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Research Article

Assessing the invasion and impact of coral-killing sponge *Terpios hoshinota* on coral reefs in the Gulf of Mannar marine biosphere reserve: A case study and review

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The encrusting cyanobacteriosponge *Terpios hoshinota* Rützler & Muzik, 1993 has caused severe and often irreversible damage to coral reefs and associated benthic communities in the Indo-Pacific region. Despite its ecological significance, the distribution patterns of *T. hoshinota* in Indian reefs is poorly understood except for limited reports. Hence, a comprehensive investigation was conducted between September 2018 and August 2019 to assess the range extent of *T. hoshinota* across 21 islands within the Gulf of Mannar Marine Biosphere Reserve (GoMMBR), located along the southeast coast of Tamil Nadu, India. Utilising coral video transect methodology, a notable outbreak of *T. hoshinota* primarily on *Montipora digitata* reefs in Thalaiyari and Valai Islands was documented, where approximately 42.8 % and 45 % of *M. digitata* coral cover were killed. Furthermore, mild to moderate infestations of *T. hoshinota* were observed on *Porites* corals in seven additional islands within the GoMMBR. There were no other factors except *T. hoshinota* that caused the corals to die (no polyps on the corals). The rapid spread of *T. hoshinota* from infested corals to other healthy corals was evidently accelerated by coral-coral interactions.

[**Keywords**: Coral restoration, Coral threats, Invasive species, *Montipora digitata*, *Porites*]

Introduction

Coral reef ecosystems are tropical rainforests of the seas that harbour thousands of species belonging to multiple taxa. They provide a wide range of benefits to the environment and society[1]. Approximately 26 % of coastlines in reef nations are protected, and these reefs provide crucial safeguards for 5.3 million people and generate economic benefits valued at $109 billion per decade[2]. In recent decades, reefs around the globe have been severely damaged by numerous invasive reef sponges[3-5]. The ubiquitous coral-killing cyanobacteriosponge, *Terpios hoshinota* Rützler & Muzik, 1993, is one of the most threatening sponges widespread in tropical reefs and damaged reefs extensively[5-10]. The rapid proliferation of *T. hoshinota* has been linked to significant coral reef degradation, with studies indicating that it can overgrow and kill coral colonies, contributing to more than fifty percent[5] and 75 % coral cover decline in affected regions[11].

Terpios hoshinota is a photoautotrophic encrusting sponge, with a thin size (< 1 mm)[8], and appears in grayish to blackish colour (greenish in ethanol[12] or pink in 1 % HCl-methanol[13]). *Terpios hoshinota* invasion on reefs was first recorded from Guam[6] and subsequently reported from other geographical regions. It is not an exclusive coral ectoparasite, because it also overgrew plastic tags[14], solid substrates, rubbles[15], and other marine flora and fauna[8,9,15,16]. It overgrows corals rapidly under favourable conditions and kills corals partly (fragments) or patch-wise (a few colonies) or completely (an entire reef patch). It releases pseudoblastula larvae[17], previously known as parenchymella larvae[13], from the osculum during June to December, midnights[18], full moon time[10,17,19], reaching maximum larval release within three days[19] and preferably settles on dead corals than live corals[10]. Laboratory observations revealed that it overgrew live *Acropora* coral by the seventh day after forming lobed tylostyle spicules and oscula[10].

The rapid spread of *T. hoshinota* on dead coral reefs inhibits larval settlement or delays the reef recruitment process or leads to mortality in the case of live corals[6,7]. Corals are extensively invaded by *T. hoshinota* because it arrests light and nutrient availability to corals. The experimental observations showed that the chemicals produced by *T. hoshinota* displayed a toxic effect on corals when propagating on corals[6]. Studies also showed that *Terpios* is known to outcompete corals and crustose coralline algae for space rather than nutrients[7,20].

The Gulf of Mannar Biosphere Reserve (GoMMBR) is one of the rich biodiversity hotspots in Southeast Asian countries that comprises 21 islands surrounded by patchy fringing reefs with rich corals and associated diversity[21]. In recent decades, reefs in these islands are experiencing potential threats from frequent bleaching events due to elevated sea surface temperatures[22-25], sedimentation[26,27], diseases[28-31], algal invasions[27,30,32-34], sponge invasion[35-37], and destructive fishing activities[30]. In India, 564 sponge species have been reported[38], of which *T. hoshinota* has gained increased attention due to its destructive nature on coral reefs[39]. The first occurrence of *T. hoshinota* as a major reef threat was observed in India from Palk Bay[35,40] and the Gulf of Mannar (Vaan Island under Tuticorin) regions[36]. A previous study suggested that *T. hoshinota* might have likely dispersed from Vaan Island and invaded reefs in other islands between Palk Bay and Tuticorin regions[36]. However, after the 2015 study[36], no extensive studies were conducted to understand its range extension in the Gulf of Mannar islands. Hence, this study conducted intensive reef surveys from the GoMMBR and found its widespread occurrence in 10 out of 21 islands. This study aimed to report the outbreak of *T. hoshinota* on *Montipora digitata* reefs and its occurrence on other coral forms in the islands of GoMMBR.

Materials and Methods

Between September 2018 and August 2019, a total of 21 islands, including Thalaiyari and Valai Islands, were surveyed. Notably, an outbreak of *T. hoshinota* was specifically recorded from reefs in Thalaiyari and Valai Islands in May 2019. Underwater field surveys were carried out one time during May 2019 (Fig. 1) from the fringing reefs of Thalaiyari (09°11’103” N, 078° 55’968” E) and Valai Islands (09°11’246” N, 078°56’375” E) distributed in the Keelakarai region under GoMMBR, Southeast coast of Tamil Nadu, India. Reef monitoring of live and dead coral cover as well as benthic cover in both Islands was surveyed using the Coral Video Transect method[41] along a 50 m belt transect. A 50 m belt transect was laid perpendicular and parallel to the shore (this is due to the reef distribution pattern) at the northern sides of Thalaiyari Island (1.5 m depth) and Valai Island (2 m depth), respectively. These two study sites are primarily dominated by *Montipora digitata* reef patches and scattered *Porites* colonies. Triplicate transect data were not obtained as the incident was observed only from specific *Montipora digitata* reef patches in both study sites. The underwater photographs of *T. hoshinota* invading reefs and its interactions with other corals were photographed using a Nikon Coolpix camera. The percentage of area damaged was analysed in Microsoft Excel.

Surface tissues of *T. hoshinota* found on coral fragments were collected using a scrapper. This tissue was crushed into a fine solution in filtered sterile seawater and observed under a Lynx microscope at 40X magnification to identify associated cyanobacteria. Spicules morphology was confirmed according to Aini & Yamashiro[42]. Seawater quality parameters were measured in situ using Eureka water probes-Manta+Water Quality Sonde CTD analyser. Corals were identified using standard taxonomic keys (www.coralsoftheworld.org/) as well as the GoMMBR regional database[21].

Results and Discussion

The outbreak of *Terpios hoshinota* was documented from two islands under the GoMMBR. It has distinct characteristics such as black-brownish texture, tylostyle spicules, encrusting nature, and endosymbiotic cyanobacteria. Its occurrence was recorded on a few coral colonies, but its presence was limited to just a few islands (Table 1). This incident was recorded during a massive bleaching event that occurred in GoMMBR during the summer of 2019. The percentage of *M. digitata* reef damaged by *T. hoshinota* was 42.8 % and 45 % in Thalaiyari and Valai Islands, respectively. The reported percentages reflect the actual coral cover of *M. digitata* at both locations, with the same proportion of coral cover being affected by *T. hoshinota* infestation. The percentage of other benthic forms observed along the video transect in Thalaiyari Island includes Acropora Branching (ACB) 18 %, Dead Coral with Algae

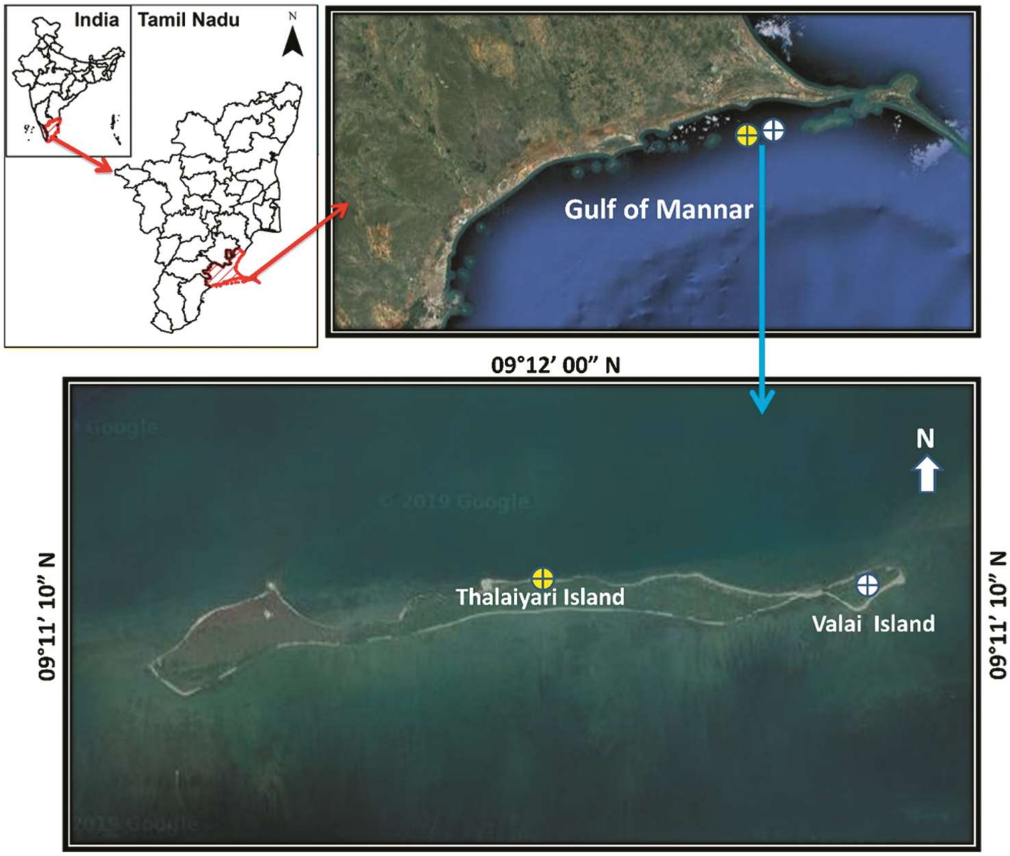

Fig. 1 — Map showing study locations (yellow circles) Thalaiyari and Valai Islands in GoMMBR

Table 1 — Environmental parameters recorded during the outbreak of *T. hoshinota* from four regions. Occurrence of *T. hoshinota* in the GoMMBR as Mild: 3 – 50 cm (n = 18); Moderate: > 50 cm – 2 m (n = 8); Outbreak: > 2 m – several meters (n = 2). KI: Krusadai Island; MI: Manoli Island; HI: Hare Island; MUI: Mulli Island; VI: Valai Island; TI: Thalaiyari Island; PVI: Puluvinichalli Island; UI: Upputhanni Island; and VNI: Vaan Island

Region	Island	Temperature (°C)	Salinity	pH	DO	Depth	Infestation level
	KI	31.17±1.08	35.38±1.16	7.54±0.08	6.13±0.44	1.78±0.45	Mild
Mandapam	MI	30.13±0.58	35.36±1.13	7.64±0.31	6.38±1.52	1.67±0.82	Mild
	HI	31.38±0.85	35.17±1.33	7.93±0.29	6.54±0.73	1.29±0.54	Moderate
	MUI	31.94±0.51	34.68±0.16	7.55±0.16	6.66±0.82	2.72±0.99	Mild
Keelakarai	VI	32.88±0.58	34.78±0.11	7.51±0.12	6.69±0.15	2.70±0.22	Outbreak
	TI	32.20±0.48	33.78±0.08	7.56±0.14	6.54±0.24	1.84±0.37	Outbreak
Vembar	PVI	31.44±1.06	36.51±0.59	7.67±0.01	6.26±0.59	3.14±0.05	Mild
	UI	31.38±0.08	36.83±0.08	7.66±0.03	6.91±0.21	2.62±0.54	Moderate
Tuticorin	VNI	32.23±0.74	35.21±0.39	7.54±0.16	6.34±0.84	1.57±0.12	Moderate

(DCA) 8.4 %, and Rubbles (R) 30.8 %. In Valai Island, ACB 3 %, DCA 12 %, and R 40 % were observed (Fig. 2). This *T. hoshinota* outbreak data will help us compare future live coral cover data with the current reef patches invaded by *T. hoshinota*.

Terpios hoshinota invasion was observed on *Montipora foliosa*, *Porites*, *Favites*, *Acropora*, and other encrusting corals. Partial damage to *Galaxea* coral was also observed from Krusadai Island. *Terpios hoshinota* overgrowing *Halimeda* sp. was observed in reefs at Manoliputti Island. A study from Mauritius observed that coral *Acropora austera* as primary substrate preference of *T. hoshinota* over other corals[16]. Nevertheless, numerous studies reported Acroporidae, Merulinidae, and Poritidae corals as the main coral groups invaded by *T. hoshinota*[40,43]. These observations indicate that *T. hoshinota* has no host-specific attack on any of the observed coral forms, suggesting that *T. hoshinota* is a space competitor rather than a nutrient miner, which

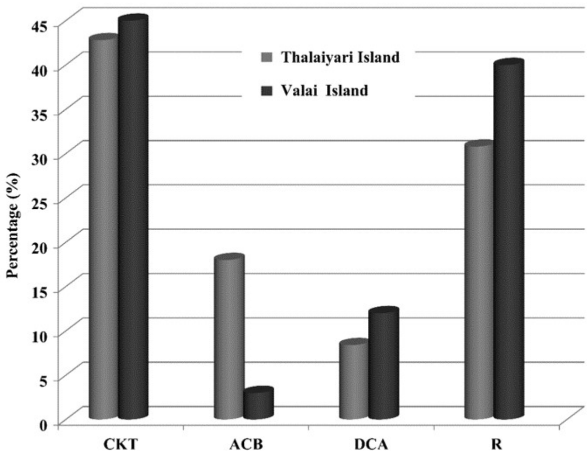

Fig. 2 — Outbreak of *T. hoshinota* that invaded live *M. digitata* reef in Thalaiyari and Valai Islands. CKT: Coral-killing *Terpios hoshinota*; ACB: *Acropora* branching; DCA: Dead coral with algae; R: rubble. Note: There is no live coral cover in both study sites because of *T. hoshinota* invasion on the entire reef. Hence, the percentage data of healthy colonies is not given. Other coral morphs found in the study areas were not within the transect, hence, data for other coral morphs is not included in the figure. Colony counts data of other coral forms mentioned in the results were obtained from areas where reef patch (surveyed in this study) has ended in both the study sites

is concurrent with the earlier studies[7,20]. These coral species were observed to have no chemical defense to display antagonism against *T. hoshinota* progression.

Although it seems hard to believe that the sponge spread is tens of meters only in one direction, the linear propagation of *T. hoshinota* was observed up to a distance between ~10 – > 50 m. Peripheral spread of *T. hoshinota* was found between the distance range of 1.5 – 3 m. The monthly progression rate of *T. hoshinota* on these coral forms was not studied due to reef surveys in other islands. A total of 22.4 m^2 of reef area in Thalaiyari Island and 10.5 m^2 in Valai Island have been affected as observed along a 50 m line transect and video transect. Other coral colonies, which were located outside the transects and affected with *T. hoshinota* in Thalaiyari Island, were *Porites* (n = 4 out of 84), *Platygyra* (n = 1 out of 2), *Favites* (n = 1 out of 24), *Favia* (n = 1), and digitate, encrusting *Montipora* sp. (n = 1 out of 12). However, reef patches of these coral species neither experienced an outbreak nor displayed any defense action against *T. hoshinota*. Significantly, *Montipora digitata* reef alone was completely invaded by *T. hoshinota* (Figs. 2 & 3). Like black band disease[44], *T. hoshinota*

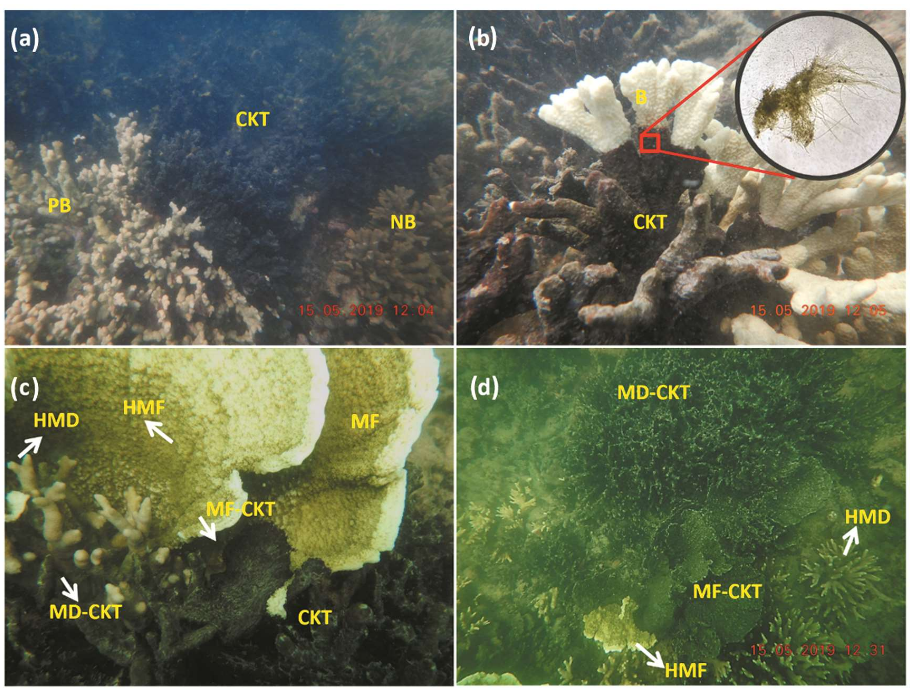

Fig. 3 — Underwater photographs showing the rapid spread of *T. hoshinota* on *Montipora* reef patch. a) Non-Bleached (NB) and Partially Bleached (PB) *M. digitata* colonies being infected by *T. hoshinota* in Thalaiyari Island; b) Spread of *T. hoshinota* on Bleached (B) *M. digitata* colony observed in Thalaiyari Island. Circle showing the presence of green-colored cyanobacteria associated with CKT-affected coral surfaces; c) Spread of *T. hoshinota* from *M. digitata* colony to *M. foliosa* colony via coral-coral interaction observed in Valai Island. MF: *M. foliosa*, HMF: Healthy colony of *M. foliosa*, HMD: Healthy colony of *M. digitata*, MD-CKT: *M. digitata* affected with coral-killing *T. hoshinota*, MF-CKT: Coral-killing *T. hoshinota* propagation onto *M. foliosa*; and d) Surface view of *T. hoshinota* propagation between *M. digitata* and *M. foliosa* seen at Valai Island

showed swift vertical propagation on massive corals and horizontal propagation on branching corals in Thalaiyari and Valai Islands.

Both bleached and non-bleached *Montipora* corals were greatly affected (Fig. 3a & b). Infected *Montipora* coral fragments revealed the presence of cyanobacteria along with *T. hoshinota* tissues (Fig. 3b). The interaction of *M. digitata* with *M. foliosa* has resulted in the rapid spread of *T. hoshinota* to *M. foliosa* in both Thalaiyari and Valai Islands, resulting in damage to *M. foliosa* coral colonies within weeks (Fig. 3c & d). Interaction between corals was observed to accelerate the spread of *T. hoshinota* to other coral species. Rapid progression of *T. hoshinota* to adjacent healthy and dead *Montipora* corals was swift from the edges of infected corals. *Terpios hoshinota* progression from *M. digitata* to *M. foliosa* colonies was accelerated by coral-coral interaction (Fig. 3c). Only some of the adjacent *M. digitata* colonies that were not interacting with *T. hoshinota* infected coral colonies were found healthy (Fig. 3d). Massive *Porites* colonies (n = 7) away from the *Montipora* reefs were also infected by *T. hoshinota* at Thalaiyari Island, indicating that *T. hoshinota* propagation to *Porites* colonies may be due to larval dispersal and settlement.

The outbreak of *T. hoshinota* was not observed in any other islands of the GoM, except for mild to moderate occurrences of *T. hoshinota* in a few islands (Table 1). However, the prevalence of *T. hoshinota* was recorded minimally in Mandapam (Hare, Manoli, and Krusadai Islands), Keelakarai (Mulli and Anaipar Islands), Vembar (Puluvinichalli and Upputhanni Islands) and Tuticorin (Vaan Island) group of islands. The invasion level of *T. hoshinota* was higher (42.8 % to 45 %) than in previous studies from Vaan Island (5 %)[36] and Palk Bay[40]. The spread of *T. hoshinota* to Valai Island was observed to originate from Thalaiyari Island. The present report contradicts the view of earlier studies[35,40,45] that suggested anthropogenic stressors as possible factors to trigger *T. hoshinota*. Because field observations during the present study indicated the presence of *T. hoshinota* in unpolluted and anthropogenic stress-free reef environments, which is in accordance with a few other studies[46,47]. Also, contrary to a previous study by van der Ent *et al.*[48], the spread of *T. hoshinota* was recorded close to the coast (nearly 4 m away from low tide) in Hare Island and Thalaiyari Island, indicating its allogenic and unrestricted spread from the coast to outer shelf reefs. *Terpios hoshinota* eating or propagating vectors were not observed in this study. Among all the coral forms, *Montipora* and *Acropora* corals were very often devastated by *T. hoshinota* in the Indo-Pacific reefs (Table 2).

Table 2 — The global prevalence of coral-killing cyanobacteriosponge, *Terpios hoshinota* and its level of damage on tropical reefs

Region	Reef site	Affected coral	Killing rate	Year	Stimulating factor	Reference
World						
American Samoa	-	-	-	-	-	7
Australia	Lizard Island	*Acropora*		2010		12
Australia	Kimberley	*Acropora* sp., *Seriatopora hystrix*		2016	Unclear	49
China	Yongxing Island	Mainly *Montipora* sp.	4.4 - 19.9%	2008 & 2010	Possibly environmental factors	46
China	Taiping Island	-	27.4%	2017	-	50
Indonesia	Kalimantan, Sulawesi, Thousand Islands	*Montipora* sp.		2011 & 2012	Anthropogenic disturbances	51
Indonesia	Spermonde Archipelago	Acroporidae, Pocilloporidae	~15%	2012	Unknown biotic or abiotic stressors	48
Indonesia	Seribu Islands	-	33.11%	2016-2017	Transitional season (dry to rainy)	15
Indonesia	Riau Islands	*Acropora*, *Montipora*		2013 & 2015		52
Japan	Tokunoshima Island	*Merulina ampliata*	87%	1984–1986	Turbidity	8
Japan	Okinoerabu Island		50%	2010		53
Japan	Ryukyus	*Acropora*, *Montipora*	36%	2009-2011	Turbidity	9
Japan	-	-	-	-	-	54

(*Contd.*)

Table 2 — The global prevalence of coral-killing cyanobacteriosponge, *Terpios hoshinota* and its level of damage on tropical reefs (*Contd.*)

Region	Reef site	Affected coral	Killing rate	Year	Stimulating factor	Reference
Japan	Okinoerabu-jima Island	Branching corals	~24%	2010-2014	Possibly water quality change by subtropical typhoons	55
Japan	Sesoko Island	*Montipora digitata*	66 mm month^{-1}	2019- 2020	Seasonal changes	56
Malaysia	Tioman Island	*Lithophyllon repanda*, *Pocillopora damicornis*		2013	Sunlight	57
Maldives	Faafu Atoll	*Acropora*, *Cyphastrea*, *Montipora*, *Pavona*, and *Porites*		2015		43
Mauritius	Anse La Raie lagoon	Branching corals	11%	2014	Unclear	14
Papua New Guinea	Kimbe Island	*Acropora*, *Goniastrea*, *Leptoria*, *Montipora*, and *Pocillopora*		2016		58
Philippines	-	-	-	-	-	7
Taiwan	Green Island	*Acropora humilis*, *Montipora efflorescens*	30%	2005–2006		59
Taiwan	Green island	-	-	-	-	45
Taiwan	Green island		30%	2008	Light availability	60
Thailand	-	-	-	-	-	7
USA	Mariana Islands, Guam	*Porites lutea*	14.5±6.1 mm d^{-1}; avg. 23 mm month^{-1}	1971	Nutrients and substrate	6
USA	Mariana Islands, Guam	*Porites lutea*	25–30%	1987	Substrate	7
USA	Pagan Island	*Porites*, volcanic boulders		Centuries old	Cyanobacterial bloom & increased volcanic activity	61
India						
Palk Bay	Palk Bay		20.7%		Elevated temperature	35
Palk Bay	Palk Bay	*Favites*, *Porites*	31.7%	2014	Anthropogenic activities	40
Palk Bay	Palk Bay	*Acropora*	75.29%	2017	NO_3 and PAR	11
Gulf of Mannar	Shingle Island, Mandapam	*Porites*	Two colonies	2019	Elevated temperature & turbidity	Present study
Gulf of Mannar	Hare Island, Mandapam	*Acropora*	Few fragments	2018	Elevated temperature & turbidity	Present study
Gulf of Mannar	Krusadai Island, Mandapam	*Galaxea*	One colony	2019	Moderate turbidity	Present study
Gulf of Mannar	Manoliputti Island, Mandapam	*Halimeda* sp.	A patch	2018	Elevated temperature & turbidity	Present study
Gulf of Mannar	Manoli Island, Mandapam	*Montipora*, *Echinopora*	A patch	2019	Elevated temperature & turbidity	Present study
Gulf of Mannar	Hare Island, Mandapam	*Favites*	One colony	2019	Elevated temperature & turbidity	Present study
Gulf of Mannar	Hare Island, Mandapam	*Porites*	Four colonies	2018-19	Elevated temperature & turbidity	Present study
Gulf of Mannar	Thalaiyari and Valai Islands, Keelakarai	*Favites*	One colony	2019	Elevated temperature & turbidity	Present study
Gulf of Mannar	Thalaiyari and Valai Islands, Keelakarai	*Montipora digitata*	42.8% & 45%	2019	Elevated temperature & turbidity	Present study

(*Contd.*)

Table 2 — The global prevalence of coral-killing cyanobacteriosponge, *Terpios hoshinota* and its level of damage on tropical reefs (*Contd.*)

Region	Reef site	Affected coral	Killing rate	Year	Stimulating factor	Reference
Gulf of Mannar	Thalaiyari Island, Keelakarai	*Porites*	Four colonies	2019	Elevated temperature & turbidity	Present study
Gulf of Mannar	Puluvinichalli Island, Vembar	*Porites*	One colony	2019	Elevated temperature & turbidity	Present study
Gulf of Mannar	Upputanni Island, Vembar	*Porites*	One colony	2019	Elevated temperature & turbidity	Present study
Gulf of Mannar	Vaan Island, Tuticorin	*Porites*	One colony	2019	Increased water turbidity	Present study
Gulf of Mannar	Vaan Island, Tuticorin	*Montipora digitata*	Small patch	2019	Moderate turbidity	Present study
Gulf of Mannar	Vaan Island, Tuticorin	*Montipora divaricata*	5%	2015		36
Lakshadweep's	Bangaram and Thinnakara Islands	*Acropora muricata*, *Cyphastrea* sp., *Dipsastraea lizardensis*, *Isopora palifera*, and *Porites lutea*	30–50 cm approx.	2016	Possibly elevated SST	47
Andaman and Nicobar Islands	-	-	-	-	-	Unknown
Gulf of Kutch	-	-	-	-	-	Unknown
Malavan	-	-	-	-	-	Unknown

The elevated sea surface temperature ranges of 32 to 36 °C (avg. 31.63 °C) recorded during massive bleaching (*Porites*, *Montipora*, *Acropora*, and *Pocillopora*) between February and May 2019 were the possible environmental factors that triggered the outbreak of *T. hoshinota* (Table 1). Although the NOAA Coral Reef Watch (CRW) SST data for the Gulf of Mannar between 1985 to 2022, has not even reached 33 °C, local temperatures obtained on the field were real-time and higher than the satellite-based SST. The findings of this study suggest that moderate turbidity (observed visually underwater as arbitrary units) and high temperatures may contribute to the outbreak of *T. hoshinota*. However, these observations require further experimental validation to confirm their role in triggering the outbreak. In contrast, low temperatures and moderate turbidity were found to promote a mild occurrence of *T. hoshinota* (Tables 1 & 2). Few reports indicated that *T. hoshinota* spread did not correlate with water turbidity[46,47]. Contrary to previous reports, this study infers that *T. hoshinota* spread in GoM reefs is triggered by turbidity, elevated SST, and possibly unconfirmed nutrient availability but not influenced by anthropogenic activities.

The rapid settlement (within a day) and metamorphosis[10,19] appear to restrict the dispersal of *T. hoshinota* larvae to far distances, and thus dispersion distances of *T. hoshinota* larvae were very short[19]. Raj *et al.*[36] suggested that *T. hoshinota* likely might have dispersed and invaded reefs in other islands between Palk Bay and Vaan Island. The water masses and current flow between Palk Bay and GoMMBR were observed to be very strong due to depth variations. As a result, the dispersion of *T. hoshinota* between Palk Bay and the GoMMBR regions may be possible via water mass movements and currents. A study also suggested a similar inference that the current pathway could play a significant role in transporting *T. hoshinota* from one region to another[46]. Further, subtropical typhoons[55] and storms[56] were observed to trigger the appearance and disappearance of *T. hoshinota* outbreak by limiting light penetration and SST and altering water quality. The shading effect has been an effective method to protect corals from *T. hoshinota*[60,62], indicating light availability as a significant factor in controlling *T. hoshinota* growth and spread.

Conclusion

Terpios hoshinota is widespread in the GoMMBR islands, and its outbreak under favourable conditions can damage reefs severely. Therefore, long-term seasonal monitoring studies are required to understand the range extension and shift of *T. hoshinota* in the GoMMBR Islands. Additionally, the development of non-invasive strategies to control *T. hoshinota* spread on coral reefs is needed to protect reefs in the GoMMBR. Delineating the molecular taxonomy of the genus *Terpios* would provide insights into the species diversity and distribution, and their ecological impacts on coral reefs of the GoMMBR. The present study data will assist in comparative studies to understand future coral cover changes and shifts that might occur in the islands of GoMMBR. *Terpios hoshinota* prevalence on a few colonies does not seem to be a cause for alarm, but certainly provides a natural opportunity under favourable conditions to disperse and invade reefs. Hence, the level of progression on coral colonies needs to be monitored seasonally for the long term to better understand its invasion on reefs.

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Conflict of Interest

Authors have no competing interests to declare.

Author Contributions

CR, TS & SK: Field surveys and data acquisition; CR: Preparation of figures; CR, TS, SK & MVR: Manuscript writing, reviewing, revision, and approved the final version of the manuscript.

Data Availability

The data that support this study will be shared upon reasonable request to the corresponding author.

References

1 Moberg F & Folke C, Ecological goods and services of coral reef ecosystems, *Ecol Econ*, 29 (1999) 215–233. https://doi.org/10.1016/S0921-8009(99)00009-9

2 Burke L & Spalding M, Shoreline protection by the world's coral reefs: Mapping the benefits to people, assets, and infrastructure, *Mar Policy*, 146 (2022) p. 105311. https://doi.org/10.1016/j.marpol.2022.105311

3 Wulff J, Sponge contributions to the geology and biology of reefs: past, present, and future, In: *Coral Reefs at the Crossroads*, edited by D K Hubbard, C S Rogers, J H Lipps & J G D Stanley, (Springer Science+Business Media, Dordrecht), 2016, pp. 103–126.

4 Chow S W, Keshavmurthy S, Reimer J D, de Voogd N, Huang H, *et al*., Population genetics and demography of the coral-killing cyanobacteriosponge, *Terpios hoshinota*, in the Indo-West Pacific, *PeerJ*, 10 (2022) p. e13451. https://doi.org/10.7717/peerj.13451

5 Fiedler B K, Montgomery A D, Chong F, Miyagi H, Carletti M, *et al.*, Delineation of outbreak stages of the coral-killing sponge *Terpios hoshinota*, *Reg Stud Mar Sci*, 80 (2024) p. 103871. https://doi.org/10.1016/j.rsma.2024.103871

6 Bryan P, Growth rate, toxicity, and distribution of the encrusting sponge *Terpios* sp. (Hadromerida: Suberitidae) in Guam, Mariana Islands, *Micronesica*, 9 (1973) 237–242.

7 Plucer-Rosario G, The effect of substratum on the growth of *Terpios*, an encrusting sponge which kills corals, *Coral Reefs*, 5 (1987) 197–200. https://doi.org/10.1007/BF00300963

8 Rützler K & Muzik K, *Terpios hoshinota*, a new cyanobacteriosponge threatening Pacific reefs, *Sci Mar*, 57 (1993) 395–403.

9 Reimer J D, Mizuyama M, Nakano M, Fujii T & Hirose E, Current status of the distribution of the coral-encrusting cyanobacteriosponge *Terpios hoshinota* in southern Japan, *Galaxea*, 13 (2011) 35–44. https://doi.org/10.3755/galaxea.13.35

10 Hsu C M, Wang J T & Chen C A, Larval release and rapid settlement of the coral-killing sponge, *Terpios hoshinota*, at Green Island, Taiwan, *Mar Biodiv*, 43 (2013) 259–260. https://doi.org/10.1007/s12526-013-0176-1

11 Dennis A & Senthilnathan L, Monitoring of coral-killing sponge (Terpios hoshinota) caused rapid coral tissue loss assessment through environmental parameters in the Palk Bay, *Reg Stud Mar Sci*, 66 (2023) 103137. https://doi.org/10.1016/j.rsma.2023.103137

12 Fujii T, Keshavmurthy S, Zhou W, Hirose E, Chen C A, *et al.*, Coralkilling cyanobacteriosponge (*Terpios hoshinota*) on the Great Barrier Reef, *Coral Reefs*, 30 (2011) p. 483. https://doi.org/10.1007/s00338-011-0734-6

13 Hirose E & Murakami A, Microscopic anatomy and pigment characterization of coral-encrusting black sponge with cyanobacterial symbiont, *Terpios hoshinota*, *Zool Sci*, 28 (2011) 199–205. https://doi.org/10.2108/zsj.28.199

14 Elliott J, Patterson M, Vitry E, Summers N & Miternique C, Morphological plasticity allows coral to actively overgrow the aggressive sponge *Terpios hoshinota* (Mauritius, Southwestern Indian Ocean), *Mar Biodiv*, 46 (2016) 489–493. https://doi.org/10.1007/s12526-015-0370-4

15 Nugraha M A, Zamani N P & Madduppa H H, Growth rate, spatial-temporal variation and prevalence of the encrusting cyanosponge (*Terpios hoshinota*) in Seribu Islands, Jakarta, *J Ilmu dan Teknol Kelaut Trop*, 12 (2020) 761–778. https://doi.org/10.29244/jitkt.v12i3.30885

16 Elliott J, Patterson M, Summers N, Miternique C, Montocchio E, *et al.*, How does the proliferation of the coral-killing sponge *Terpios hoshinota* affect benthic community structure on coral reefs?, *Coral Reefs*, 35 (2016) 1083–1095. https://doi.org/10.1007/s00338-016-1434-z

17 Nozawa Y, Huang Y & Hirose E, Seasonality and lunar periodicity in the sexual reproduction of the coral-killing

sponge, *Terpios hoshinota*, *Coral Reefs*, 35 (2016) 1071–1081. https://doi.org/10.1007/s00338-016-1417-0

18 Hirose Y, Aini S N & Yamashiro H, Coral-killing sponge *Terpios hoshinota* releases larvae at midnight, *Coral Reefs*, 41 (2022) 149–160. https://doi.org/10.1007/s00338-021-02210-x

19 Wang J T, Hirose E, Hsu C M, Chen Y Y, Meng P J, *et al.*, A coralkilling sponge, *Terpios hoshinota*, releases larvae harboring cyanobacterial symbionts: an implication of dispersal, *Zool Stud*, 51 (2012) 314–320. https://doi.org/10.1007/s00338-021-02210-x

20 Syue S, Hsu C & Soong K, Testing of how and why the *Terpios hoshinota* sponge kills stony corals, *Sci Rep*, 11 (2021) p. 7661. https://doi.org/10.1038/s41598-021-87350-4

21 ENVIS, *Database on Gulf of Mannar Biosphere Reserve*, (Department of Environment and Forest, Government of Tamilnadu, Chennai), 2015.

22 Edward J K P, Mathews G, Raj K D, Laju R L, Bharath M S, *et al*., Coral mortality in the Gulf of Mannar, southeastern India, due to bleaching caused by elevated sea temperature in 2016, *Curr Sci*, 114 (2018) 1967–1972. https://doi.org/10.18520/cs/v114/i09/1967-1972

23 Krishnan P, Purvaja R, Sreeraj C R, Raghuraman R, Robin R S, *et al*., Differential bleaching patterns in corals of Palk Bay and the Gulf of Mannar, *Curr Sci*, 114 (2018) 670–685. https://doi.org/10.18520/cs/v114/i03/679-685

24 Koushik S, Ramesh C, Shunmugaraj T & Murthy M V R, High sea surface temperature induces local coral bleaching in Gulf of Mannar and Palk Bay regions, south east coast of India – a status report, *Int J Wildl Endanger Species Conserv*, 3 (2020) 131–138.

25 Ramesh C, Koushik S, Shunmugaraj T & Murthy M V R, Exhibition of bleaching resistance via adaptive bleaching pattern by coral reefs of the Gulf of Mannar during massive bleaching event 2019, *J Mar Sci*, 2 (2020) 1–5. https://doi.org/10.30564/jms.v2i2.1666

26 Ramesh C H, Koushik S, Shunmugaraj T & Murthy M V R, Seasonal studies on in situ coral transplantation in the Gulf of Mannar Marine Biosphere Reserve, Southeast coast of Tamil Nadu, India, *Ecol Eng*, 152 (2020) p. 105884. https://doi.org/10.1016/j.ecoleng.2020.105884

27 Ramesh C H, Koushik S, Shunmugaraj T & Murthy M V R, Factors affecting coral reefs in the Gulf of Mannar, *J Wildl Res*, 7 (2019) 16–22.

28 Thinesh T, Mathews G, Raj K D & Edward J K P, Variation in black and white band disease progression in corals of the Gulf of Mannar and Palk Bay, Southeastern India, *Dis Aquat Organ*, 110 (2014) 227–234. https://doi.org/10.3354/dao02750

29 Thangaradjou T, Machendiranathan M, Ranith R, Senthilnathan L & Sasamal S K, Coral disease prevalence in Gulf of Mannar and Lakshadweep Islands, *Indian J Geo-Marine Sci*, 45 (2016) 1755–1762.

30 Ramesh C H, Koushik S, Shunmugaraj T & Murthy M V R, Baseline survey on coral diseases, stress factors and new threats in coral reefs of Gulf of Mannar Marine Biosphere, India, *J Mar Sci*, 01 (2019) 31–48. https://doi.org/10.30564/jms.v1i1.835

31 Sharma D & Ravindran C, Diseases and pathogens of marine invertebrate corals in Indian reefs, *J Invertebr Pathol*, 173 (2020) p. 107373. https://doi.org/10.1016/j.jip.2020.107373

32 Manikandan B & Ravindran J, Differential response of coral communities to *Caulerpa* spp. bloom in the reefs of Indian Ocean, *Environ Sci Pollut Res*, 24 (2017) 3912–3922. https://doi.org/10.1007/s11356-016-8136-5

33 Ramesh C H, Koushik S, Shunmugaraj T & Murthy M V R, Bioinvasive seaweed genus, *Turbinaria* in coral reefs of Gulf of Mannar, *J Life Sci*, 6 (2019b) 1–4. https://doi.org/10.20448/journal.504.2019.61.1.4

34 Ramesh C H, Koushik S, Shunmugaraj T & Murthy M V R, Impact of toxic cyanobacterium *Lyngbya majuscula* and green algae *Ulva reticulata* blooms on corals reefs of Gulf of Mannar Marine Biosphere Reserve, Southeast coast of Tamil Nadu, India, *IJSR*, 10 (2019) 34581–34583. http://dx.doi.org/10.24327/ijrsr.2019.1009.3926

35 Thinesh T, Mathews G, Raj K D & Edward J K P, Outbreaks of *Acropora* white syndrome and *Terpios* sponge overgrowth combined with coral mortality in Palk Bay, southeast coast of India, *Dis Aquat Organ*, 126 (2017) 63–70. https://doi.org/10.3354/dao03155

36 Raj K D, Bharath M S, Mathews G, Aeby G S & Edward J K P, Coral-killing sponge *Terpios hoshinota* invades the corals of Gulf of Mannar, Southeast India, *Curr Sci*, 114 (2018) 1117–1119. https://doi.org/10.18520/cs/v114/i05/1117-1119

37 Ramesh C H, Koushik S, Shunmugaraj T & Murthy M V R, Opportunistic infestation of boring sponge *Cliona* sp. on naturally settled *Porites lutea* on concrete manhole rings in Mandapam region, Tamil Nadu, *J Terr Mar Res*, 03 (2019) 1–3.

38 Sivaleela G & Raghunathan C, Fauna of India Checklist Porifera Version 1.0, *Zoological Survey of India*, (2024) 2–16. https://doi.org/10.26515/Fauna/1/2023/Porifera

39 Sabith D B K K & Mohan P M, A review on taxonomy of Lakshadweep sponges and its checklist, *Curr Trends Ocean Mar Sci*, 4 (2021) p. 114.

40 Thinesh T, Jose A P, Hassan S, Selvan M K & Selvin J, Intrusion of coral-killing sponge (*Terpios hoshinota*) on the reef of Palk Bay, *Curr Sci*, 109 (2015) 1030–1032. https://doi.org/10.18520/cs/v109/i6/1030-1032

41 Lam K, Shin P K S, Bradbeer R, Randall D, Ku K K K, *et al*., A comparison of video and point intercept transect methods for monitoring subtropical coral communities, *J Exp Mar Bio Ecol*, 333 (2006) 115–128. https://doi.org/10.1016/j.jembe.2005.12.009

42 Aini S N & Yamashiro H, Densities of cyanobacterial cells, spicules, and particles in the coral-killing sponge *Terpios hoshinota* in Sesoko Island, Okinawa, Japan, *Plankton Benthos Res*, 17 (3) (2022) 263–270. https://doi.org/10.3800/pbr.17.263

43 Montano S, Chou W, Chen C A, Galli P & Reimer J D, First record of the coralkilling sponge *Terpios hoshinota* in the Maldives and Indian Ocean, *Bull Mar Sci*, 91 (2015) 97–98. https://doi.org/10.5343/bms.2014.1054

44 Richardson L L, Horizontal and vertical migration patterns of *Phormidium corallyticum* and *Beggiatoa* spp. associated with black-band disease of corals, *Microb Ecol*, 32 (1996) 323–335. https://doi.org/10.1007/BF00183066

45 Chen S L, Kuo C Y & Chen C A, Spatial distribution and temporal variation of an outbreak of the cyanobacteriosponge, *Terpios hoshinota*, and benthos composition on the coral reefs of Green Island, *Natl Park Bull*, 19 (2009) 32–45.

46 Shi Q, Liu G H, Yan H Q & Zhang H L, Black disease (*Terpios hoshinota*): A probable cause for the rapid coral mortality at the northern reef of Yongxing Island in the South China Sea, *Ambio*, 41 (2012) 446–455. https://doi.org/10.1007/s13280-011-0245-2

47 Das R R, Sreeraj C R, Mohan G, Abhilash K R, Samuel D, *et al*., Incursion of the killer sponge *Terpios hoshinota* Rützler & Muzik, 1993 on the coral reefs of the Lakshadweep archipelago, Arabian Sea, *J Threat Taxa*, 12 (2019) 17009–17013. https://doi.org/10.11609/jott.5790.12.14.17009-17013

48 van der Ent E, Hoeksema B W & de Voogd N J, Abundance and genetic variation of the coral-killing cyanobacteriosponge *Terpios hoshinota* in the Spermonde Archipelago, SW Sulawesi, Indonesia, *J Mar Biol Assoc UK*, 96 (2016) 453–463. https://doi.org/10.1017/S002531541500034X

49 Fromont J, Richards Z T & Wilson N G, First report of the coralkilling sponge *Terpios hoshinota* Rutzler and Muzik, 1993 in Western Australia: A new threat to Kimberley coral reefs? *Diversity*, 11 (2019) p. 184. https://doi.org/10.3390/d11100184

50 Yang S Y, Chen H J, Ho M J, Chen Y J, Huang Y Y, *et al.*, Outbreak of coral-killing cyanobacteriasponge, *Terpios hoshinota* in Taiping Island (Itu Aba), Spratlys, South China Sea, *Bull Mar Sci*, 94 (2018) 1543–1544. https://doi.org/10.5343/bms.2018.0023

51 De Voogd N J, Cleary D F R & Dekker F, The coralkilling sponge *Terpios hoshinota* invade Indonesia, *Coral Reefs*, 32 (2013) p. 755. https://doi.org/10.1007/s00338-013-1030-4

52 Madduppa H, Schupp P J, Faisal M R, Sastria M Y & Thoms C, Persistent outbreaks of the black disease sponge *Terpios hoshinota* in Indonesian coral reefs, *Mar Biodiv*, 47 (2017) 149–151. https://doi.org/10.1007/s12526-015-0426-5

53 Reimer J D, Nozawa Y & Hirose E, Domination and disappearance of the black sponge: a quarter century after the initial *Terpios* outbreak in southern Japan, *Zool Stud*, 50 (2011) p. 395.

54 Yamaguchi M, Introduction to the study of coral reefs 4 coralreef sponges (1) Sponges as destroyers of reef-building corals, *Aquabiology*, 8 (1986) 88–92.

55 Yomogida M, Mizuyama M, Kubomura T & Reimer J D, Disappearance and return of an outbreak of the coral-killing cyanobacteriosponge *Terpios hoshinota* in southern Japan, *Zool Stud*, 56 (2017) p. 7. https://doi.org/10.6620/ZS.2017.56-07

56 Aini S N, Tang S L & Yamashiro H, Monthly progression rates of the coral-killing sponge *Terpios hoshinota* in Sesoko Island, Okinawa, Japan, *Coral Reefs*, 40 (2021) 973–981. https://doi.org/10.1007/s00338-021-02099-6

57 Hoeksema B W Z W & de Voogd N J, Partial mortality in corals overgrown by the sponge *Terpios hoshinota* at Tioman Island, Peninsular Malaysia (South China Sea), *Bull Mar Sci*, 90 (2014) 989–990. https://doi.org/10.5343/bms.2014.1047

58 Ekins M, Willis B, Bridge T, Srinivasan M, Rowley S, The coral killing sponge *Terpios hoshinota* in Kimbe Bay, Papua New Guinea, *Mem Queensl Mus Nat*, 60 (2017) 174–175. https://dx.doi.org/10.17082/j.2204-1478.60.2017.2017-02

59 Liao M H, Tang S L, Hsu G M, Wen K C, Wu H, The ‘black disease’ of reef-building corals at Green Island, Taiwan – outbreak of a cyanobacteriosponge, *Terpios hoshinota* (Suberitidae: Hadromerida), *Zool Stud*, 46 (2007) p. 520.

60 Soong K, Yang S L & Chen C A, A novel dispersal mechanism of a coral-threatening sponge, *Terpios hoshinota* (Suberitidae: Porifera), *Zool Stud*, 48 (2009) p. 596.

61 Schils T, Episodic eruptions of volcanic ash trigger a reversible cascade of nuisance species outbreaks in pristine coral habitats, *PLoS One*, 7 (2012) p. e46639. https://doi.org/10.1371/journal.pone.0046639

62 Thinesh T, Meenatchi R, Pasiyappazham R, Jose P A, Selvan M, *et al.*, Short-term in situ shading effectively mitigates linear progression of coral-killing sponge *Terpios hoshinota*, *PLoS One*, 12 (2017) p. e0187004. https://doi.org/10.1371/journal.pone.0182365