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RESEARCH

A cup half full: the first assessment on the distribution, ecology and need for conservation of the threatened Neptune's cup sponge, *Cliona patera*, in the Gulf of Thailand

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Abstract The Neptune's cup sponge is an iconic species found in marine soft sediment habitats in the Indo-West Pacific, with a history of overharvesting and extreme population declines. Access to SCUBA diving surveys has allowed for its rediscovery at Singapore, its type locality; however, with fewer than ten living individuals documented in the twenty-first century, the species is believed to be in need of conservation. Here, we share the results from surveys across the Gulf of Thailand, allowing for a documentation of 29 additional individuals, with information on their ecology and distribution. Of the 29 individuals, extensive damage or mortality caused by marine debris is recorded for six individuals, and one further individual is believed to be lost due to an unknown cause. Documented threats from the Gulf of Thailand differ from those in Singapore; however, low population sizes and poor connectivity remain a significant concern for the survival of the species.

Keywords Discarded fishing gear · Marine debris · Microbial mats · Porifera · Soft sediment habitats

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Introduction

After over a century of absence from its type locality, Singapore, the iconic sponge *Cliona patera* (Hardwicke, 1820) was rediscovered in Singaporean waters based on two records (Tun & Goh, 2011). Subsequent surveys revealed a further five specimens from Singapore, with most of these later relocated to a protected area to minimise further population losses to the endangered species (Quek et al., 2022). The apparent global extinction and rediscovery of the species is comprehensively documented by Lim et al. (2012) and is currently known from fewer than a dozen in situ specimens, with museum records and trawled specimens far outnumbering living specimens (ALA, 2023;

Lim et al., 2012). Outside of Singapore, twenty-first century records include those from Western Australia, the Northern Territory, and Northern Queensland (ALA, 2023; NIWA, 2016; WAM, 2022) and Papua New Guinea (QMP, 2003); however, no corresponding visual nor ecological information could be found for living specimens from these locations.

The Gulf of Thailand is currently the geographically nearest region to the type locality for which living specimens are known. Within the Gulf of Thailand, the only photographic records of the species come from the apparent recent discovery of the species from Cambodia (Ho et al., 2021; Knight, 2018). Two additional records of the species from published material come from the Eastern Gulf. The first corresponds to a record from Chonburi province, where the secondary metabolites of a single specimen from Koh Larn were studied (Sawangwong et al., 2008). The second comes from a collected specimen in 2015, under the records of the Florida Museum of Natural History (FMNH, 2023), from Koh Talu in Rayong province. While neither record contains any corresponding visual nor ecological information, they nonetheless make up a significant fraction of the total known population from the Southeast Asia region.

In addition to biogeographic records and a long and complex taxonomic history (Lim et al., 2012; Quek et al., 2022), studies have investigated the biochemistry and microbial diversity of the sponge (Ho et al., 2021; Sawangwong et al., 2008). To date, only a single investigation has been carried out on the faunal ecology of the species. Quek et al. (2022) documented extensive predation on two of the transplanted individuals of *C. patera*, by unknown predators. Their genetic investigation and population investigation suggest that low genetic diversity and extensive predation are the leading threats to *C. patera* in Singaporean waters.

Here, we aim to expand the known distribution of *C. patera* from within the Gulf of Thailand and to assess the threats and conservation priorities of the species from the region. We also aim to provide the first assessment on the ecological value of the species in its habitat to further the known biology of the species.

Materials and methods

Between September 2020 and April 2023, roving diver biodiversity surveys were carried out, using SCUBA, at soft sediment habitats in three provinces in the eastern Gulf of Thailand. The survey locations were at islands in the proximity of Pattaya (Chonburi province), the Koh Mun Nai archipelago (Rayong province) and Koh Mak (Trat province). Data were collected on the presence or absence of individuals of *Cliona patera* at each site, with a minimum of 100 m^2 assessed per surveyed site. Survey sites were separated between near-shore and isolated pinnacle sites to differentiate between topography and site-use differences. Near-shore sites were sites that were within 1 km of a shoreline (supratidal landmass) measuring at least 500 m in length/circumference, and isolated pinnacles were those that were greater than 1 km from a shoreline measuring at least 500 m. Survey distance was quantified via boat or surface-mounted GPS (see Mehrotra & Scott, 2016) where possible, or was estimated via approximate underwater mapping (utilising depth profiles and measuring reels), to quantify number of individuals per site. Survey depths were determined by reef topography and the edge of the reef slope, with overall depth range from 5.0 to 20.0 m.

For each individual observed, data was collected on substrate depth, overall health of sponge (noting signs of damage or tissue loss) and photographic documentation. In addition, a close visual investigation was made of the sponge tissue, including on the inside and outside of the 'cup' (where relevant) and on surface of the benthos within 50 cm of each sponge to identify associated flora and fauna that appeared to be utilising the sponge as habitat. Fish diversity within 50 cm proximity of each sponge, or hiding within the cup, was also noted. Associated marine life was not quantified per sponge, instead only being documented as present or absent, and qualifying use of sponge tissue if applicable. Identification of associated marine life was made to family or genus level in situ where possible or identified based on photographs to most reliable taxonomic classification.

In addition to these surveys, data was also collected from published sources to develop an initial baseline for the population of the species from the Gulf of Thailand. This includes already documented observations (FMNH, 2023; Sawangwong

et al., 2008) and previous soft sediment biodiversity assessments from Koh Tao (Suratthani province), the Koh Mun Nai archipelago and nearby pinnacles to these islands (Mehrotra et al., 2021; Mehrotra et al., 2023). Finally, two previously unpublished records are shared, from Hin Ploeng (Rayong province) and Had Nang Rum (Chonburi province) based on incidental observations in 2015 and 2017, respectively. Where possible, these datasets were standardised to establish a map of minimum population density for the Gulf of Thailand. Maps were created by first initially plotting observations in Google Earth Pro (v. 7.3.6.9345), followed by establishing layers and base-map data in QGIS (v. 3.22.16-Białowieża), before being finalised and illustrated in Adobe Illustrator (v. 26.5).

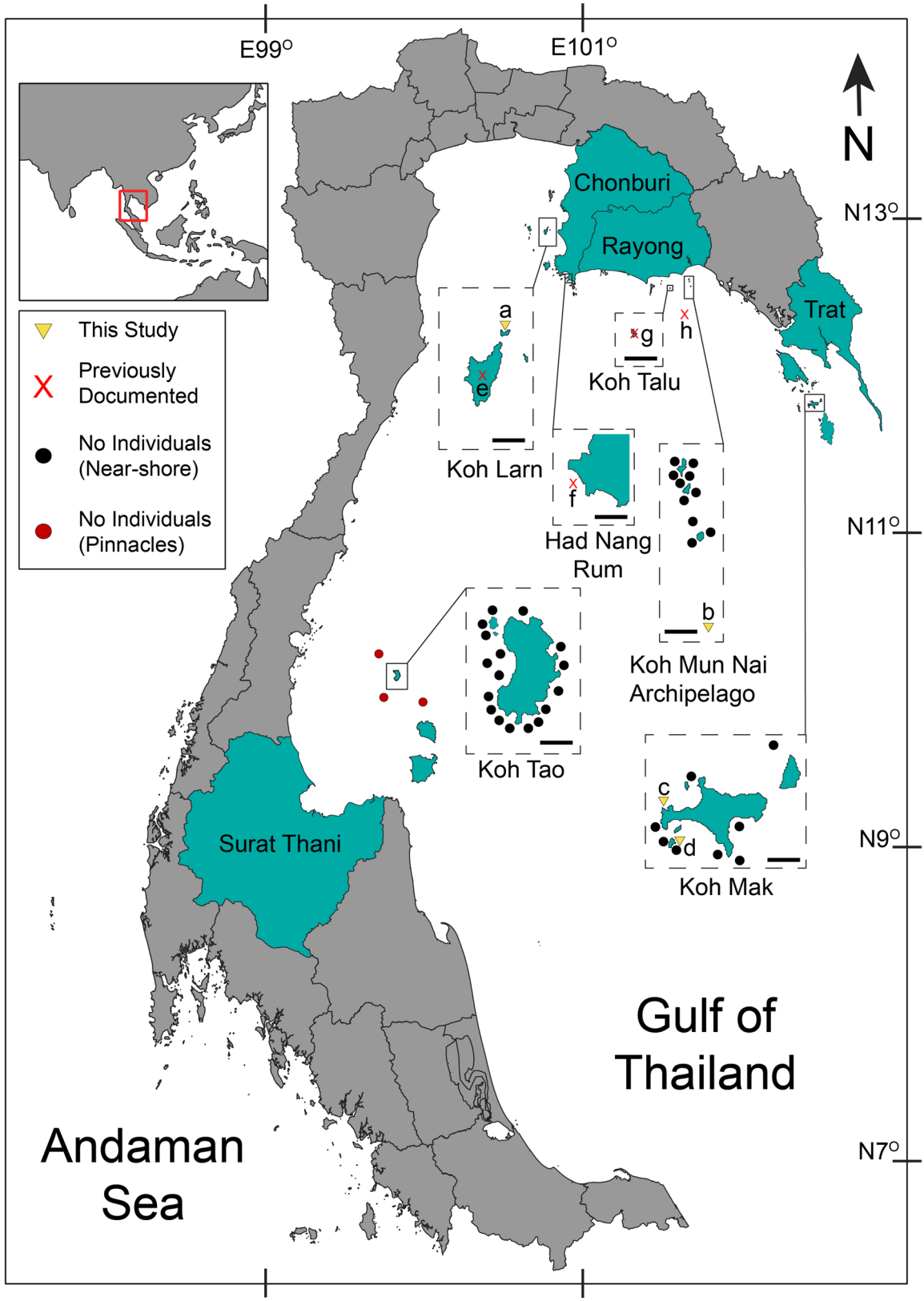
Results and discussion

Surveys conducted allowed for documentation of 25 individuals of *C. patera*, which were found at depths ranging from 5.5 to 19.5 m. With the addition of four individuals from previous records, outside of the survey areas presently documented, biogeographic data was collected on 29 individuals from the Gulf of Thailand (Fig. 1). The highest density of individuals was documented near the island of Koh Sak in Chonburi province, where a total of 17 individuals were documented from within the survey area. The second highest density was found near Koh Rayang Nok, near the island of Koh Mak, in Trat province, with six individuals from the surveyed area. The remaining two novel records were found at Koh Phi (Trat) and near the shipwreck of the HTMS Petra in Rayong Province.

The last of these records was found with some evidence to suggest it to be artificially introduced by entanglement in discarded fishing gear. This was determined by an absence of individuals based on surveys conducted around the site in 2021 and early 2022. A damaged, individual was later recorded from the same previously surveyed areas in December 2022, with a small base anchored into the substrate, and discarded fishing cages and nets less than 10 m away. A subsequent survey in April 2023 revealed the individual to be uprooted and partially buried, at least 20 m away from its initial documentation (as inferred based on measured distance from shipwreck) with majority of the tissue having degraded (Fig. 2A, B). Throughout the survey period, the surface of the shipwreck and seafloor around it was found to be regularly covered in netting and lines from discarded fishing gear (unpub. data). A previously unpublished record by one of the authors was made at Hin Ploeng (Rayong province) in 2015; however, extensive surveys between 2021 and 2023 revealed no remaining individuals from the site. Surveys in 2020 and 2021 focused largely in Rayong province, yielding no individuals of *C. patera*, with all observations found in the last year of surveys.

Assessment of associated fauna and flora revealed that 15 of the 25 individuals hosted multiple patches of microbial film (Table 1), adhering to the inner or exposed surface of the sponge. Upon dispersal, the sponge appeared paler but still healthy underneath (Fig. 3E, F). The inside of the cup of 19 individuals had collected sediment and biogenic matter, including several intact skeletons of soft sediment-associated corals such as *Heterocyathus* spp., *Heteropsammia moretonensis* Wells, 1964 and *Cycloseris fragilis* (Alcock, 1893). Visual inspection revealed the sediment collected was largely comprised of large particle sizes (> 5 mm), including many broken bivalve shells, suggesting nearby origins as opposed to wave-action or current-driven origins. Nine of the individuals, all from near Koh Sak, were found to host multiple species of sponge at their base, with four also hosting a diversity of hydroids and four hosting an assortment of bivalves. Additionally, six individuals of *C. patera* were found to host fish under or within the sponge. Fish were found to be using the sponge as shelter and did not swim away upon examination, including species of Lutjanidae (three sponges), Epinephelinae (three sponges), Pomacentridae (three sponges), Chaetodontidae (one sponge) and Diodontidae (one sponge).

In addition to the single specimen from near the HTMS Petra, five of the seven individuals documented from Trat province were found to be either entangled or damaged by marine debris, recently uprooted, or both uprooted and entangled (Fig. 2C–F). One specimen from Koh Sak was found with minor entanglement in plastic. Subsequent surveys of one specimen from Koh Mak which had been entangled 6 months prior (Fig. 2F) revealed it to be healthy and have recovered from tissue damage caused by the netting.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This Study
Previously Documented
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Chonburi
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a
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Koh Larn
Koh Talu
Had Nang Rum
Koh Mun Nai Archipelago
Koh Tao
Koh Mak
Gulf of Thailand
Andaman Sea

◂**Fig. 1** Sites surveyed for presence or absence of *Cliona patera* in the Gulf of Thailand. Near-shore survey sites at which no individuals were found are denoted as black dots, with offshore pinnacle survey sites with no individuals found are denoted as red dots. Sites at which *C. patera* were found are denoted by yellow triangles and are labelled. Site a = Koh Sak (n = 17), b = HTMS Petra (n = 1), c = Koh Phi (n = 1), d = Koh Rayang Nok (n = 6). Sites from which previous records of *C. patera* have been documented are denoted by a red cross and are labelled, e = Koh Larn (n = 1, precise location unknown), f = Had Nang Rum (n = 1), g = Koh Talu (n = 1, precise location unknown), h = Hin Ploeng (n = 1). Scale bars in map insets represent 2 km

The present surveys more than double the known population of living *C. patera* individuals; however, the global population data still suggests fewer than 40 known individuals (ALA, 2023; FMNH, 2023; Ho et al., 2021; Knight, 2018; Lim et al., 2012; NIWA, 2016; QMP, 2003; Sawangwong et al., 2008; WAM, 2022). However, this is very likely an underestimation (Quek et al., 2022) as much of their historic range (i.e. Australia) and contemporary range (i.e. Cambodia) have yet to be explicitly surveyed for *C. patera* populations. The increasing access to SCUBA diving infrastructure and survey techniques has played an essential role in the discovery and documentation of the majority of known living individuals. This infrastructure, and the vast tourism and recreational industry it supports, is nonetheless unlikely to allow for documentation of more individuals without being directed and applied to biodiversity monitoring and management. This is elucidated by our findings documenting 17 individuals near the coral reefs of Koh Sak, an island that has a long history of tourism and sees daily recreational SCUBA diving, often with well over 100 divers visiting the small island. Despite this, the remarkable population of *C. patera* has remained undocumented to date, largely due to the species being found in soft sediment habitats outside of conventionally visited coral reef areas. Our surveys were carried out at a small, yet broad range of sites and were able to document at least one individual at each of the surveyed provinces, strongly indicating the presence of yet more individuals in areas outside of our surveyed locations. It is nonetheless noteworthy that previous surveys in the Gulf of Thailand, either specific to Porifera (Putchakarn, 2007, 2011) or specific to soft sediment habitats (Mehrotra et al., 2021; Mehrotra et al., 2023), were unable to find individuals of *C. patera*.

The surveys in which we documented the presence of *C. patera* further allowed for visual documentation of other fauna or flora appearing to use *C. patera* as habitat. Perhaps the most notable of these was common finding of microbial mats covering the surface on the inside of the cup. These marine microbial mats, often termed cyanobacterial mats due to the proportionally high abundance of Cyanobacteria, may be a growing threat to marine biodiversity (Ford et al., 2018) and have been found in both reef and soft sediment habitats in the Gulf of Thailand (Stuij et al., 2023). An investigation into microbes associated with *C. patera* in Singapore found no evidence of Cyanobacteria (Ho et al., 2021); therefore, investigations into the microbial communities on the sponge surfaces from the Gulf of Thailand may yield a deeper understanding of the sponge-microbe associations.

Faunal communities utilising *C. patera* as habitat in our findings were broadly divided into two groups. The first corresponds to the motile fauna, such as a small number of benthic crabs and largely demersal or pelagic fish. We observed, unsurprisingly, that larger individuals of *C. patera* with greater complexity hosted greater abundances of fish and motile invertebrate fauna. However, more surprisingly, we observed that the majority of fish taxa were reef associated (damselfish, butterflyfish, groupers and snappers) and are not typically associated with deeper soft sediment habitats. Additionally, the greatest abundances of these were on the sponges in Koh Mak, as opposed to Koh Sak, and did not appear to be influenced by distance from the nearest reef. However, these observations are largely anecdotal with further investigations needed on both counts. If these trends do persist upon closer examination, it may suggest that the role of *C. patera* in fish communities is determined more by location (and local disturbances) than population density. A contrasting perspective was provided by Quek et al. (2022) that suggested that spongivorous fish may be a leading threat to *C. patera* and indeed that relocation of the few dispersed individuals to be in relatively close proximity may have contributed to tissue loss due to supporting more fish. While we did not observe active predation in our brief observation of each sponge, we did note the consistency of material collected within each cup. Due to the large particle sizes and biotic

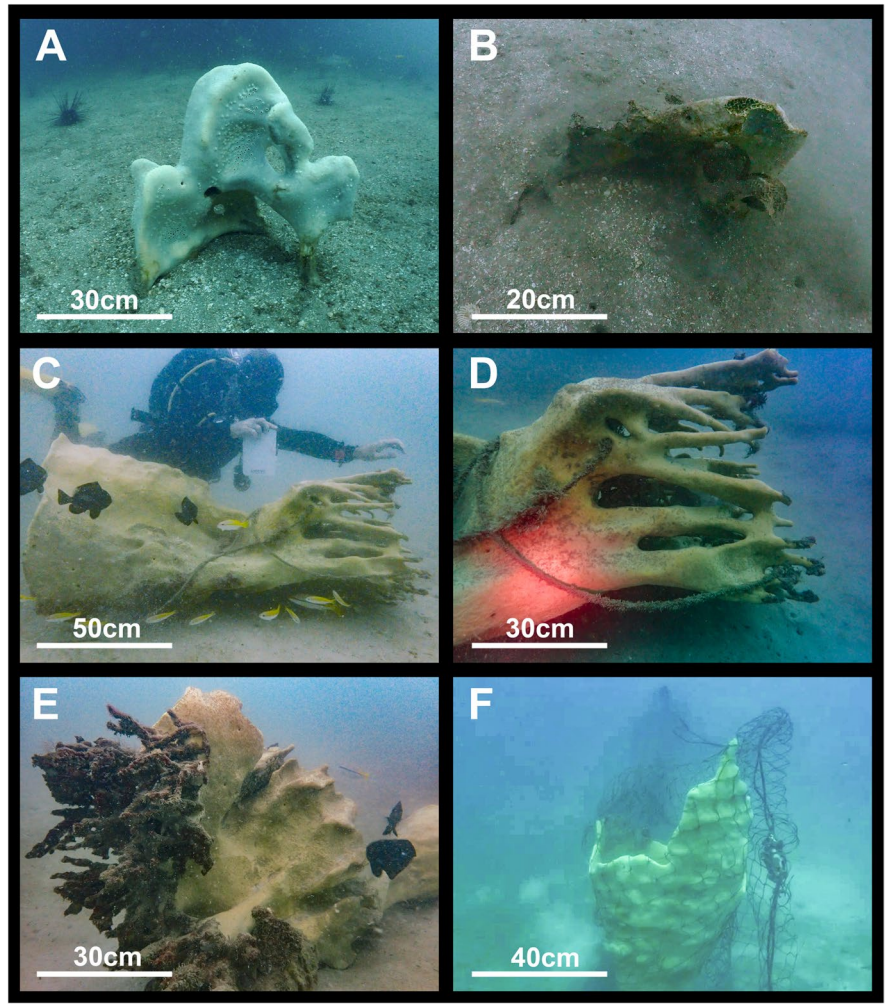

Fig. 2 Cases of damage, entanglement or mortality of *Cliona patera* from the Gulf of Thailand. **A** Specimen NCTH18 observed in December 2022. **B** Specimen NCTH18 observed in April 2023. **C** Specimen NCTH23, uprooted with associated fish. **D** Specimen NCTH23 with entangled rope around base. **E** Specimen NCTH20, uprooted with marine debris entangled. **F** Specimen NCTH19 entangled in discarded fishing gear

origins of many particles (coral skeletons and bivalves), it is likely that relocation was mediated by fauna, perhaps via the oral or faecal route.

The second faunal group associated with *C. patera* was composed of sessile colonisers at the base of most sponges, particularly bivalves, hydroids and other sponges. The soft sediment habitats of Thailand have been shown to host unique habitat types, hosting numerous rare and previously unstudied fauna (Mehrotra et al., 2021; Mehrotra et al., 2023). These include several newly described sea slug species, which feed on prey such as algae, corals, hydroids and sponges, many of which may be specific to these habitats (Mehrotra et al., 2020; Mehrotra et al., 2021). The increase in substrate complexity and density of colonisers caused by *C. patera* individuals may yield further biodiversity records.

Conclusions

In their assessment on the threats to the Singaporean population of *C. patera*, Quek et al. (2022) noted spongivory and poor population connectivity. Our findings suggest that the leading threat to individuals in the Gulf of Thailand is entanglement, damage or uprooting from marine debris, particularly passive or active fishing activities. In the latter case, trawling has already been shown to impact *C. patera* populations, on account of the nature of many individuals documented in the twentieth century (Lim et al., 2012), and therefore, continuation of such activities in areas with no biodiversity monitoring and poor marine policy may result in further population losses. Our findings however show that secondary impacts such as

Table 1 List of *Cliona patera* specimens recorded from the Gulf of Thailand from surveys conducted between 2020 and 2023, including notes on depth, ecology, health and threats

Specimen number	Site	Province	Depth (m)	Health and threats	Motile fauna	Sessile flora/fauna
NCTH1	Koh Sak	Chonburi	5.5	Intact, attached	-	-
NCTH2	Koh Sak	Chonburi	11.6	Intact, attached	-	Microbial mats in cup
NCTH3	Koh Sak	Chonburi	11.7	Intact, attached	-	Microbial mats in cup
NCTH4	Koh Sak	Chonburi	11.9	Intact, attached	-	Misc. Porifera colonising base, microbial mats in cup
NCTH5	Koh Sak	Chonburi	11.4	Intact attached, cup missing, amorphous 'base'.	*Diodon liturosus* Shaw, 1804	Misc. Porifera colonising base, microbial mats in cup
NCTH6	Koh Sak	Chonburi	11.4	Intact, attached, plastic entangled on base	-	Misc. Porifera colonising base, microbial mats in cup
NCTH7	Koh Sak	Chonburi	11.3	Intact, attached	-	*Malleus* sp. bivalve at base, microbial mats in cup
NCTH8	Koh Sak	Chonburi	11.3	Intact, attached	-	Misc. Porifera and Hydrozoa colonising base, microbial mats in cup
NCTH9	Koh Sak	Chonburi	11.4	Intact, attached	-	Misc. Porifera, Bivalvia and Hydrozoa colonising base, microbial mats in cup
NCTH10	Koh Sak	Chonburi	10.7	Intact, attached	-	Misc. Porifera, Bivalvia and Hydrozoa colonising base, microbial mats in cup
NCTH11	Koh Sak	Chonburi	10.7	Intact, attached	-	Microbial mats in cup
NCTH12	Koh Sak	Chonburi	11.1	Intact, attached	-	-
NCTH13	Koh Sak	Chonburi	11.3	Intact, attached	-	-
NCTH14	Koh Sak	Chonburi	11.6	Intact, attached, lying on its side	-	Misc. Porifera and Bivalvia colonising base, microbial mats in cup
NCTH15	Koh Sak	Chonburi	11.4	Intact, attached	-	Misc. Porifera colonising base, microbial mats in cup
NCTH16	Koh Sak	Chonburi	11.4	Intact attached, cup missing, amorphous 'base'	-	Misc. Porifera, Bivalvia and Hydrozoa colonising base
NCTH17	Koh Sak	Chonburi	8	Intact, attached	-	*Malleus* sp. bivalve at base
NCTH18	HTMS Petra	Rayong	19.5	Intact, loosely attached. Subsequently detached and dead	-	-
NCTH19	Koh Phi	Trat	14.2	Intact, attached, entangled in fishing net which was removed	-	Microbial mats in cup

Table 1 (continued)

Specimen number	Site	Province	Depth (m)	Health and threats	Motile fauna	Sessile flora/fauna
NCTH20	Koh Rayang Nok	Trat	12	Uprooted, entangled in rope and fishing flag	*Dascyllus trimaculatus* (Rüppell, 1829), *Heniochus acuminatus* (Linnaeus, 1758), *Epinephelus* sp., Lutjanidae spp.	-
NCTH21	Koh Rayang Nok	Trat	12.8	Uprooted, however, base re-established	-	-
NCTH22	Koh Rayang Nok	Trat	14.1	Large base, cup missing, marine debris entangled	Apogonidae sp.	-
NCTH23	Koh Rayang Nok	Trat	14.3	Uprooted, partial tissue mortality, entangled in rope	*Dascyllus trimaculatus* (Rüppell, 1829), *Epinephelus* spp., Lutjanidae spp.	Microbial mats outside cup
NCTH24	Koh Rayang Nok	Trat	11.3	Intact, attached	Epinephelinae sp.	Microbial mats outside cup
NCTH25	Koh Rayang Nok	Trat	6.5	Intact, attached	*Dascyllus trimaculatus* (Rüppell, 1829), Lutjanidae spp.	-

from discarded fishing gear (DFG) are also a significant threat to the population within the Gulf of Thailand. The threat to benthic faunal communities from DFG has been increasingly highlighted from around the world, with Southeast Asia being a leading contributor of marine debris (Galgani et al., 2018; Jambeck et al., 2015). Relatively little documentation exists on the scale of DFG on marine habitats in the Gulf of Thailand; however, there has been a recent increase in attention driven by high-profile entanglement of large areas of reef habitat (DMCR, 2021; Wongnutpranont et al., 2021).

Our findings do nonetheless agree with Quek et al. (2022) in that poor population connectivity, and the resulting genetic implications are a serious concern for the survival of the species in the region. While the increase in total population, identification of sub-populations and an increase in the overall range of the species certainly improve the dire situation somewhat, these findings by themselves by no means offer a natural path to recovery. In a period of less than a year, we were able to find 25 individuals of *C. patera*, during which time one individual was confirmed to have died and a further three were found uprooted and unsecured to the benthos. Additionally, one recorded individual from Hin Ploeng in 2015 was nowhere to be found in 2021 onwards. A clear picture of effective conservation measures would require first a deeper understanding on the biology and ecology of the species in question to better understand potential for recovery from stressors at both the individual and population level. Nonetheless, given a long history of poaching and the present threats from DFG, we suggest that enforced protection of these areas may reduce these stressors somewhat. Active restrictions on anchoring and fishing in these areas will reduce the risk of uprooting. Among the greatest active measures, however, remains the surveying and identification of more populations of the species, as well as a deeper study into population genetics and spawning dynamics. Lacking fundamental biological information pertaining to reproduction and in the absence of directed management efforts and interventions to prevent further losses, the known populations of *C. patera* face an uncertain future.

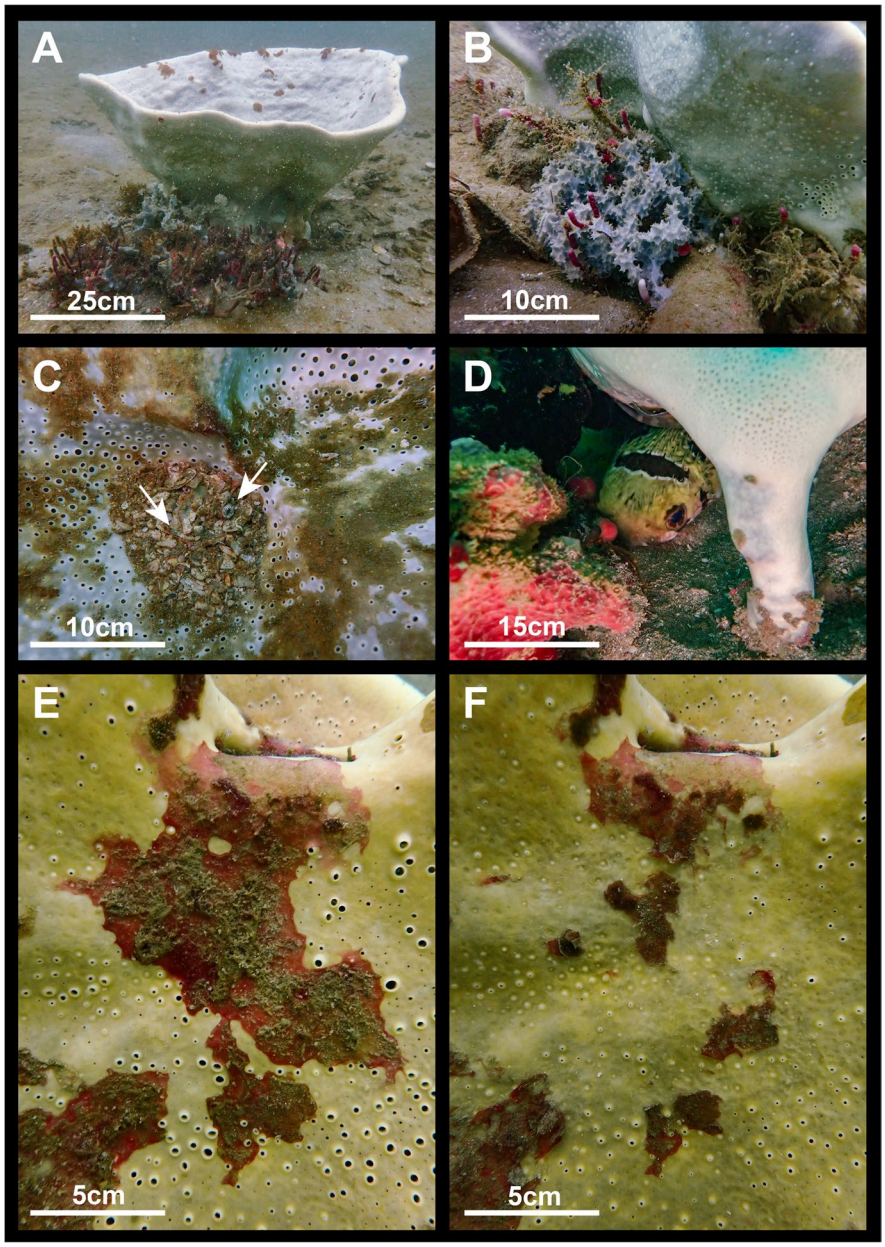

Fig. 3 Observed fauna and flora associated with *Cliona patera* from the Gulf of Thailand. **A** and **B** Specimen NCTH10 with colonisers at base. **C** Specimen NCTH15, with microbial mats adhering to sponge surface and skeletons of the coral *Heterocyathus* indicated with arrows. **D** Specimen NCTH5 with colonisers and *Diodon liturosus* hiding at the base. **E** and **F** Specimen NCTH9, before and after dispersal of microbial mats on sponge surface

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Author contribution Study conception and design was carried out by Rahul Mehrotra and Trent McGrath. Data collection was performed by Rahul Mehrotra, Trent McGrath, Tim McCabe, Matthias Desmolles, Coline Monchanin and Sumaitt Putchakarn. Data analysis and visualisation was carried out by Rahul Mehrotra. The first draft of the manuscript was written by all authors and all authors commented on subsequent versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The majority of data that support the findings of this study are included within the manuscript itself. However, restrictions apply to the availability of location-specific data (precise coordinates and photographs), due to the sensitive nature of the organisms studied and the historic extraction/damage to marine resources in the region, and are thus not publicly available. Data are however available from the authors upon reasonable request and with permission from the Marine and Coastal Resources Research Center, Eastern Gulf of Thailand, Department of Marine and Costal Resources.

Declarations

Ethics approval and consent to participate All authors have read, understood and complied as applicable with the statement on 'Ethical responsibilities of Authors' as found in the Instructions for Authors. All authors have provided consent to participate.

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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