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Biological Community in Submerged Caves and Marine Lakes in ha Long-Cat Ba Area, Vietnam

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Abstract: Submerged caves and marine lakes are two iconic and common ecosystems in Ha Long-Cat Ba area. However, their biological characteristics are poorly known since very limited studies have been conducted. The aim of this study was to investigate biodiversity in these ecosystems. Three submerged caves (Hang Sang, Hang Toi and Qua Bang) and three marine lakes (Dau Be, Ang Du and Qua Bang) were chosen for study. The results showed that organism communities in submerged caves were abundant with over 142 species found. The popular groups comprised sponge and soft coral which were distributed along the length of the caves. Several species with high economic value were widespread in the caves, including stone crab *Myomenippe hardwickii*, flower crab *Portunus pelagicus*, cone snails *Trochus pyramis*, shoemaker spinefoot *Siganus sutor*, snapper *Lutjanus russellii*. Species that permanently live in caves were not detected. In the lakes where water is well exchanged to the sea, coral reefs were found and they usually formed a narrow band around the lakes. Sandy beaches were often observed around the lakes at the depths of 0.5-2 m, containing specialty species as clam (*Sanguinolaria diphos)*, snout otter clam (*Lutraria rhychaena)*, sea cucumbers with high density (in Dau Be, Qua Bang). There was no coral reef in the enclosed lake (Ang Du) because of low salinity.

Key words: Karst, habitat, biodiversity, organism, environment.

1. Introduction

Karstic processes in carbonate rocks have resulted in the formation of marine caves in many coastal marine areas of the world (Gerovasileiou and Voultsiadou, 2012). Marine cave ecosystems are characterized by its rich biodiversity, distinct fauna and ecological features (Navarro-Barranco et al., 2013). Although studies on marine cave were improved together with the appearance of Scuba diving equipment, the understanding on marine cave's biology has remained limited.

Marine lakes are isolated bodies of seawater separated from the ocean by a surrounding land barrier (Dawson and Hamner, 2005). Considered as outstanding ecosystems, marine lakes may contain unusual populations of divergent marine organisms that have been isolated from adjacent sea. Approximately 200 marine lakes are reported worldwide so far (Mlakar et al., 2015).

Characterized by more than 2,000 karstic islands, Ha Long-Cat Ba area is considered as one of the most extensive and best-developed areas of tower karst in the world. Karstic processes have created many submerged caves and enclosed and semi-enclosed marine lakes in this area. Although these two ecosystems are special in the region, no study had been conducted due to lack of equipment and research experience. Until 2003 the scientists from Institute of Marine Environment and Resources (Vietnam) and University of Genoa (Italy) in collaboration projects on biodiversity conservation in the coastal zone of Vietnam surveyed several submerged caves and marine lakes. Their work only focused on sponge group while other organisms received little attention. The results published by Cerrano et al. (2006) and Azzini et al. (2007) were recorded 63 sponge species in whole Ha Long-Cat Ba area which comprises

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submerged caves and marine lakes. After that no biological study in these ecosystems has been performed.

To gain a deeper understanding on biological communities in submerged caves and marine lakes as fundamental for management and conservation, we have conducted further research on different organism groups, including zoobenthos, algae, sponges, coral and fish in 3 submerged caves (Hang Toi, Hang Sang and Qua Bang) and 3 marine lakes (Ang Du, Dau Be and Qua Bang). Our results provide new biodiversity data in submerged caves and add more data in marine lakes in Ha Long-Cat Ba area.

2. Materials and Methods

2.1 Study Area

Surveyed submerged caves and marine lakes are presented in Table 1 and Figure 1.

Table 1 Description of submerged caves and marine lakes in the present study.

Submerged cave	**Description**
Hang Sang	Geographic coordinates: 20°48′01″ N-107°05′52″ E; direction: east-west; length: 80 m; width: 10 m (15 m at its widest point); height: 4-5 m. Outside of the cave is Van Tai cove, inside of the cave is a marine lake with an area of around 7.5 ha.
Hang Toi	Geographic coordinates: 20°48′18″ N-107°05′59″ E; direction: east-west; length: 250 m; width: 4 m; height: 3 m. The cave is completely submerged at high tide. It is connected to a marine lake with an area of around 3.8 ha.
Qua Bang	Geographic coordinates: 20°48′11″ N-107°04′18″ E; direction: northwest-southeast; length: 90 m; including two parts: front part is large, width: 10 m, height: 5 m and length: 30 m. Remaining part is small and connected to Qua Bang lake inside.
Marine lake	**Description**
Ang Du	Geographic coordinates: 20°47′32″ N-107°07′59″ E; length: 180 m; width: 110 m; area: 1.9 ha. This enclosed lake has no entrance communicate with the sea. Little amount of the lake water is exchanged with the seawater through the fissures of the rocky walls.
Dau Be	Geographic coordinates: 20°44′59″ N-107°08′09″ E; length: 310 m; width: 65 m; area: 2 ha; depth: 6 m. Lake water is exchanged frequently since it is connected to the sea. Sandy mud bottoms, with a narrow strip of coral reef distributed sparsely around the lake.
Qua Bang	Geographic coordinates: 20°48′35″ N-107°04′30″ E; length: 470 m; width: 140 m; area: 6.6 ha. Lake water is exchanged to the sea through a submerged cave (Qua Bang cave). Around the lake (submerged part) is sandy bottom at the depths of 0.4-1.5 m, followed by a narrow strip of corals and sandy and muddy bottom at the depths of 4-6 m at the lake center.

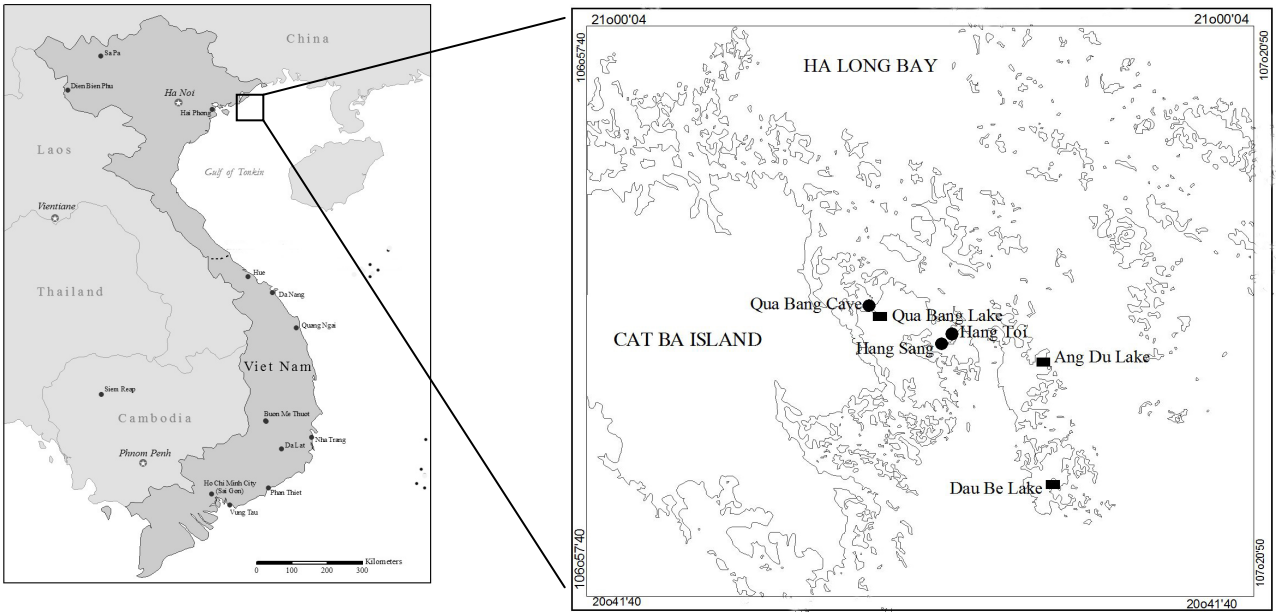

Fig. 1 Position of submerged caves and marine lakes in the present study.

2.2 Sample Collection and Analyses

• Zoobenthos: Applying sampling method for zoobenthos in intertidal and subtidal zones to study submerged caves and marine lakes.

Intertidal zone: Following Gunjanova's sampling method (1972), zoobenthic samples were collected vertically from high intertidal zone to mid-intertidal zone and low intertidal zone. Quantitative samples were taken in 40 x 40cm standard frames.

Subtidal: Samples were collected follow English's instruction (1997), using Ponar Dredge with sampling area of 0.05 m^2. On the reefs and submerged caves, qualitative and quantitative samples were collected using Scuba diving equipment.

Sample preservation and analyses: Zoobenthic organisms were separated into groups (molluscs, crustaceans, echinoderms ...), preserved ethanol 70%.

• Corals, sponges, seaweeds and fishes: Scuba diving equipment was used for survey and sampling English et al. (1997).

All collected samples were classified to species based on morphological method.

3. Results

3.1 Marine Biodiversity

Total 142 species in 5 groups were found in submerged caves and marine lakes in Ha Long-Cat Ba area: fish, coral, sponge, zoobenthos, seaweed. In particular the number of coral species was highest (53 species), followed by benthos (32 species), sponge (31 species), fish (14 species) and the number of seaweeds was lowest (12 species) (Fig. 2).

• Fish community: 14 marine fish species were identified, belonging to 12 families. 4 species were recorded first time in Ha Long-Cat Ba waters: *Lethrinus nebulosus* (Lethrinidae), *Abudefduf margariteus* (Pomacentridae), *Siganus sutor* (Siganidae), *Scorpaenodes varipinnis* (Scorpaenidae). Highest species number was observed in Dau Be lake (6 species), followed by Qua Bang cave (5 species), Hang Sang cave (4 species), the remaining sites had 1-2 species. There were economic fish genera detected in submerged caves and marine lakes: *Mugil*, *Amblygobius*, *Siganus*, *Cheilodipterus*, *Lutjanus, Hemiramphus ...*

• Seaweed community: 12 seaweed species in 4 phyla were listed in the surveyed marine lakes, 4 red algae species (Rhodophyta), 3 brown algae species (Phaeophyta), 3 green algae species (Chlorophyta) and 2 blue-green algae species (Cyanophyta). Although recorded species were limited, most of them are valuable, including 5 economic species (*Polycavernosa fastigiata*, *Gigartina intermedia*, *Acanthophora orientalis*, *Caulerpa racemosa*, *Enteromorpha compressa*), 7 species are significant in industry and medicine (*Ceratodiction spongiosum*, *Polycavernosa fastigiata*, *Gigartina intermedia*, *Dictyota linearis*, *Lobophora variegata*, *Padina boryana*, *Codium arabicum*) and 1 rare species (*Codium arabicum*). In submerged caves seaweed species were not found since they are unable to photosynthesize under poor light condition.

• Sponge community: 31 sponge species were dectected, belonging to 20 families: Suberitidae, Phloeodictyidae, Aplysinidae, Tetillidae, Chalinidae, Clionaidae, Dictyonellidae, Dysideidae, Raspailiidae, Halichondriidae, Mycalidae, Ancorinidae, Petrosiidae, Suberitidae, Spongiidae, Tedaniidae, Tethyidae. Elaborately, species in Halichondriidae family were richest (8 species), followed by Clionaidae family (4 species), Ancorinidae, Tethyidae, Suberitidae families had 2 species and remaining families consisted of only one species. The number of species in submerged caves and marine lakes was relatively abundant. The highest species number was listed in Hang Toi (12 species in 16 families) and the lowest species number was listed in Qua Bang cave (7 species in 7 families). The common species: *Aplysina* sp., *Cladocroce* sp., *Cliona celata*, *Spheciospongia solida*, *Haliclona (Haliclona)* sp., *Stelletta aruensis*, *Spongia irregularis*, *Tethya seychellensis*, *Xestospongia cf. testudinaria*.

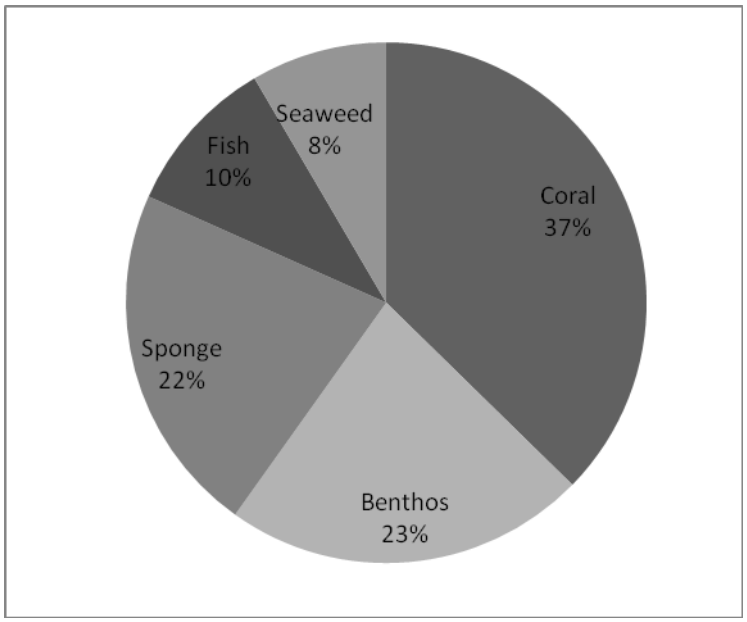

Fig. 2 Percentage of different species groups found in submerged caves and marine lakes.

Sponge was a common and dominant group in submerged caves. They lived on rocky bottom or symbiotic with horn corals. Many sponge species are being used to extract active substances for medicine.

• Coral communiy: 53 coral species were identified in marine lakes and submerged caves, including 41 hard coral species (most of them lived in marine lakes) and 12 soft coral species (most of them lived in submerged caves). Of the three studied lakes, there are only 2 lakes including coral reefs (Dau Be and Qua Bang). Although corals formed reefs in marine lakes, their areas were not large, approximately 500 m^2 and 300 m^2 in Dau Be and Qua Bang, respectively. Coral reefs played an important role in marine lakes since they created shelters for marine creatures. Coral species as *Pavona decussata*, *Echinopora lamellos*, *Goniopora columna, G. lobata* were homes for reef fishes and molluscs. In submerged caves soft corals and sponges were two main groups with high species diversity. This study recorded well-developed populations of soft coral *Carijoa riisei* in Hang Toi and Qua Bang where the coverage was up to 80%. They were attached on wall, ceiling and floor of the caves, even on shells of molluscs, oysters and mussels. They were also distributed in places without light, forming large mats with areas of 1-5 m^2.

• Zoobenthic community: 32 species in 22 families were listed, belonging different groups Polycheata, Mollusca, Echinodermata, and Crustacea. Mollusca was the most popular group with 23 species (13 families), followed by echinodermata with 6 species (6 families), crustacea with 2 species (2 families), and polychaeta were the least popular group with 1 species (1 family).

Mollusc species were main composition of zoobenthic community. 8 gastropod species were recorded, belonging to families Buccinidae, Cerithidae, thiaridae, Muriadae, Trochidae, Naticidae. Moreover, 14 bivalve species were listed, belonging to families Arcidae, Mytilidae, Pectinidae, Pteriidae, Cardiidae, Veneridae, Pinnidae. Veneridae family was most abundant with 5 species, and families Arcidae, Pectinidae and Pinnidae were least abundant with 1 species. *Septifer bilocularis* and *Isognomon isognomum* were popular in Dau Be lake, *Perna viridis, Septifer bilocularis, Chlamys nobilis, Isognomon legumen* were widespread in Hang Toi cave. As food and economic species, *Cardium multipunctatum, Marcia marmorata Arcaa navicularis*, *Chlamys nobilis, Pteria (Pinctada) martensii, Atrina*

pectinata have been overexploited.

There were 6 species of phylum Echinodermata, in 6 families, including *Archaster typicus* (Archasteridae), *Diadema savignyi* (Diadematidae), *Echinometra mathaei* (Echinometridae), *Heliocidaris crassispina* (Echinometridae), *Holothuria (Halodeima) atra* (Holothuriidae), *Cercodemas anceps* (Cucumariidae). Echinoderm species in Ha Long-Cat Ba waters have been overfished since they are raw materials for food and medicine.

Phylum crustacea had two species *Charybdis (Charybdis) hellerii* (Portunidae) and *Myomenippe hardwickii* (Menippidae). Both of them are food and economic species.

Limited polychaete species was found in submerged caves and marine lakes, only one species *Clymenura tenuis (*Maldanidae) was observed.

In terms of zoobenthic composition in submerged caves and marine lakes, mollusc species were dominant with the abundance of snails and bivalves. Due to their food and medicinal values, several species as mollusc, crab, sea cucumber and sea star have been overexploited. As a consequence, organism groups with 1-2 species are under the risk of disapperance if the overexploitation is not stopped or these animals face adversely environmental conditions.

Zoobenthic diversity in different submerged caves and marine lakes were significantly different. The number of species was highest in Hang Toi cave (18 species), followed by Qua Bang cave (11 species), 6 species were recorded in each lake of Dau Be, Hang Sang and Qua Bang, and the lowest species number was found in Ang Du lake (3 species).

3.2 Habitat Diversity in Submerged Caves and Marine Lakes

Our results showed that, although the areas of submerged caves and marine lake/s are not large, they usually contain several specific habitats that are shelters for marine creatures, forming biodiversity in studied sites. Based on our surveys, we have identified four major habitat types, namely:

- Rocky-gravelly habitat: This habitat comprised small areas around Dau Be and Qua Bang lakes and submerged caves. Rock, pebbles and gravel were exposed at the lowest tidal level. Rocky habitat in submerged caves and semi-enclosed marine lakes played a key role in these ecosystems. Its biodiversity was high with the popularity of zoobenthos such as crabs *Charybdis (Charybdis) hellerii, Myomenippe hardwickii*, and molluscs *Cypraea scurra, Siphonalia sp.*, *Ostreidae* sp., *Trochus pyramis, Perna viridis, Cardium multipunctatum*.... Echinoderm species such as sea cucumbers *Holothuria (Halodeima) atra*, *Heliocidaris crassispina* and *Cercodemas anceps* were also observed. Especially in Hang Toi and Qua Bang caves, soft coral *Carijoa riisei* were densely distributed on cave walls where are influenced markedly by tidal fluctuation. In addition, coverage of sponge community was very high.

Species composition in rocky habitat in enclosed marine lake (Ang Du) was relatively low. Recorded zoobenthic species included crab *Charybdis (Charybdis) hellerii*, snail *Cypraea scurra*, *Siphonalia sp* and oyster Ostreidae.

- Sandy habitat: This habitat was placed in Dau Be and Qua Bang lakes and Qua Bang and Hang Toi submerged caves. Overall, their areas were small areas in the caves. Regular movement of water result in accumulation of sand on cave bottom with areas of around 5-10 m^2. However, sometimes the length of sandy beach was up to 40 m as at the end of Hang Toi cave. Sandy-muddy bottom in Qua Bang cave was formed due to the difference in width of its front part and rear part. The front part near the entrance is quite large (over 10 m), while the rear part is narrow (2-4 m) so water flowing through this area is slowed down, leading to the accumulation of sandy and muddy sediments. In marine lakes this habitat accounted for large areas. They formed beaches surround Dau Be and Qua Bang lakes at the depths of 0.5-2 m. Numerous

Table 2 Valuable and rare species in submerged caves and marine lakes.

Name	Economic value species	Rare species	Medicinal species
Fish			
Hemiramphus far (Fossk., 1775)	+		
Lethrinus nebulosus (Forssk., 1775)*	+		
Gerres oyena (Forssk., 1775)	+		
Scolopsis lineata (Q. & G., 1824)	+		
Lutjanus russellii (Blkr., 1849)	+		
Abudefduf margariteus (Cuv., 1830)*	+		
Chelmon rostratus (Linn., 1758)		+	
Siganus fuscescen (Houtt., 1782)	+		
Siganus sutor (Val., 1835)*	+		
Mugil sp.	+		
Scorpaenodes varipinnis (Smit., 1957)*	+		
Sebastapistes sp.	+		
Amblygobius phalaena (Val., 1837)	+		
Seaweed			
Ceratodiction spongiosum Zanard.			+
Polycavernosa fastigiata Chang et Xia	+		+
Gigartina intermedia Sur.	+		+
Acanthophora orientalis J. Ag.	+		
Dictyota linearis (C. Ag.) Grev.			+
Lobophora variegata (Lamx.) Wom.			+
Padina boryana Thyvi			+
Caulerpa racemosa (Forsk.) J. Ag.	+		
Codium arabicum Kuetz.		+	+
Enteromorpha compressa (L.) Grev.	+		
Zoobenthos			
Trochus pyramis Lamark	+	+	
Mauritia scurra (Gmelin, 1791)	+		
Arenifodiens vagina (Lamarck, 1819)	+		
Perna viridis (Linnaeus, 1758)	+		
Chlamys nobilis (Röding, 1798)	+		
Pteria (Pinctada) martensii (Dunker, 1872)	+		
Trachycardium sp.	+		
Anomalodiscus squamosus (Linnaeus, 1758)	+		
Circe scripta (Linnaeus, 1758)	+		
Gafrarium divaricatum (Gmelin, 1791)	+		
Gafrarium pectinatum (Linnaeus, 1758)	+		
Marcia recens (Holten, 1802)	+		
Atrina pectinata (Linnaeus, 1767)	+		
Archaster typicus Müller & Troschel, 1840	+		
Diadema savignyi (Audouin, 1829)			+
Echinometra mathaei (Blainville, 1825)			+
Holothuria (Halodeima) atra Jaeger, 1833	+		
Heliocidaris crassispina (A. Agassiz, 1864)	+		
Cercodemas anceps Selenka, 1867			+
Charybdis hellerii (A. Milne-Edwards, 1867)	+		
Myomenippe hardwickii (Gray, 1831)	+		

organisms were recognized in this habitat such as molluscs Chlamys nobilis, Arcaa navicularis, Cardium multipunctatum, Atrina pectinata, Samguinolaria maculosa, Marcia marmorata, Gofrarium divaricalum, and starfish Archaster typicus.

• Coral reef: Coral reef was only present in the lakes that are regularly exchanged water with the sea as Dau Be and Qua Bang. There was no coral reef in Ang Du due to low salinity and in the caves due to lack of light. Coral reef areas in marine lakes were relatively small, distributed at the depths of 2-4 m. They formed narrow strips around the lake centers. Degradation of coral reefs was indicated by high percentage of dead corals and low percentage of live corals (10-25%). Popular coral genera were found in the lakes include: *Favia*, *Porites*, *Pavona*, *Symphyllia*, *Goniopora* and *Galaxea*. Coral reefs were homes for numerous organisms with the popularity of molluscs such as *Seftifer lilocularis*, *Perna viridis*, *Isognomon legumen*, *Cardium multipunctatum* and *Atrina pectinata*. Widespread echinoderm speciews in this ecosystem included *Diadema urchins* and *Mathaei savignyi*.

• Muddy habitat: This habitat was only observed in marine lakes, distributed at the lake centers with the depths of 3-6 m. In enclosed lakes (Ang Du) decay of dead leaves caused stinky smell. Limited organisms were detected in this habitat, only 1 polychaete and several small sized sneils were listed.

4. Conclusions

Dominant communities in submeged caves were sponges and soft corals that were distributed from entrance to completely dark place. There was no differences in the distribution of organism groups follow the depth of the caves. Algae and hard corals were not found in the caves due to lack of light. 14 fish species, 12 seaweed species, 31 sponge species, 53 coral species, 1 polychaete species, 23 species of molluscs, echinoderms 6 species, 2 crustaceans were dectected in submerged caves and marine lakes. Many of them are valuable species in term of economy, industry and medicine. Especially in this study 4 fish species were discovered and added to the list of fish in Ha Long-Cat Ba waters. Species that live permanently in submerged caves and marine lakes were not detected.

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