Sponges of the marine karst lakes and of the coast of the islands of Ha Long Bay (North Vietnam)

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Abstract: The purpose of this paper is to describe the sponge assemblages of the marine karst lakes and some coastal sites in the islands of Ha Long Bay (Vietnam). These lakes are very shallow basins with a bottom covered by mud and vegetable debris. Patches of mangroves were seldom observed, while isolated colonies of massive corals are frequently found. Some lakes show a connection with the surrounding sea, evidenced by the flow of tidal streams; others are apparently closed but connected to the sea through the cavities of the karst system. The coast of Ha Long Bay islands are characterized by shallow depth, murky waters, patchy and low diversity reefs, and very low water-movement. A total of 63 demosponge species were identified: 46 species were recorded in the marine lakes, while 23 of them were never found outside the lakes. Extreme variations in environmental conditions occur yearly in the lakes, due to heavy monsoon rains that cause a stratification of the water column. A thermal crisis was recorded at the end of the summer in the Hang Du I lake, with bottom temperatures as high as 36˚C. Sponges can withstand these conditions but undergo important rearrangements, with a late summer degeneration followed by a very quick fall and winter growth.

Keywords: Porifera, anchialine lakes, karst islands, environmental stress, Tonkin Gulf

Introduction

The Ha Long Bay (Vietnam) is located in the northern part of the Tonkin Gulf, in a shallow water area of the South China Sea where more than 3000 karst islands of different sizes are present. Karstic processes, enhanced by the tropical conditions, carved out of the limestone many depressions, leading to the formation of shallow salt water lakes similar to the meromictic marine lakes of Palau (Hamner and Hamner 1998) and to the anchialine lakes of East Kalimantan (Indonesia), where the only specific study on the sponge fauna of these special environments is in progress (de Voogd *et al.* 2006).

The scope of this study was to investigate the species composition of the sponge fauna of the lakes compared with that of the coastal areas of the isles of the bay.

The sponges of the coast of Vietnam are still scarcely studied. In fact one can find only a paper by Lindgren (1898), an inventory by Dawydoff (1952), a study of a collection from Nha Trang (Lévi 1961) and a recent paper devoted to boring sponges (Calcinai *et al.* 2006) among the literature. A checklist of sponges recorded from the South China Sea by Hooper *et al.* (2000) reports as many as 161 demosponges (106 of which identified at species level) from the coast of Vietnam.

Materials and methods

Description of the study area

The climatic conditions of the study area are tropical, with a mean annual air temperature of 25°C, warm and wet summer monsoons (up to 2000 mm/year of rain) from May to October and relatively cold and dry winter monsoons from November to April (Tang 2001).

The marine lakes are remarkably different from one another in the degree of isolation from the surrounding sea. In some lakes, connection is detectable by the flow of tidal streams. Sometimes artificial canals have been built to enhance this water exchange. However, some lakes are apparently closed, being connected to the sea only through the cavities of the karst system. They are no more in pristine conditions, having been exploited for fishery, mollusc harvesting and aquaculture by people dwelling in boat villages located around the islands.

In the surrounding sea, owing to the presence of thousands of islands, water is calm and turbid. The mean tidal excursion ranges between 3 and 4 m, salinity ranges around 32‰, and sea-water temperature varies between a minimum of 23°C at the end of winter and 29°-30°C in late summer (Tang 2001).

Sampling

Three field campaigns were performed in April 2003, September 2003 and April 2004, in a joint venture between the Università Politecnica delle Marche and the Hai Phong Institute of Oceanology (HIO) for the study of biodiversity and conservation in a coastal area of Vietnam.

Samples were collected either through SCUBA diving or snorkelling in 15 sites located in Ha Long Bay Islands (Fig. 1). Eight of these sites are salt lakes, while seven are located along the coast surrounding the islands. The latter were chosen among those periodically surveyed for biodiversity assessments by the team of HIO. Sponges were collected from the rocky shores of both the lakes and the islands down to a depth of about 3 m and from the small reefs along the islands, which are only slightly deeper (7-8 m). Lakes were considered as open (Hang Du II, Hang Tham, Hang Luong), semi-enclosed (Dau Be, Cat Ba, Me Cung) and enclosed (Hang Du I, Bui Xam) when they were connected to the sea by large canals, small conduits or through the karst system, respectively. No quantitative sampling was taken, but in each sampling station all the discrete sponge species were collected by three divers during 45 minutes of dive. The small-encrusting and cryptic species were not collected. Whenever possible, sponge specimens were photographed in the field, or on board after collection; they were fixed in 4% formaldehyde solution in sea water and preserved in 60% ethanol. Some specimens were dried.

Results

Distribution

Sixty three demosponges have been identified (36 to species level), out of 182 specimens collected from the marine lakes and the coasts of the isles of Ha Long Bay (Table 1). Forty six species were found in the lakes and 40 in the bay; 23 species were found only in the lakes and 17 only in the bay (Table 1).

According to presence/absence data, the most common species in the studied area, including lakes and coastal sites, were *Dysidea cinerea* Keller, 1889 and *Haliclona (Haliclona)* sp. 2 (present in 60% of the collecting stations), *Tethya seychellensis* (Wright, 1881) (53%), *Haliclona* (*Gellius) cymaeformis* (Esper, 1794) and *Spheciospongia tentorioides* (Dendy, 1905) (46.6%), and *Mycale philippensis* (Dendy, 1896) (40%). However, in the absence of quantitative

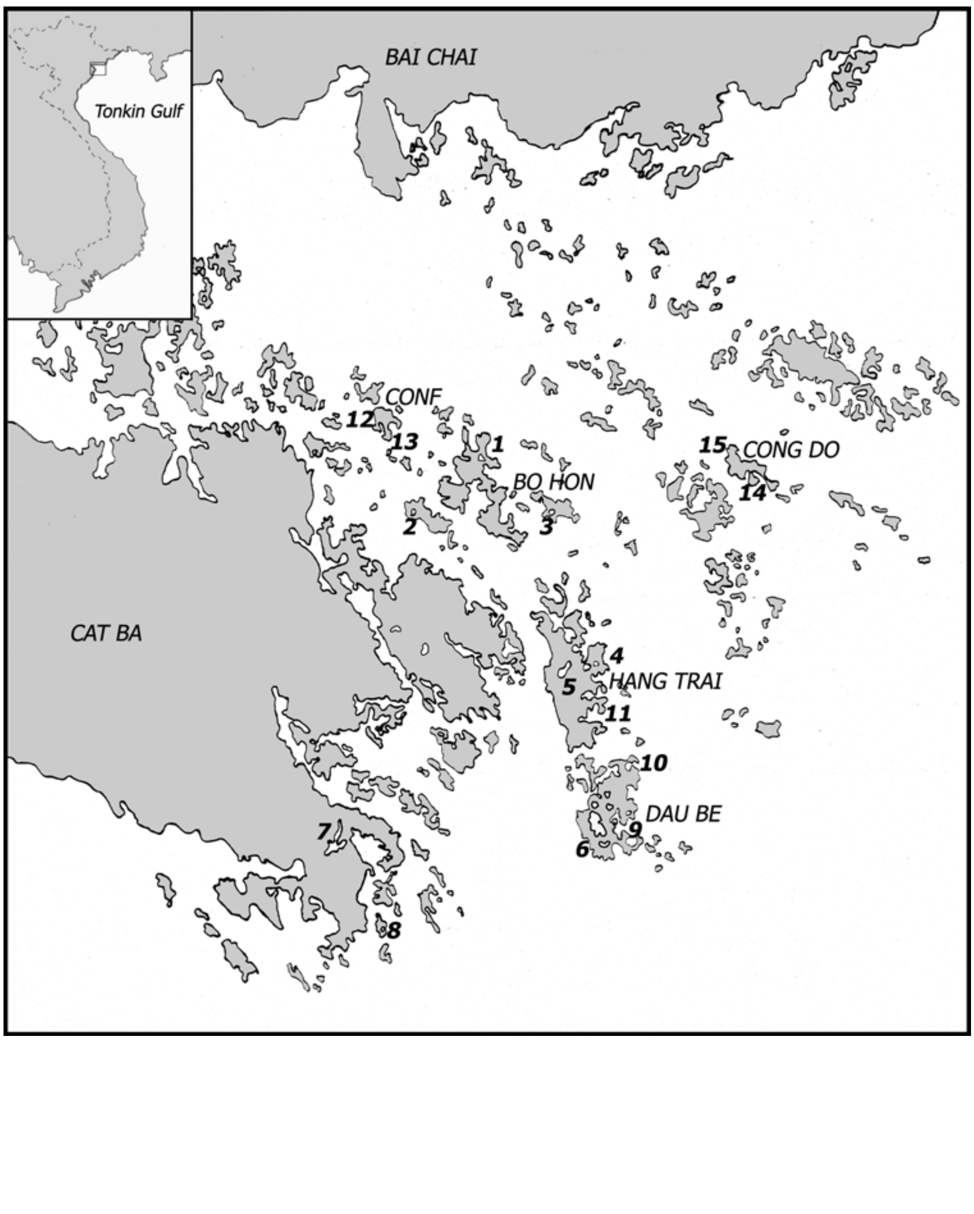


Fig. 1: Location of the marine lakes and coastal sites surveyed in six island groups (Bo Hon, Hang Trai, Dau Be, Cat Ba, Conf and Cong Do) in the western part of Ha Long Bay (Vietnam): 1-Hang Luong Lake; 2-Me Cung Lake; 3-Bui Xam Lake; 4-Hang Du I Lake; 5-Hang Du II Lake; 6-Dau Be Lake; 7-Cat Ba Lake; 8-Hang Tham Lake; 9-Coastal site I; 10-Coastal site II; 11-Coastal site III; 12-Coastal site IV; 13-Coastal site V; 14-Hang Toi Dark Cave; 15-Coastal site VI.

Table 1: List of the Demosponge species collected from some marine lakes and coastal sites of Ha Long Bay: 1-Hang Luong Lake; 2-Me Cung Lake; 3-Bui Xam Lake; 4-Hang Du I Lake; 5-Hang Du II Lake; 6-Dau Be Lake; 7-Cat Ba Lake; 8-Hang Tham Lake; 9-Coastal site I; 10-Coastal site II; 11-Coastal site III; 12-Coastal site IV; 13-Coastal site V; 14-Hang Toi Dark Cave; 15- Coastal site VI. The species that are new records for Vietnam are marked by "*".

Species	Marine Lakes								Coastal sites						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Aaptos cf. *pernucleata* (Carter, 1870) *				●											
Acanthella hispida Pulitzer-Finali, 1980 *										●		●			
Aka mucosa (Bergquist, 1965) *			●			●					●				
Amorphinopsis excavans Carter, 1887 *											●				
Amphimedon sp.		●	●									●			●
Aplysina sp.												●		●	
Biemna megalosigma Hentschel, 1912 *									●			●	●		
Bubaris sp.											●				
Callyspongia sp.									●						
Chondrilla australiensis Carter, 1873	●		●		●					●		●			
Cinachyrella australiensis (Carter, 1886) *														●	
Cladocroce sp.	●	●	●		●	●				●				●	
Clathria sp.			●												
Cliona aurivilli (Lindgren, 1897)			●	●	●										
Cliona celata Grant, 1826				●	●							●		●	●
Cliona orientalis Thiele, 1900 *	●		●		●						●				
Cliona sp.					●										
Cliothosa hancocki (Topsent, 1888)		●	●									●	●		●
Desmanthus incrustans (Topsent, 1889) *			●												
Dictyonella sp. 1				●											
Dictyonella sp. 2					●										
Dysidea cinerea Keller, 1889 *	●	●	●		●	●		●	●		●				●
Dysidea cf. *fragilis* (Montagu, 1818)		●	●		●				●						
Echinodictyum asperum Ridley and Dendy, 1886						●			●					●	
Eurypon sp.			●												
Gelliodes fibulatus (Carter, 1881)								●	●						
Halichondria sp.			●												●
Haliclona (*Gellius*) *cymaeformis* (Esper, 1794)	●		●		●	●			●				●		●
Haliclona (Haliclona) sp. 1			●						●			●			
Haliclona (Haliclona) sp. 2	●	●	●		●	●	●			●			●	●	
Haliclona (Haliclona) sp. 3				●											
Haliclona (Haliclona) sp. 4			●												
Haliclona (Haliclona) sp. 5					●										
Haliclona (Haliclona) sp. 6										●					
Haliclona (Reniera) sp. 1														●	
Haliclona (Reniera) sp. 2				●											
Haliclona (Reniera) sp. 3						●									
Haliclona (Gellius) sp.			●		●	●		●							
Hyattella intestinalis (Lamarck, 1814) *									●	●					●
Ircinia echinata (Keller, 1889) *												●			
Ircinia sp.			●												
Mycale (*Mycale*) *crassissima* (Dendy, 1905)					●										
Mycale (Zygomycale) parishi (Bowerbank, 1875) *	●	●										●	●		●
Mycale (*Mycale*) *philippensis* (Dendy, 1896)	●	●	●		●		●							●	
Mycale (Mycale) sp.												●			
Penares cf. *sollasi* Thiele, 1900 *														●	
Petrosia (Petrosia) nigricans Lindgren, 1897 *			●							●				●	
Pione carpenteri (Hancock, 1867) *			●	●											
Suberites sp. 1				●		●									
Suberites sp. 2					●										
Protosuberites sp. 1			●	●											
Protosuberites sp. 2															●
Spheciospongia solida Ridley and Dendy, 1886											●			●	
Spheciospongia tentorioides (Dendy, 1905) *	●	●	●		●							●	●		●
Spirastrella cf. *cunctatrix* Schmidt, 1868 *					●	●									
Spirastrella decumbens Ridley, 1884 *			●												
Spongia irregularis (von Lendenfeld, 1885)	●		●			●					●			●	
Stelletta aruensis Hentschel, 1912 *														●	
Tedania (Tedania) brevispiculata Thiele, 1903	●		●		●									●	
Terpios cruciata Dendy, 1905 *					●										
Tethya seychellensis (Wright, 1881) *	●	●	●	●			●	●				●		●	
Topsentia cavernosa (Topsent, 1897) *									●						
Xestospongia cf. *testudinaria* (Lamarck, 1815) *			●							●				●	●

data but based on field observations, *Haliclona (Gellius) cymaeformis,* living in symbiotic association with the rodophyte alga *Ceratodictyon spongiosum* Zanardini, 1878, was the most abundant species, thriving with an impressive number of specimens on all the horizontal substrates, even in very shallow waters where it might be exposed to air at low tide. It was dark green in colour and may vary in shape from thickly encrusting to massive or, more often, bushy (Fig. 2A). A remarkable number of boring sponges i.e. *Aka mucosa* (Bergquist, 1965), *Cliona celata* Grant, 1826, *C. orientalis* Thiele, 1900, *Cliothosa hancocki* (Topsent, 1888), *Spheciospongia tentorioides,* and *Cliona aurivilli* (Lindgren, 1897) – the latter according to Calcinai *et al.* (2006) – were found both in the lakes and in the surrounding sea, while the distribution of *Pione carpenteri* (Hancock, 1867) and *Spirastrella decumbens* Ridley, 1884 seems to be restricted to the lakes (Table 1).

The bay

In the costal stations of the bay we have observed that sponges settled on two types of substrates: The calcareous rocky shores of the islands, extending down to 3-4 m in depth and the coral gardens which proliferate on the horizontal surfaces to a depth of about 8 m. On the coast, the suitable substrate for sponge settlement was very scarce, due to the dense belt of bivalve molluscs. Horny sponges such as *Dysidea cinerea, Dysidea* cf. *fragilis* (Montagu, 1818), *Spongia irregularis* (von Lendenfeld, 1885), as well as several species of Haplosclerida (*Haliclona* spp., *Cladocroce* sp.) and *Tethya seychellensis* were the most common species on the rocky shores.

In the coral gardens, sponges behave as opportunistic species, dwelling on corals [e.g. *Gelliodes fibulatus* (Carter, 1881), *Amphimedon* sp., *Ircinia echinata* (Keller, 1889)], on pockets of sediment in between corals (*Biemna megalosigma* Hentschel, 1912), and on coral rubble [*Acanthella hispida* Pulitzer-Finali, 1980, *Spheciospongia tentorioides, Xestospongia* cf. *testudinaria* (Lamarck, 1815)]. These last two species were particularly abundant and seem to contribute to consolidate the coral fragments.

Along the coast of the islands one can find some peculiar habitats represented by semi-dark environments, such as a rocky tunnel with a steady current, open at both ends, leading to Xang Luong cove in the Island of Bo Hon and Hang Toi Cave, a cavity with a depth of 1-1.5 m, in the Island of Cong Do (Fig. 1). In these habitats, sponges were abundant and diverse. *Cinachyrella australiensis* (Carter, 1886), *Penares* cf. *sollasi* Thiele, 1900, and *Stelletta aruensis* Hentschel, 1912 have been recorded in Hang Toi Cave only.

In the above mentioned tunnel steady water movement supported numerous colonies of the octocoral *Carijoa riisei* (Duchassaing and Michelotti, 1860).

Several sponge species [*Callyspongia* sp., *Mycale philippensis, Mycale (Mycale) crassissima* (Dendy, 1905), *Spirastrella* cf. *cunctatrix* Schmidt, 1868, *Tedania (Tedania) brevispiculata* Thiele, 1903 and some unidentified *Haliclona*] were epizoic on *Carijoa* colonies in the Ha Long Bay. They initially use the octocoral skeleton as support and subsequently overgrow it completely. *Haliclona (Haliclona)* sp. 2 (Fig. 2C) has been observed on a colony already covered by *Mycale philippensis*. *Carijoa* appears to be unharmed by the epizoic sponges because its anthocodia are free to expand and retract (Fig. 2B).

The lakes

Among the pool of 23 species recorded only in the lakes, strong differences among the different basins were observed. The only species recorded in 50% of the lakes is *Haliclona (Gellius)* sp.; four other species i.e. *Pione carpenteri* (Hancock, 1867), *Suberites* sp. 1, *Protosuberites* sp. 1, *Spirastrella* cf. *cunctatrix*, were present in 25% of the lakes. Each of the other 18 species was recorded only in one lake.

The highest number of species (28) was found in the enclosed lake of Bui Xam, which has no detectable connection to the sea. 70% of these species were found both in the lakes and the coastal stations. Three species, *Clathria* sp., *Eurypon* sp. and *Spirastrella decumbens* were found only in this lake.

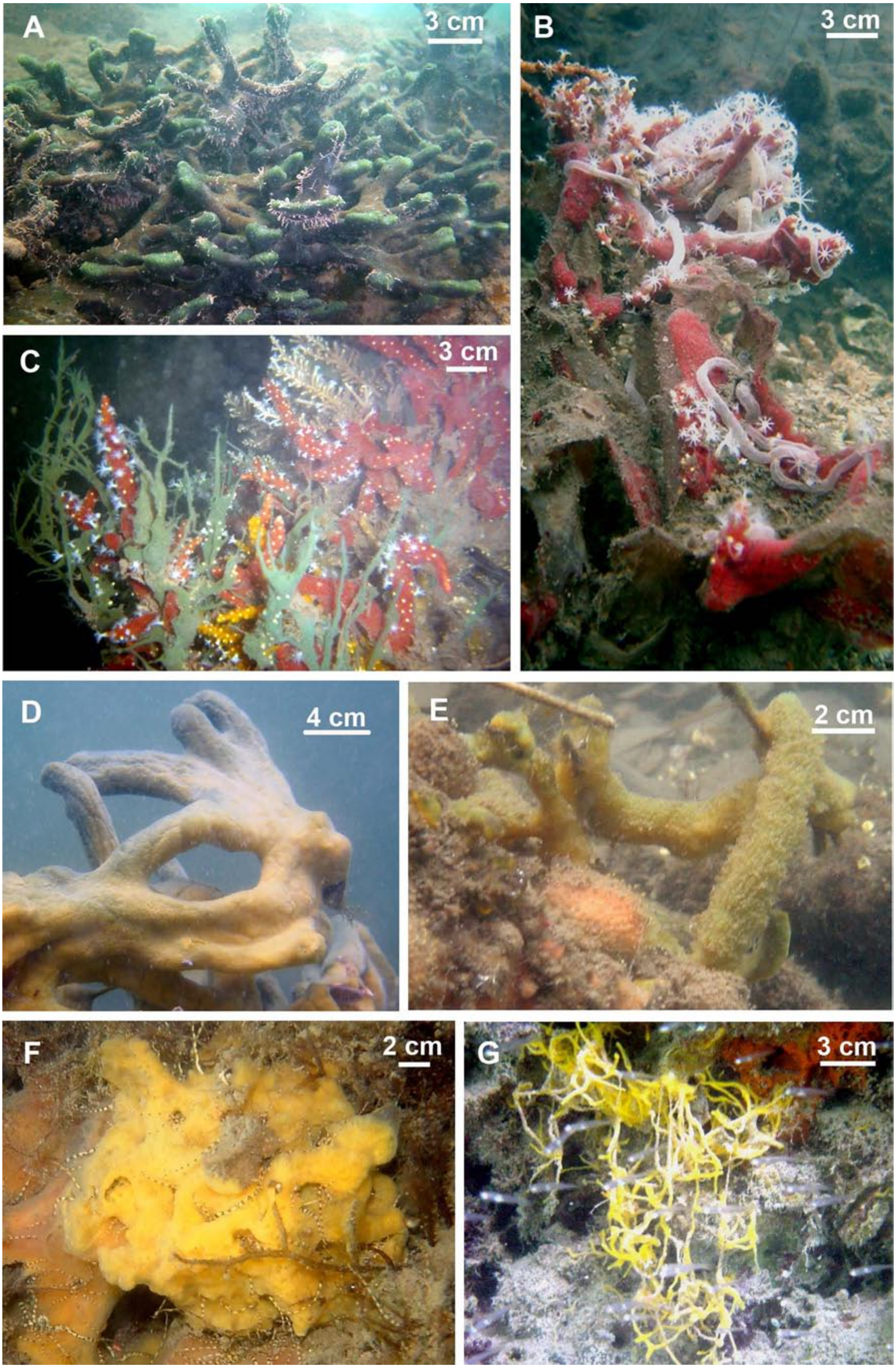
In the enclosed lake of Hang Du I, ten species were identified, 7.5% of which were in common with the coastal stations. However, *Aaptos* cf. *pernucleata* (Carter, 1870), *Dictyonella* sp. 1, *Haliclona (Haliclona)* sp. 3 and *Haliclona (Reniera)* sp. 2 were found only in this lake. *Suberites* sp. 1, a very abundant species as regards the number and size of specimens, was found just in Hang Du I and in Dau Be, a lake connected to the sea by small conduits. *Pione carpenteri* and *Spirastrella decumbens* seem to be restricted to the enclosed lakes of Hang Du I and Bui Xam.

In three lakes, Hang Luong, Me Cung and Cat Ba, the sponge fauna was completely composed of species that were also present in the bay, while in Hang Du II, Dau Be and Hang Tham the overlapping with the bay fauna ranged between 55 and 75%.

Ecology

Hang Du I lake was studied in detail because of the extreme variability of its environmental conditions directly affecting the sponge fauna. Direct observations of *Suberites* sp. 1 showed that during the dry season, in winter and early spring, numerous healthy specimens thrived close to the lake surface (Fig. 2D). In late spring and summer, morphological rearrangements and degeneration phenomena due to the combined effect of rainwater stratification with high temperatures were observed in this upper zone (Fig. 2E). Particularly evident was the case of *Protosuberites* sp. 1 (Fig. 2F, G). As soon as water cooled again, very quick fall and winter growth followed, but the original conditions did not seem to be restored after a single season.

Fig. 2: A. *Haliclona (Gellius) cymaeformis*: a bushy specimen. **B.** Sponges associated with colonies of the octocoral *Carijoa riisei.* Polyps continue their filtering activity; the worm-like organisms are synaptid holothurians. **C.** Epizoic sponges on *Carijoa* colonies: *Haliclona (Haliclona)* sp. 2 (green) and *Mycale (Mycale) philippensis* (red). Morphological rearrangements of two sponge species of the Hang Du I lake in spring and late summer: **D-E.** *Suberites* sp. 1; **F-G.** *Protosuberites* sp. 1.


A
3 cm
B
3 cm
C
3 cm
D
4 cm
E
2 cm
F
2 cm
G
3 cm

Biogeography

Twenty-three species, corresponding to 63.8% of the 36 fully identified sponges of our collection, are new records for the coast of Vietnam (Table 1). Most of these species (32 out of 36) are distributed in the Indian Ocean, including the Red Sea, and in the West Pacific Ocean, including Australia. Three of them (*Cliona celata, Dysidea fragilis*, *Tethya seychellensis*) are considered cosmopolitan, while a single species, *Aaptos pernucleata,* is known from the West Indies only.

Discussion

The recorded data suggest that the sponge fauna of the Tonkin Gulf is similar to that of the adjacent tropical areas of Indonesia and Northern Australia. Both the peculiar geomorphology and oceanography of the bay may represent important factors negatively affecting the northern expansion of sponges.

The number of species found in the lakes (46) is comparable to that found until now in four anchialine lakes of East Kalimantan "which were thought to represent a lagoonal reef of a former barrier reef complex" (de Voogd *et al.* 2006). A species particularly adapted and restricted to the lakes appears to be *Suberites* sp. 1, very likely cospecific with the *Suberites* sp. reported from Lake Satonda (Palau) and East Kalimantan Lakes (Indonesia) (de Voogd *et al.* 2006).

The species composition of sponge fauna is very different in the studied lakes without any apparent relation with the observed degree of connection to the open sea. This fact results from the comparison of the number of sponge species, 28 and 10, respectively, recorded in the two "enclosed" lakes of Bui Xam and Hang Du I. The occurrence of scattered colonies of massive corals – which are present in Bui Xam and absent in Hang Du I – suggests the presence of an undetected, large connection between the first lake and the open sea. Conversely, the high degree of isolation and the peculiar character of the above mentioned lake are confirmed by the presence of a dense population of the non-stinging jellyfish (*Rhizostoma* sp.) (Cerrano *et al*. 2006) and four species of sponges – out of a total of 10 – which are absent elsewhere. The different degree of isolation from the open sea of these two lakes is demonstrated by the severe water stratification occurring in Hang Du I, while in the Bui Xam lake stratification phenomena are less intense. Due to the stillness of this sheltered basin, a light and cool rainwater layer (salinity < 7 ‰) as thick as 150 cm (on a maximum lake depth of about 6 m) stratifies on the lake surface thus preventing the normal mixing of the water column. This resulted in an abnormal rising of the bottom temperature, which was as high as 36°C in September 2003 (Fig. 3). This thermal crisis produced a surplus of organic debris, coming from vegetable and animal decay, that deposits on the lake's muddy bottom that became anoxic (Cerrano *et al.* 2006). The spring conditions, recorded in April 2003 and 2004, were each similar and presumably bound to the climatic pattern of the year (Fig. 3).

Seasonal variations in temperature and salinity such as those recorded in Hang Du I remarkably affect the sponge fauna. The response to the environmental stress seems to be related to the sponge position on the bottom, because Clionaid species and *Tethya seychellensis,* living in sheltered habitats, appear unaffected, whereas *Suberites* sp. 1 and *Pseudosuberites* sp. 1, living in exposed locations, show evident regression. Rapid growth rates as those observed after the late summer crisis were already recorded in sponges after negative events (Ayling 1983). These growth rates may be also supported by increased food abundance (Duckworth *et al.* 2003) resulting from the restoration of the normal conditions in the water column. Summer temperatures in temperate regions normally cause positive growth rates in sponges (Turon *et al*. 1998, Tanaka 2002) whereas sponge shrinking was associated to colder temperatures (Duckworth and Battershill 2001). However, persistence of high water temperatures in late summer may stress benthic organisms, sometimes triggering mass casualties (Cerrano *et al*. 2000). Regression and reorganization of adult sponges – apparently neither related to environmental stress nor to a seasonal cycle – were observed in natural conditions (Pansini and Pronzato 1990, Bell and Smith 2004).

Besides salinity variations, another physical factor affecting sponge fauna both in lakes and coastal sites appears to be the high water turbidity. The impact of sedimentation on sponges is well known (Sarà and Vacelet 1973, Bell and Smith 2004) as is the defensive reaction set up by sponges in order to avoid clogging of their aquiferous system (Reiswig 1971, Bell 2004, Cerrano *et al*. 2004). In a shallow water area such as Ha Long Bay, tidal range and competition with bivalve molluscs reduce the space available for sponge settlement on vertical substrates and overhangs, which are protected from sediment deposition. This may cause an overall reduction of the specific richness of porifera but may also select taxa producing fistules (e.g. *Biemna megalosigma*), adapted to live partially buried by the sediment on horizontal substrates.

Symbiosis may be the clue for explaining the great abundance of *Haliclona (Gellius) cymaeformis,* associated with the rodophyte *Ceratodyction spongiosum*, in the intertidal and subtidal of the bay. Steindler *et al.* (2002) suggest that the photosynthetic activity of the algae may fulfill the energetic needs of the sponges when they stop filtering, being partially emerged at low tide, and that symbionts protect them from UV radiation, particularly intense in shallow water. In addition, Pile *et al.* (2003) showed that the sponge, feeding on nitrogen-rich bacteria and protozoans of the ultraplankton, can meet the nitrogen demand of both partners of the symbiotic association. Therefore, several positive factors could allow *Haliclona (Gellius) cymaeformis* to thrive in the shallow water environment even in the presence of rather low water transparency.

Until the present, marine lake biota is poorly known, but they very likely host many species new to science as the taxonomy of sponges here suggests. As highlighted by Dawson and Hamner (2005) marine lakes offer the possibility to study the founder effect at different stages, in relation to their age and level of isolation. The lakes of North Vietnam are smaller than Palau and Indonesian ones and host a fauna very interesting in relation to speciation processes and to its physiology, being strongly adapted to sudden modifications of the environmental parameters. These aspects may at least partially explain the large variation in qualitative composition

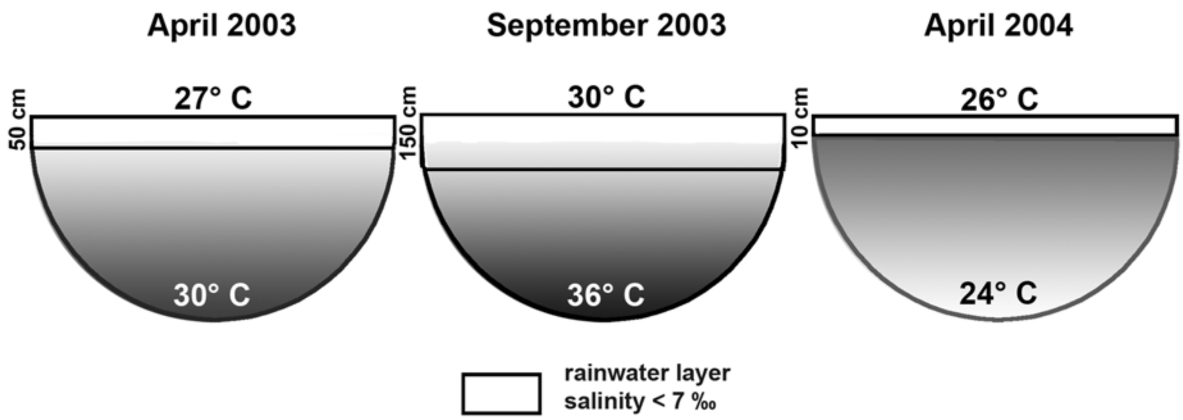


Fig. 3: Environmental variations in Hang Du I lake.

of the sponge fauna between different lakes, and between the lakes and the surrounding marine areas. It is important to increase the knowledge of these unique habitats before human activities and climate change would irreparably damage them.

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