community Engagement**: To protect marine ecosystems, the involvement of local government and communities in environmental preservation may be prioritized.
- **Ecotourism**: To support local economies without degrading environmental health, Bangladesh's Department of Tourism may conduct a detailed study through Subject-Matter-Experts to promote ecotourism.
- **National/Regional Collaboration**: Collaboration among various stakeholders (national, regional, global) may facilitate research, funding and knowledge sharing for environmental preservation. Beside these local actions, global actions such as limiting global warming and minimizing marine pollution, ocean acidification are highly desirable for the sustainable livelihood of future generations.

Declarations

Credit Authorship Contribution Statement

Rezaur Rahman: Conceptualization, Methodology, Data collection & analysis, Writing
K. M. Azam Choudhury: Supervision, Visualization, Validation, Editing
Mirza Golam Kibria: Data collection and analysis, Writing
Tonia Astrid Capuano: Supervision, Editing

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Data Availability: The ecosystem parameters collected by the researchers from 2022 to 2025, are under the custody of the corresponding author and can be made available upon request.

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