INSTITUTE OF ECOLOGY AND BIOLOGICAL RESOURCES

NAGAO NATURAL ENVIRONMENTAL FOUNDATION

INSTITUTE FOR NATURAL RESOURCES AND ENVIRONMENTAL STUDIES

FINAL REPORT FOR MACROINVERTEBRATE (2018-2021)

Hanoi, 2021

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(CRES Cont) (Outline proposed by CRES 10/7/2021, updated 11/2021)

Acknowledgment

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1. General information

1.1. Authors of the report

Le Hung Anh - lehunganh@gmail.com, Do Van Tu - dovantu.iebr@gmail.com, Cao Thi Kim Thu - c_thu@yahoo.com, Dang Van Dong - dongjohn.1710@gmail.com, Nguyen Tong Cuong - tongcuongvst31@gmail.com, Phan Thi Yen - phanyen2510@gmail.com.

1.2 Group members (leader, key researcher and assistant researcher)

Group members involving the surveys, lab works and writing report included: Le Hung Anh (Team leader), Do Van Tu (Key researcher), Cao Thi Kim Thu (aquatic insect expert), Dang Van Dong (Research assistant), Nguyen Tong Cuong (Research assistant), Phan Thi Yen (PhD student).

2. Research

This report presents the results of our surveys on macroinvertebrates in four protected areas in Northern Mountainous Vietnam for limestone ecosystems, including Cham Chu Species and Habitat Conservation Area (Cham Chu SHCA) in Tuyen Quang Province, Bac Me Nature Reserve (Bac Me NA) in Ha Giang Province, Nam Xuan Lac Nature Reserve (Nam Xuan Lac NR) in Bac Kan Province, Phia Oac – Phia Den National Park (Phia Oac – Phia Den NP) in Cao Bang Province.

2.1. Abstract

+ Main points about problem, methodology and main results/finding for each site and for the northern mountainous region

+ Main points about analysis between sites and recommendation, related to conservation policies.

From October 2018 to April 2021, two surveys have been conducted for each of the protected areas in Northern Mountainous Vietnam, including Cham Chu SHCA, Bac Me NA, Nam Xuan Lac NR, Phia Oac – Phia Den NP. We recorded 264 taxa of macroinvertebrate belonging to 3 phyla (Annelida, Arthropoda, Mollusca), 5 classes

(Gastropoda, Bivalvia, Malacostraca, Insecta, Oligochaeta), 16 orders, 86 families, 192 genera from 71 survey sites. Thirteen shrimp species (*Macrobrachium vietnamense*, *Caridina caobangensis*, *C.* cf. *pacbo*, *C. pseudoserrata*, *C. tricincta*, *C.* sp.1, *C.* sp.2, *C.* sp.3, *C.* sp.4, C.sp.5, C. sp.6, C. sp.7, *C.* sp.8) and eight crab species (*Tiwaripotamon* sp. *Indochinamon* sp.1, *I.* sp.2, *I.* sp.3, *I.* sp.4, *I.* sp.5, *I.* sp.6, *I.* sp.7) (see Appendix 2) are considered as endemic of Vietnam. The crab and shrimp taxa have not been identified species level possibly new species. This is the first data on macroinvertebrate diversity in these areas. The number of species assessed as threatened with extinction in this limestone karst area is very high, around 8% of total recorded species. Small streams and caves in the forests, habitats of the endemic and endangered species, are the high priority areas for conservation. The ecosystem health of limestone forests is declining by the encroachment of forest land for cultivation, grazing cattle, mining, infrastructure and residential development, electrofishing and invasive species. Besides, water pollution by widely using pesticides and herbicides in agriculture is also an important threat to aquatic fauna. The biotic indices $BMWP^{VIET}$ and ASPT showed poor water quality in some sites. To reduce the rate of biodiversity loss for these karst ecosystems, a focus should be on minimizing the threats; promoting methods of sustainable use of biological resources; biodiversity must be mainstreamed in all sectoral plans, plans and strategies and comprehensively applied in strategic environmental assessments and environmental impact assessments on biodiversity, and especially ensure the participation of the local communities and stakeholders in the activities of the protected areas.

2.2. Background of the study

Northern Vietnam is geologically and environmentally complex, a mixture of granite and limestone, uplands and delta, jagged peaks and humid lowlands, and tropical and subtropical species. This diversity reflects northern Vietnam's position near the intersection of the tropical and subtropical zones and the biotic influence of three biogeographic units: Indochina, south China, and coastal Indochina (Sterling et al., 2006).

The limestone mountains in the North of Vietnam are considered as one of the biodiversity hotspots. However, the data on macroinvertebrates here are very few. In the face of increasing biodiversity losses, more comprehensive studies, including many groups of organisms, are required. Together with studies on economic and social conditions, it will allow making a full assessment of the status of biodiversity as well as the pressures on the ecosystem.

2.3. Literature review

There are no published reports on macroinvertebrates in the protected areas, except for the work of Cao (2011) on result of the preliminary survey of the composition of the stonefly order Plecoptera (Insecta) in Phia Oac-Phia Den NP (Cao, 2011). This showed the list of 16 species belonging to 12 genera, 4 families of stonefly order Plecoptera.

2.4. Group's purpose and subjects

This project purposes:

(1) to obtain a more accurate assessment of macroinvertebrate (or macrobenthos)

diversity in limestone ecosystems of four protected areas in Northern Mountainous Vietnam, including Cham Chu Species and Habitat Conservation Area (Cham Chu SHCA) in Tuyen Quang Province, Bac Me Nature Reserve (Bac Me NA) in Ha Giang Province, Nam Xuan Lac Nature Reserve (Nam Xuan Lac NR) in Bac Kan Province, Phia Oac – Phia Den National Park (Phia Oac – Phia Den NP) in Cao Bang Province;

(2) to contribute the data for assessing the conservation status and to propose conservation measures for macroinvertebrate in Vietnam;

(3) to assess the biological water quality of studied areas based on diversity indices of macroinvertebrate.

2.5. Materials and methods

2.5.1. Sampling procedure

From October 2018 to April 2021, two surveys have been conducted for each of protected areas in Northern Mountainous Vietnam, including Cham Chu SHCA, Bac Me NA, Nam Xuan Lac NR, Phia Oac – Phia Den NP. Macroinvertebrate was collected from 71 sites in different habitats including swamp, small and big streams and cave streams. The detail of localities, coordinates and the survey dates were shown in Appendix 1 and Fig. 1. Besides the inventory sites (collected as many species as possible, we conducted several quantitative samplings. Moreover, macroinvertebrates were also sampled in the areas affected by deforestation, agriculture, residential and infrastructure development to assess impact on the water quality through the biotic indices. The collecting methods included catching by Surber Sampler (30 cm × 30 cm, 0.5 mm mesh size, Fig. 2a), hand net (Fig. 2b) and hands.

Living specimens were photographed by the digital camera to record the coloration, then preserved in 90% alcohol. In the survey, we also recorded information about the coordinates, elevation, substrate, stream width, the impact of humans and photographed the habitats.

a) Cham Chu NR

b) Bac Me NR

c) Phia Oac-Phia Den NP

d) Nam Xuan Lac HSCA

Figure 1. The map of the survey sites in the four protected areas

a) Collecting sample by Surber Sampler b) Collecting sample by hand net

Figure 2. Collecting macroinvertebrate samples

2.5.2. The macroinvetebrate identification

In the laboratory, macroinvetebrate was sorted, identified when possible to the species level, and counted. The identification was based on their morphological characteristics. For example, the shell characteristics are important to identify mollusc. Concerning crustaceans, we primarily based on Gonopod 1 and 2 of male, abdominal segments, carapace shape (for crabs) and endopod of male first pleopod, appendix interna of endopod, appendix masculina of male second pleopod, rostrum, stylocerite, scaphocerite, pereiopods, fifth and sixth abdominal somites, telson, uropodal diaeresis, egg size (for shrimps).

The specimens were identified based on taxonomic documents such as Đặng Ngọc Thanh & Hồ Thanh Hải, 2012, 2018; Dai, 1999; Liang, 2004; Yeo & Ng, 2007; Cumberlidge & Ng, 2009 (for molluscs, crabs and shrimps); Nguyen Xuan Quynh (2001, 2002), Thu (2002), Vinh (2003), McCafferty & Provonsha (2003), Quigley (1993), Sangradub & Boonsoong (2004), Huy (2005) (for aquatic insects).

2.5.3. Data analysis

In order to learn about the diversity level, we calculated some biodiversity indices as Shannon-Wiener Diversity index (H’), Simpson’s Diversity Index (D), Margalef's diversity index (d), Pielou's evenness index (J’).

- Shannon-Wiener index (H’): $H' = -\sum P_i \log_e P_i$, in which $P_i = N_i/N$, where N_i is the number of individuals belonging to the i^{th} species, N is the total number of all species encountered in the sample. This index is used to determine the heterogeneity of the community.

- Simpson index: $(1-\lambda') = 1 - \sum(N_i(N_i-1)/(N(N-1)))$, where N_i is the number of individuals belonging to the i^{th} species, N is the total number of all species encountered in the sample. This index is used to measure the degree of concentration when individuals are classified into types.

- Margalef's diversity index: $d = (S-1)/\log N$, where S is the total number of species and N is the total number of individuals. Margalef index is used to determine the species richness of the community.

- Pielou's evenness index: J'= H'/Log(S), where H' is Shannon-Wiener index, S is the total number of species. This index is used to assess the evenness of a community. J' is constrained between 0 and 1.

Multivariate analysis was performed to compare macrozoobenthic communities' structure between water bodies (impacted streams vs. unimpacted streams; streams inside vs. outside the caves). Abundances were Log(X+1) transformed to minimize the influence of the most dominant taxa. A non-metric multidimensional scaling (MDS) based on Bray-Curtis similarity coefficient was carried out to obtain an ordination plot. SIMPER tests were performed to determine which species contributed to within-group similarity and between-group dissimilarity. ANOSIM was used to test for statistically significant differences between groups (impacted streams vs. unimpacted streams; streams outside caves vs. streams inside caves). All analyses conducted by Primer v6.0 (Clarke and Warwick, 2006).

The metrics, such as Biological Monitoring Working Party (BMWP) – Viet, Average Score Per Taxon (ASPT) and Shannon–Wiener index (H') were used to assess the ecological quality. BMWP was set up in the UK in 1976, which result in a new system (National Water Council, 1981) generally known as the BMWP score. With the exception of Oligochaeta, this system utilizes family level data, each family is assigned a score according to its perceived susceptibility to (organic) pollution. The individual scores are summed to give a total score for the sample. A variation of the total BMWP Score is provided by dividing the score by the number of families that contribute to it, giving Average Score Per Taxon (ASPT). The $BMWP^{VIET}$ score is calculated using the score provided by Nguyen et al. (2004). This is based on the system that is routinely used in the UK but has been modified to take account of some additional families that occur in Southeast Asia but not in the UK, and also to take account of some differences that are apparent between tolerances of some families between two regions. These changes were based in part on the work done by Mustow (1997) and others, in Thailand but also on observations of family occurrences in relation to water quality in Vietnam (see reviewed in Nguyen et al., 2004).

The Total Score for a site is calculated by adding together all of the scores for individual families that are collected at the site. However, several workers, for example, Pinder and Farr (1987) and Thorne and Williams (1998), have recommended using the average score per taxon (ASPT). The ASPT is calculated by dividing the total score by the number of "scoring taxon" in the sample. $BMWP^{VIET}$ and ASPT scores and their corresponding water quality classes were shown in Table 1.

Table 1. $BMWP^{VIET}$ and ASPT scores and their corresponding water quality classes (Nguyen et al., 2004; Walley & Hawkes, 1997)

BMWP score	ASPT score	Category	Interpretation
0–10	2.9–1	Very poor	Heavily polluted
11–40	4.9–3	Poor	Polluted or impacted
41–70	5.9–5	Moderate	Moderately impacted
71–100	7.9–6	Good	Clean but slightly impacted
>100	10–8	Very good	Unpolluted, unimpacted

2.5.4. Conservation status assessment

The species considered as endemic for Vietnam with limited distribution were evaluated and categorized according to the criteria of IUCN in 2016 (Version 12). The species was evaluated into one of eight categories based on the criteria of the threat level of extinction as the rate of decline, population size, area of geographic distribution, and degree of population and distribution fragmentation. The categories are Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near threatened (NT), Less concern (LC), Data Deficient (DD) and Not Evaluated (NT) (Fig. 3, Table 2).

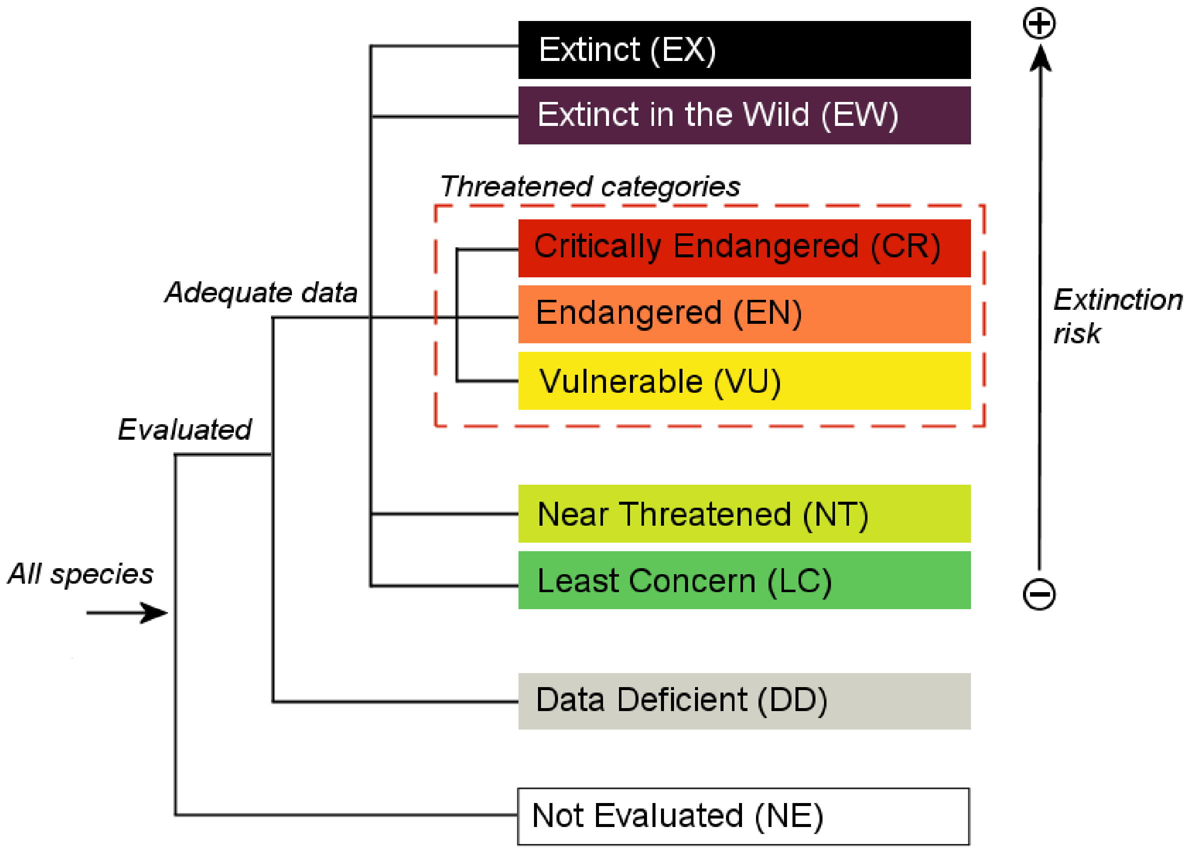

Figure 3. Structure of the IUCN Red List Categories (sources: IUCN Standards and Petitions Subcommittee. 2016. Guidelines for Using the IUCN Red List Categories and Criteria. Version 12. Prepared by the Standards and Petitions Subcommittee. Downloadable from http://www.iucnredlist.org/documents/RedListGuidelines.pdf)

Table 2. Summary of the five criteria (A-E) used to evaluate if a taxon belongs in a threatened category (Critically Endangered, Endangered or Vulnerable). Sources: IUCN Standards and Petitions Subcommittee. 2016. Guidelines for Using the IUCN Red List Categories and Criteria. Version 12. Prepared by the Standards and Petitions Subcommittee)

A. Population size reduction. Population reduction (measured over the longer of 10 years or 3 generations) based on any of A1 to A4	Critically Endangered	Endangered	Vulnerable
A1	≥ 90%	≥ 70%	≥ 50%
A2, A3 & A4	≥ 80%	≥ 50%	≥ 30%

- **A1** Population reduction observed, estimated, inferred, or suspected in the past where the causes of the reduction are clearly reversible AND understood AND have ceased.
- **A2** Population reduction observed, estimated, inferred, or suspected in the past where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.
- **A3** Population reduction projected, inferred or suspected to be met in the future (up to a maximum of 100 years) *[(a) cannot be used for A3]*.
- **A4** An observed, estimated, inferred, projected or suspected population reduction where the time period must include both the past and the future (up to a max. of 100 years in future), and where the causes of reduction may not have ceased OR may not be understood OR may not be reversible.

based on any of the following:

- (a) direct observation *[except A3]*
- (b) an index of abundance appropriate to the taxon
- (c) a decline in area of occupancy (AOO), extent of occurrence (EOO) and/or habitat quality
- (d) actual or potential levels of exploitation
- (e) effects of introduced taxa, hybridization, pathogens, pollutants, competitors or parasites.

B. Geographic range in the form of either B1 (extent of occurrence) AND/OR B2 (area of occupancy)	Critically Endangered	Endangered	Vulnerable
B1. Extent of occurrence (EOO)	< 100 km²	< 5,000 km²	< 20,000 km²
B2. Area of occupancy (AOO)	< 10 km²	< 500 km²	< 2,000 km²
AND at least 2 of the following 3 conditions:			
(a) Severely fragmented OR Number of locations	= 1	≤ 5	≤ 10
(b) Continuing decline observed, estimated, inferred or projected in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) area, extent and/or quality of habitat; (iv) number of locations or subpopulations; (v) number of mature individuals			
(c) Extreme fluctuations in any of: (i) extent of occurrence; (ii) area of occupancy; (iii) number of locations or subpopulations; (iv) number of mature individuals			

C. Small population size and decline	Critically Endangered	Endangered	Vulnerable
Number of mature individuals	< 250	< 2,500	< 10,000
AND at least one of C1 or C2			
C1. An observed, estimated or projected continuing decline of at least (up to a max. of 100 years in future):	25% in 3 years or 1 generation (whichever is longer)	20% in 5 years or 2 generations (whichever is longer)	10% in 10 years or 3 generations (whichever is longer)
C2. An observed, estimated, projected or inferred continuing decline AND at least 1 of the following 3 conditions:			
(a) (i) Number of mature individuals in each subpopulation	≤ 50	≤ 250	≤ 1,000
(ii) % of mature individuals in one subpopulation =	90–100%	95–100%	100%
(b) Extreme fluctuations in the number of mature individuals			

D. Very small or restricted population	Critically Endangered	Endangered	Vulnerable
D. Number of mature individuals	< 50	< 250	D1. < 1,000
D2. *Only applies to the VU category* Restricted area of occupancy or number of locations with a plausible future threat that could drive the taxon to CR or EX in a very short time.	-	-	D2. typically: AOO < 20 km² or number of locations ≤ 5

E. Quantitative Analysis	Critically Endangered	Endangered	Vulnerable
Indicating the probability of extinction in the wild to be:	≥ 50% in 10 years or 3 generations, whichever is longer (100 years max.)	≥ 20% in 20 years or 5 generations, whichever is longer (100 years max.)	≥ 10% in 100 years

2.6. Results

2.6.1. Species diversity and composition

We recorded 264 taxa of macroinvertebrate belonging to 3 phyla (Annelida, Arthropoda, Mollusca), 5 classes (Gastropoda, Bivalvia, Malacostraca, Insecta, Oligochaeta), 16 orders, 86 families, 192 genera from 71 survey sites (Table 3). Insecta dominated with 218 taxa, followed by Malacostraca (crabs and shrimps) with 29 species, Gastropoda (snails) with 13 species, and Bivalvia (clams) with 3 species and Oligochaeta with only 1 species. This is the first relatively complete data on macroinvertebrate diversity in these protected areas.

Thirteen shrimp species (*Macrobrachium vietnamense*, *Caridina caobangensis*, *C.* cf. *pacbo*, *C. pseudoserrata*, *C. tricincta*, *C.* sp.1, *C.* sp.2, *C.* sp.3, *C.* sp.4, C.sp.5, C. sp.6, C. sp.7, *C.* sp.8) and eight crab species (*Tiwaripotamon* sp. *Indochinamon* sp.1, *I.* sp.2, *I.* sp.3, *I.* sp.4, *I.* sp.5, *I.* sp.6, *I.* sp.7) (see Appendix 2) are considered as endemic of Vietnam. The crab and shrimp taxa have not been identified species level possibly new species. Up to now, they were only found in the limestone mountains of Northeast Vietnam. The species with the highest frequency encounter are *Procloeon* sp., *Hydropsyche* sp., *Chironomus* sp. (insect), *Neocaridina palmata* (atyid shrimp). *Pomacea canaliculata* (golden apple snail), an alien invasive species recorded in some sites of the protected areas.

Table 3. The checklist of taxon was recorded in four protected areas (BM: Bac Me NR, CC: Cham Chu NR, NXL: Nam Xuan Lac HSCA, PO: Phia Oac-Phia Den NP).

No	Taxon	BM	CC	NXL	PO
	Annelida				
	Oligochaeta				
	Not assigned				
	Not assigned				
1.	Oligochaeta	+			
	Arthropoda				
	Insecta				
	Coleoptera				
	Dytiscidae				
2.	*Laccophilus* sp.				+
	Elmidae				
3.	*Ancyronyx* sp.	+			
4.	*Cleptelmis* sp.			+	+
5.	Elmidae		+		
6.	*Lara* sp.			+	+
7.	*Macronychus* sp.	+		+	+
8.	*Microcylloepus* sp.			+	+
9.	*Neocylloepus* sp.			+	
10.	*Ordobrevia* sp.	+			+
11.	*Stenelmis* sp.				+
12.	*Zaitzevia* sp.				+
	Gyrinidae				
13.	*Dineutus* sp.				+
14.	*Dineutus* sp.			+	
15.	*Gyrinus* sp.				+
	Hydrochidae				
16.	*Hydrochus* sp.			+	
	Hydrophilidae				
17.	*Berosus* sp.			+	
18.	*Hydrobius* sp.				+
19.	*Hydrophilus* sp.			+	+
20.	*Laccobius* sp.				+
21.	*Sternolophus* sp.				+
	Psephenidae				
22.	*Acneus* sp.	+		+	
23.	*Dicranopselaphus* sp.			+	

No	Taxon	BM	CC	NXL	PO
24.	*Ectopria* sp.			+	
25.	Psephenidae	+	+		
26.	*Psephenus* sp.	+		+	+
	Ptilodactylidae				
27.	*Sternocolus* sp.				+
	Scirtidae				
28.	*Cyphon* sp.	+		+	+
29.	*Prionocyphon* sp.				+
	Staphylinidae				
30.	*Sternus* sp.				+
	Diptera				
	Athericidae				
31.	*Atherix* sp.			+	+
	Chironomidae				
32.	Chironomidae		+		
33.	*Chironomus* sp.	+		+	+
	Simuliidae				
34.	*Simulium* sp.	+		+	+
	Tabanidae				
35.	*Chrysops* sp.			+	
36.	*Tabanus* sp.			+	
	Tipulidae				
37.	*Antocha* sp.	+		+	+
38.	*Dicranota* sp.	+			+
39.	*Hexatoma* sp.	+		+	+
40.	*Limnophila* sp.				+
41.	*Tipula* sp.			+	+
42.	Tipulidae	+	+		+
	Ephemeroptera				
	Baetidae				
43.	*Acentrella* sp.			+	+
44.	Baetidae		+		
45.	*Baetiella* sp.				+
46.	*Baetis* sp.	+			+
47.	*Labiobaetis* sp.			+	
48.	*Platybaetis edmundsi* Müller-Liebenau, 1980	+			
49.	*Procloeon* sp.	+		+	+
	Caenidae				
50.	Caenidae		+		
51.	*Caenis cornigera* Kang & Yang, 1994			+	
52.	*Caenis* sp.	+		+	
	Ephemerellidae				
53.	*Crinitella coheri* (Allen & Edmunds, 1963)				+
54.	*Drunellla perculta* (Allen 1971)				+
55.	Ephemerellidae		+		
56.	*Serratella albostriata* Tong & Dudgeon, 2000	+		+	+
57.	*Torleya nepalica* Allen & Edmunds, 1963			+	
58.	*Torleya* sp.				+
	Ephemeridae				
59.	*Ephemera longiventris* Navás, 1917			+	
60.	*Ephemera serica* Eaton, 1871			+	+
61.	*Ephemera* sp.	+		+	

No	Taxon	BM	CC	NXL	PO
	Ephemeridae		+		
	Euthyplociidae				
62.	*Polyplocia orientalis* Nguyen & Bae, 2003			+	
63.	*Polyplocia* sp.			+	
	Heptageniidae				
64.	*Afronurus cervina* (Braasch & Soldán, 1984)			+	
65.	*Afronurus landai* (Braasch & Soldán, 1984)			+	
66.	*Asionurus primus* Braasch & Soldán, 1986				+
67.	*Compsoneuria thienemanni* (Ulmer, 1939)			+	+
68.	*Ecdyonurus* sp.			+	+
69.	*Epeorus aculeatus* Braasch, 1990				+
70.	*Epeorus bifurcatus* Braasch & Soldán, 1979			+	
71.	*Epeorus hieroglyphicus* Braasch & Soldán, 1984				+
72.	*Epeorus tiberius* Braasch & Soldán, 1984			+	
73.	Heptageniidae		+		
74.	*Iron martinus* Braasch & Soldán, 1984				+
75.	*Iron* sp.				+
76.	*Paegniodes dao* Nguyen & Bae, 2004			+	+
77.	*Paegniodes* sp.			+	
78.	*Rhithrogena parva* (Ulmer, 1912)			+	
79.	*Thalerosphyrus vietnamensis* (Dang, 1967)	+		+	+
	Isonychiidae				
80.	*Isonychia formosana* (Ulmer, 1912)				+
	Leptophlebiidae				
81.	*Choroterpes proba* Ulmer, 1939			+	
82.	*Choroterpes trifurcata* Ueno, 1928			+	+
83.	*Choroterpides major* Ulmer, 1939				+
84.	*Choroterpides* sp.				+
85.	*Habrophlebiodes prominens* Ulmer, 1939	+			+
86.	*Isca janiceae* Peters & Edmunds, 1970				+
87.	*Isca* sp.			+	
88.	Leptophlebiidae		+		
	Potamanthidae				
89.	*Potamanthus formosus* Eaton, 1892				+
	Vietnamellidae				
90.	*Vietnamella thani* Tshernova, 1972	+		+	+
	Hemiptera				
	Aphelocheiridae				
91.	Aphelocheiridae		+		
92.	*Aphelocheirus robustus* Nieser & Chen, 1991	+		+	
93.	*Aphelocheirus* sp.			+	+
	Corixidae				
94.	Corixidae		+		
	Gerridae				
95.	Gerridae		+		
96.	*Metrocoris* sp.	+			+
97.	*Onychotrechus* sp.	+			+
	Hebridae				
98.	Hebridae		+		
99.	*Hebrus* sp.				+
	Helotrephidae				
100.	*Placytrephes* sp.				+

No	Taxon	BM	CC	NXL	PO
101.	*Tiphotrephes* sp.				+
	Naucoridae				
102.	*Gestroiella siamensis* Polhemus, Polhemus & Sites, 2008				+
103.	*Gestroiella* sp.	+		+	
104.	*Heleocoris* sp.	+			
	Nepidae				
105.	*Cercotmetus brevipes* Montandon, 1909	+			
106.	*Cercotmetus* sp.			+	
	Notonectidae				
107.	*Enithares* sp.	+			+
	Veliidae				
108.	*Entomovella* sp.				+
109.	*Rhagovelia* sp.			+	
110.	Veliidae		+		
	Lepidoptera				
	Crambidae				
111.	*Eoophyla* sp.			+	
	Pyralidae				
112.	*Parapoynx* sp.				+
113.	*Potamomusa* sp.	+		+	
	Megaloptera				
	Corydalidae				
114.	Corydalidae		+		
115.	*Corydalus* sp.			+	+
116.	*Neochauliodes sinensis* (Walker, 1853)				+
117.	*Neochauliodes* sp.			+	
118.	*Parachauliodes* sp.			+	
119.	*Protohermes* sp.	+			
	Neuroptera				
	Neurorthidae				
120.	*Autroneurorthus* sp.				+
	Not assigned				
	Not assigned				
121.	Insecta spp.		+		+
	Odonata				
	Aeshnidae				
122.	*Aeschnophlebia* sp.	+		+	
123.	*Cephalaeschna* sp.			+	+
124.	*Planaeschna* sp.			+	+
	Calopterygidae				
125.	*Matrona* sp.			+	
126.	*Mnais* sp.				+
127.	*Neurobasis chinensis* Linnaeus, 1758	+			
128.	*Neurobasis* sp.			+	+
	Coenagrionidae				
129.	*Agriocnemis* sp.	+			
130.	*Cercion hieroglyphicum* Brauer 1865	+			
	Cordulegastridae				
131.	*Anotogaster* sp.	+		+	+
132.	*Epitheca* sp.				+
	Corduliidae				
133.	*Epophthalmia elegans* Brauer, 1865	+			

No	Taxon	BM	CC	NXL	PO
134.	*Somatochlora* sp.	+			
	Euphaeidae				
135.	*Anisopleura* sp.	+		+	+
136.	Euphaeidae		+		
	Gomphidae				
137.	*Burmagomphus* sp.	+			
138.	*Gomophidia* sp.				+
139.	Gomphidae		+		
140.	*Heliogomphus* sp.				+
141.	*Lamelligomphus* sp.			+	
142.	*Leptogomphus* sp.	+			+
143.	*Megalogomphus* sp.	+			
144.	*Melligomphus* sp.	+		+	+
145.	*Ophiogomphus* sp.			+	
146.	*Paragomphus* sp.			+	
147.	*Sinogomphus* sp.			+	+
148.	*Stylogomphus* sp.			+	+
149.	*Stylurus* sp.			+	
	Lestoideidae				
150.	*Philoganga* sp.			+	
	Libellulidae				
151.	*Lyriothemis* sp.	+			
	Macromiidae				
152.	*Macromia* sp.	+		+	+
153.	Macromiidae		+		
	Platycnemididae				
154.	*Copera* sp.			+	
	Platystictidae				
155.	*Drepanosticta* sp.			+	
156.	*Drepanosticta sundana* Krüger, 1898	+			
	Protoneuridae				
157.	*Prodasineura* sp.			+	
	Plecoptera				
	Leuctridae				
158.	Leuctridae		+		
159.	*Rhopalopsole* sp.	+		+	+
	Nemouridae				
160.	*Amphinemura* sp.				+
161.	*Nemoura* sp.			+	+
162.	Nemouridae		+		
163.	*Protonemoura* sp.				+
164.	*Sphaeronemoura* sp.				+
	Peltoperlidae				
165.	*Cryptoperla bisaeta* (Kawai, 1968)			+	+
166.	*Cryptoperla karen* Stark, 1989				+
167.	*Peltoperlopsis malickyi* Stark & Sivec, 1999				+
	Perlidae				
168.	*Acroneuria apicalis* Stark & Sivec, 2008				+
169.	*Acroneuria magnifica* Cao, T.K.T. & Bae, 2007				+
170.	*Acroneuria* sp.				+
171.	*Brahmana flavomarginata* Wu, 1962			+	+
172.	*Etrocorema nigrogeniculatum* (Enderlein, 1909)	+		+	+

No	Taxon	BM	CC	NXL	PO
173.	*Flavoperla dao* Stark & Sivec, 2008				+
174.	*Flavoperla hmong* Stark & Sivec, 2008				+
175.	*Kamimuria atra* Sivec & Stark, 2008				+
176.	*Kamimuria punctata* Sivec & Stark, 2008				+
177.	*Kamimuria* sp.				+
178.	*Neoperla hamata* Jewett, 1975				+
179.	*Neoperla melanocephala* Navás, 1931				+
180.	*Neoperla sinuata* Stark & Sivec, 2008				+
181.	*Neoperla* sp.			+	+
182.	*Neoperla yao* Stark, 1987				+
183.	*Neoperla yentu* Cao, T.K.T. & Bae, 2007				+
184.	*Neoperla zonata* Stark & Sivec, 2008				+
185.	*Neoperlops vietnamellus* Cao, T.K.T. & Bae, 2008	+		+	+
186.	Perlidae		+		
187.	*Phanoperla* sp.				+
188.	*Sinacroneuria biocellata* Stark & Sivec, 2008				+
189.	*Togoperla* sp.			+	+
190.	*Togoperla thinhi* Cao, T.K.T. & Bae, 2010				+
	Styloperlidae				
191.	*Cerconychia sapa* Stark & Sivec, 2007				+
	Trichoptera				
	Brachycentridae				
192.	*Micrasema* sp.	+		+	+
	Calamoceratidae				
193.	*Anisocentropus* sp.	+		+	+
	Chrysomelidae				
194.	*Donacia* sp.				+
	Ecnomidae				
195.	Ecnomidae		+		
	Glossosomatidae				
196.	*Glossosoma* sp.			+	+
	Helicopsychidae				
197.	*Helicopsyche* sp.				+
198.	Helicopsychidae		+		
	Hydropsychidae				
199.	*Arctopsyche* sp.	+		+	+
200.	*Cheumatopsyche* sp.	+		+	+
201.	*Hydropsyche* sp.	+		+	+
202.	*Macrosternum* sp.	+			
203.	*Parapsyche* sp.	+			+
	Hydroptilidae				
204.	*Hydroptila* sp.	+			
	Lepidostomatidae				
205.	*Lepidostoma* sp.				+
	Leptoceridae				
206.	Leptoceridae		+		
	Limnephilidae				
207.	Limnephilidae		+		
208.	*Nothopsyche* sp.			+	
	Odontoceridae				
209.	*Marilia* sp.				+
210.	Odontoceridae		+		

No	Taxon	BM	CC	NXL	PO
211.	*Psilotreta* sp.				+
	Philopotamidae				
212.	*Chimarra* sp.			+	
213.	*Wormaldia* sp.				+
	Polycentropodidae				
214.	*Neureclipsis* sp.	+			+
215.	*Polycentropus* sp.	+		+	
	Rhyacophilidae				
216.	*Rhyacophila* sp.	+			+
217.	Rhyacophilidae		+		
	Stenopsychidae				
218.	*Stenopsyche* sp.				+
	Malacostraca				
	Decapoda				
	Atyidae				
219.	*Caridina caobangensis* Li & Liang, 2002				+
220.	*Caridina cf. pacbo* Do, von Rintelen & Dang, 2020				+
221.	*Caridina lanceifrons* Yu, 1936		+	+	
222.	*Caridina macrophora* Kemp, 1918		+		
223.	*Caridina pseudoserrata* Dang & Do, 2007				+
224.	*Caridina* sp.1		+		
225.	*Caridina* sp.2		+		
226.	*Caridina* sp.3	+			
227.	*Caridina* sp.4				+
228.	*Caridina* sp.5			+	
229.	*Caridina* sp.6			+	
230.	*Caridina* sp.7			+	
231.	*Caridina* sp.8		+		
232.	*Caridna tricincta* Do, von Rintelen & Dang, 2020	+			
233.	*Neocaridina palmata* Cai, 1996	+		+	+
	Gecarcinucidae				
234.	*Somanniathelphusa pax* Ng & Kosuge, 1995		+		
235.	*Somanniathelphusa* sp.			+	
	Palaemonidae				
236.	*Macrobrachium mieni* Dang, 1975		+		
237.	*Macrobrachium vietnamense* Dang, 1972		+		
238.	*Macrobrachium yui* Holthuis, 1950	+		+	
239.	*Macrobrachium nipponense* (De Haan, 1849)	+		+	+
	Potamidae				
240.	*Indochinamon* sp.1	+	+		
241.	*Indochinamon* sp.2		+		
242.	*Indochinamon* sp.3	+			
243.	*Indochinamon* sp.4				+
244.	*Indochinamon* sp.5				+
245.	*Indochinamon* sp.6			+	
246.	*Indochinamon* sp.7			+	
247.	*Tiwaripotamon* sp.		+		
	Mollusca				
	Bivalvia				
	Venerida				
	Cyrenidae				
248.	*Corbicula cyreniformis* Prime, 1860		+		

No	Taxon	BM	CC	NXL	PO
249.	*Corbicula lamarckiana* Prime, 1867		+		
250.	*Corbicula* sp.	+	+	+	+
	Gastropoda				
	Architaenioglossa				
	Ampullariidae				
251.	*Pomacea canaliculata* (Lamarck, 1819)	+	+		
	Viviparidae				
252.	*Angulyagra polyzonata* (Frauenfeld, 1862)	+	+	+	
253.	*Cipangopaludina leucythoides* (Benson, 1856)			+	
254.	*Sinotaia aeruginosa* (Reeve, 1863)	+	+		
	Littorinimorpha				
	Pomatiopsidae				
255.	*Vietricula pioacensis* Dang & Ho, 2011				+
	Stenothyridae				
256.	*Stenothyra messageri* Bavey & Dautzenberg, 1899		+		
	Not assigned				
	Lymnaeidae				
257.	*Orientogalba viridis* (Quoy & Gaimard, 1833)	+	+	+	+
	Planorbidae				
258.	*Gyraulus convexiusculus* (Hutton, 1849)	+	+	+	+
259.	**Sorbeoconcha**				
	Pachychilidae				
260.	*Sulcospira tonkiniana* (Morlet, 1887)		+	+	+
	Semisulcospiridae				
261.	*Hua jacqueti* (Dautzenberg & Fischer, 1906)	+	+		
	Thiaridae				
262.	*Melanoides tuberculata* (Müller, 1774)	+	+	+	
263.	*Tarebia granifera* (Lamarck, 1816)		+	+	
264.	*Mieniplotia scabra* (Müller, 1774)		+		
	Total taxa	**76**	**54**	**112**	**142**

2.6.2. Species richness, abundance, biodiversity indices and community structure

a) Species richness, abundance, biodiversity indices

- The results from quantitative sites showed that the average species richness of macroinvertebrate ranged from 2 species (PO8) to 16 species (PO10). The average abundance of macroinvertebrate ranged from 33 ind.m^{-2} (PO14) to 726 ind.m^{-2} (BM13). The average of Shannon-Wiener index (H') displayed from 0.33 (PO8) to 2.59 (PO10) (Table 4). In Nam Xuan Lac, several resampled sites showed that the abundance and species richness in the dry season sites were higher compared to the rainy season (214 ind.m^{-2} vs. 183 ind.m^{-2}, 11 species vs. 9 species, respectively) (Table 4).

Table 4. Species richness, individual/m^{-2} (N), and diversity indices: Margalef's (d), Pielou's evenness (J'), Shannon-Wiener (H'), Simpson (1-λ') in some survey sites

Sites	S	N	d	J'	H'(loge)	(1-λ')
BM6	10	296	1.52	0.89	1.91	0.82
BM7	9	211	1.44	0.95	1.91	0.84
BM8	4	152	0.68	0.93	1.37	0.73
BM9	7	633	0.86	0.43	0.87	0.41

Sites	S	N	d	J'	H'(loge)	(1-λ')
BM11	5	563	0.65	0.44	0.70	0.33
BM12	6	189	1.02	0.79	1.44	0.67
BM13	10	726	1.37	0.48	1.09	0.45
BM14	10	552	1.48	0.87	1.97	0.83
CC9	5	252	0.73	0.86	1.28	0.68
CC10	7	148	1.09	0.93	1.55	0.71
NXL2_R	10	278	1.51	0.90	2.02	0.84
NXL3_D	13	219	2.17	0.91	2.30	0.86
NXL3_R	7	107	1.27	0.94	1.75	0.78
NXL4_D	9	181	1.53	0.87	1.89	0.79
NXL4_R	7	137	1.22	0.91	1.75	0.79
NXL5_D	11	194	1.90	0.95	2.27	0.89
NXL5_R	6	156	0.99	0.84	1.49	0.70
NXL7_R	11	206	1.89	0.92	2.21	0.87
NXL8_R	10	159	1.71	0.94	2.14	0.87
NXL9_R	11	241	1.82	0.92	2.17	0.86
NXL10_D	12	263	1.92	0.92	2.18	0.87
PO2	8	311	1.23	0.73	1.49	0.66
PO3	6	93	1.18	0.97	1.77	0.83
PO4	7	211	1.09	0.93	1.64	0.79
PO5	12	304	1.99	0.89	2.18	0.85
PO6	6	193	0.90	0.80	1.38	0.68
PO7	4	137	0.63	0.76	1.03	0.55
PO8	2	63	0.20	0.71	0.33	0.17
PO9	9	204	1.50	0.88	1.74	0.71
PO10	16	370	2.59	0.93	2.59	0.91
PO13	5	78	0.99	0.95	1.57	0.77
PO14	3	33	0.46	0.99	0.91	0.59

b) Community structure

- In Cham Chu NR, the MDS stress level (<0.1) corresponded to a good ordination without a misleading interpretation. The ANOSIM test showed significant differences in faunistic composition between groups ($R = 1$, $p = 0.005$). At 50 % similarity level, a MDS plot showed a separation among four groups of second survey sites in Cham Chu PA corresponding to different macroinvertebrate assemblages (Fig. 4). The first group (Group 1) clustered two sites (CĐ1=CC9 and CĐ2=CC10) sampled in the natural forests with almost unimpacted. This group was characterized by numerical dominance and major contribution of a small shrimp family (Atyidae) as *Caridina* sp.2, *C. lanceifrons* (SIMPER test). The second (CĐ3=CC11) (Group 2) and the third groups (CĐ4=CC12) (Group 3) sampled in the streams near the rice fields showed from slightly to moderated impacted, respectively. These groups are particularly characterized by a high abundance of snails as *Melanoides tuberculate* and *Hua jacqueti*. The species *M. tuberculate* can be tolerated the polluted environment. The last group included the streams in the caves (CĐ5=CC14, CĐ6=CC15, CĐ7=CC16) (Group 4). Only three species of macroinvertebrate were found in here (*Indochinamon* sp.1 (crab), *Caridina* sp.2 and *Macrobrachium* sp. (shrimp)). These species also distribute in the streams outside of the caves. Our results displayed the differences between the macroinvertebrate communities in impacted with unimpacted areas and between outside and inside of the caves in terms of species composition and abundance.

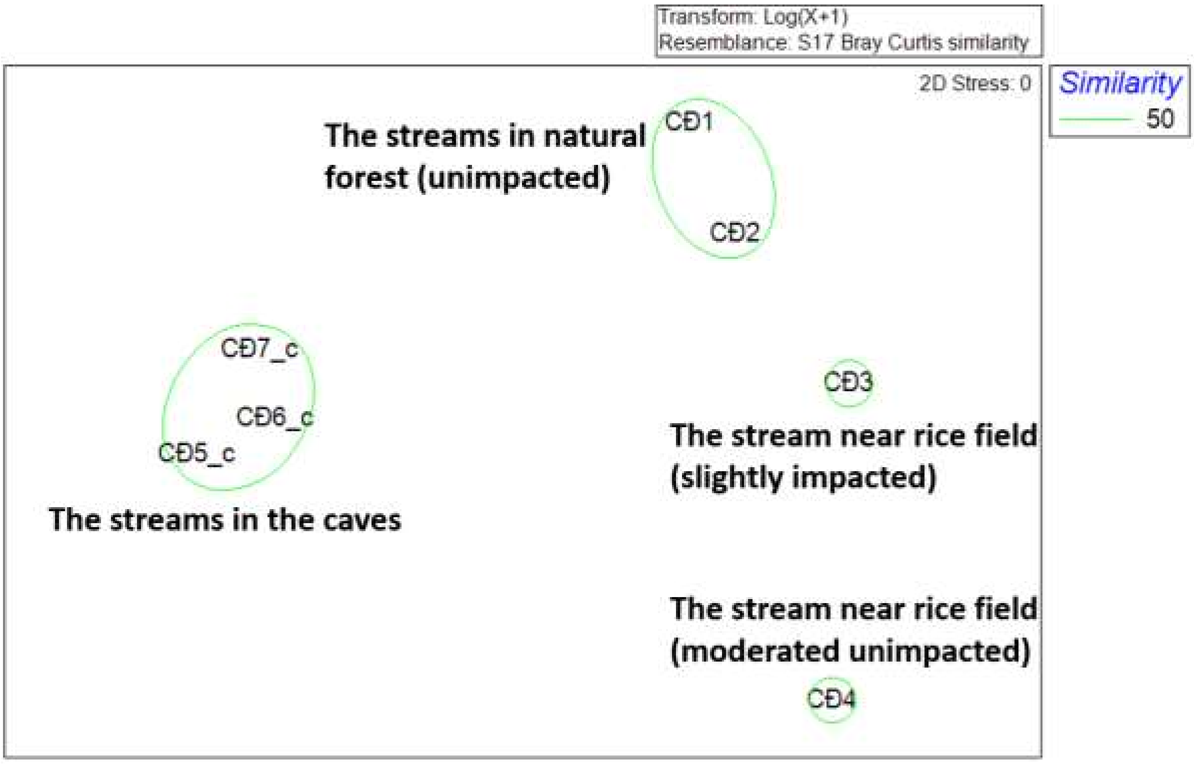

Figure 4. Non-metric macroinvertebrate assemblages multidimensional scaling (MDS) of sites (in Cham Chu NR) based on the Bray–Curtis similarity matrix on log10(x+1)-transformed abundance data and gathered at 50 % similarity level

- In Bac Me NR, The MDS stress level (<0.1) corresponded to a good ordination without a misleading interpretation. The ANOSIM test showed significant differences in faunistic composition between groups (R = 0.8, p = 0.02). At 30 % similarity level, the MDS plot showed a separation among two main groups second survey sites in Bac Me NR corresponding to different macroinvertebrate assemblages (Fig. 5). The first group (Group 1) clustered three sites (LN1=BM9, LC1=BM11, LC2=BM13) sampled nearby the natural forests with almost no significant impact. This group was characterized by numerical dominance and major contribution of a small shrimp family (Atyidae) as *Neocaridina palmata* and aquatic insect (*Thalerosphyrus vietnamensis*) (SIMPER test). Noteworthy, *Chironomus* sp., an indicator of organic pollution also was quite dominant in this group. One of the possible reasons for this is that these sites are located not far from residential or agricultural areas. The second including four sites LN4=BM14, MS1=BM6, MS2=BM7, MS3=BM8 sampled in the streams near the rice or corn fields showed from slightly to moderated impacted. These groups are particularly characterized by a high abundance of *Chironomus* sp.. This species can be tolerated in the polluted environment. The last group included only one site (LC1=BM11) (Group 3). This site characterized by the dominant of atyid shrimp (*Neocaridina palmata*) and two unique species (*Ancyronyx* sp., *Corbicula* sp.) compared to other sites such as. This site has a relatively large slope, large flow rate, boulder bottom. That may explain the difference of the benthic community here. Therefore, our results displayed the differences between the macroinvertebrate communities in minor impacted with unimpacted areas in terms of species composition and abundance.

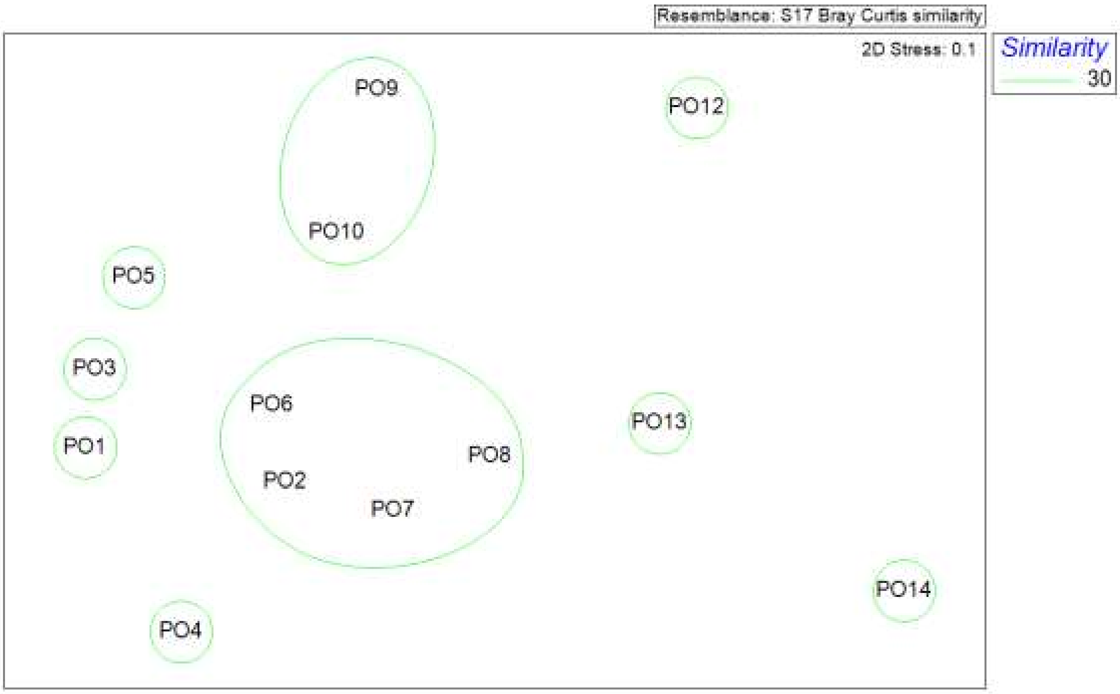

Figure 5. Non-metric macroinvertebrate assemblages multidimensional scaling (MDS) of sites (in Bac Me NR) based on the Bray–Curtis similarity matrix on log10(x+1)-transformed abundance data and gathered at 40 % similarity level

- In Nam Xuan Lac HSCA and Phia Oac-Phia Den NP, the MDS stress level (>0.1) corresponded to a not good ordination. It means that it is very heterogeneity between the macroinvertebrate assemblages in the survey sites.

2.6.3. Endangered species and species of conservation value

Among the species recorded in the study area, thirteen shrimp species (*Macrobrachium vietnamense*, *Caridina caobangensis*, *C.* cf. *pacbo*, *C. pseudoserrata*, *C. tricincta*, *C.* sp.1, *C.* sp.2, *C.* sp.3, *C.* sp.4, C.sp.5, C. sp.6, C. sp.7, *C.* sp.8) and eight crab species (*Tiwaripotamon* sp. *Indochinamon* sp.1, *I.* sp.2, *I.* sp.3, *I.* sp.4, *I.* sp.5, *I.* sp.6, *I.* sp.7), accounting for 8% of the total recorded species, are considered endemic to limestone areas in northeastern Vietnam. Especially, *Caridna tricincta* only recorded at Du Gia-Bac Me NP and Na Hang NR. These species have an estimated extent of occurrence less than 20000 km^2. The area of natural forests has been significantly reduced in Vietnam since the end of the war, accompanied by a decline in forest quality. The shrinking and degradation of habitats have been able to lead to the disappearance of many aquatic species. Increasing conversion of forest area to agricultural land, along with environmental pollution (using pesticides in agriculture, mining, etc.) is making the population of these species declining. The pressure to exploit natural resources is increasing and there is no evidence to show that this decline will stop. According to the IUCN 2021 criteria, these species are at least assessed as Vulnerable (VU). Any species with a limited distribution range are in danger of being threatened by fragmentation of the population caused by land use change. These shrimp and crab species can decline very quickly and even become extinct in a short time. Therefore, they need to be prioritized for conservation. Other macroinvertebrate species can be considered as Least Concerned as their distribution are quite wide.

2.6.4. Species newly witnessed in the study areas

Eight shrimp species of *Caridina* genus (Atyidae) and seven crab species of *Indochinamon* genus (Potamidae) as mentioned before are possible new species. We are continuing to analyze the morphological characteristics and possibly combine molecular analysis to describe these species.

2.6.5. Biotic indices and water quality

In general, $BMWP^{VIET}$ and ASPT indices are good indicators for water quality. They displayed the impact of agriculture and deforestation on biodiversity and water quality in the streams nearby the agricultural areas.

- In Bac Me NR: $BMWP^{VIET}$ scores indicated a very good, good or moderate water quality from the sites considered as slightly impacted or impacted. ASPT seems to be a better indicator when showed almost (3 per four sites) impacted sites as moderated impacted and only one slightly impacted site (BM11) identified as moderated impacted (Table 4).

- In Cham Chu NR: $BMWP^{VIET}$ scores are larger than 100 in CC9 and CC10 indicates a very good water quality of small streams in the natural forests. However, in the streams are nearby the rice fields (CC11 and CC12) BMWP scores are from 82 to 86 shows a slight impact on water quality. ASPT shows from good (slightly impacted) in CC9, CC10 and CC11 sites to moderate water quality (moderately impacted) in CC12 sites (Table 4).

- In Nam Xuan Lac HSCA: $BMWP^{VIET}$ scores indicated from polluted or impacted to very good water quality. Two sites (NXL1, NXL6) displayed polluted or impacted to moderated water quality located in the areas affected by agriculture and waste from human activities. ASPT also showed four sites as moderated impacted (NXL1, NXL5, NXL6, NXL7, NXL10) (Table 4).

- In Phia Oac-Phia Den NP: $BMWP^{VIET}$ scores indicated a moderate or polluted water quality from the sites considered as impacted (PO6, PO7, PO8, P12). Two sites as PO13, PO14 displayed moderated impact are the forests dominated by only bamboo trees. ASPT also showed almost (3 per 5 sites) impacted sites as moderated impacted (PO6, PO7, PO8) (Table 4).

Table 4. $BMWP^{VIET}$ and ASPT scores in some survey sites and their corresponding water quality classes

Sites	$BMWP^{VIET}$	Water quality	ASPT	Water quality
BM6	77	Good	5	Moderate
BM7	127	Very good	6	Good
BM8	58	Moderate	5	Moderate
BM9	68	Moderate	6	Good
BM11	65	Moderate	5	Moderate
BM12	93	Good	6	Good

BM13	136	Very good	6	Good
BM14	116	Very good	5	Moderate
CC9	100	Very good	7.1	Good
CC10	101	Very good	6.7	Good
CC11	86	Good	6.1	Good
CC12	82	Good	5.9	Moderate
NXL1	31	Poor	4.4	Poor
NXL2	97	Good	6.9	Good
NXL3	221	Very good	6.9	Good
NXL4	159	Very good	6.4	Good
NXL5	106	Very good	5.9	Moderate
NXL6	47	Moderate	4.7	Poor
NXL7	142	Very good	5.7	Moderate
NXL8	104	Very good	6.5	Good
NXL9	121	Very good	6.1	Good
NXL10	138	Very good	5.8	Moderate
PO1	162	Very good	6.2	Good
PO2	96	Good	6.0	Good
PO3	136	Very good	6.8	Good
PO4	156	Very good	6.5	Good
PO5	161	Very good	6.0	Good
PO6	37	Poor	5.3	Moderate
PO7	52	Moderate	5.2	Moderate
PO8	37	Poor	5.3	Moderate
PO9	145	Very good	7.3	Good
PO10	167	Very good	6.4	Good
PO12	59	Moderate	6.6	Good
PO13	65	Moderate	5.9	Moderate
PO14	43	Moderate	6.1	Good

2.6.6. Natural and socio-economic context and main human impacts/threats on biological group

The mountainous areas of northern Vietnam are home to many ethnic minority groups. The economy here is still very underdeveloped, along with backward agricultural farming. The lives of local people mainly depend on the exploitation of forest resources. Shrimp, crab, mussels, snails, mussels along with fish are aquatic resources that are still exploited for daily food or sold in markets. They can be considered an important source of livelihood as well as contribute to ensuring food security for this area.

2.7 Discussion

With 264 taxa have been recorded and many endemic species have been recorded, our study shows a high level of diversity and endemism in the diversity of limestone regions in Vietnam. Karst areas have formed “islands within islands,” and these are known to contain high levels of endemism (Clements et al., 2006).

Faunistically, northern Vietnam is a transition zone between the Palearctic fauna of

Mainland China, and the South East Asiatic fauna in Indochina, and extending all the way South to Malaysia and Indonesia. Such transition zones are often rich in species and endemics, and northern Vietnam is no exception to this. Its humid climate and varied topography and geology have added to the local wealth of biodiversity (Vermeulen & Maassen, 2003, unpublished report).

The number of species assessed as threatened with extinction in these limestone karsts area is very high, around 8% of total recorded species. Small streams and caves in the forests of the protected areas, habitats of the endemic and endangered species, are the high priority areas for conservation.

The ecosystem health of the protected areas is declining by the encroachment of forest land for cultivation, grazing cattle, mining, infrastructure and residential development, electrofishing and invasive species. Besides, local people polluted water sources by widely using pesticides and herbicide in agriculture. Research by Lam et al. (2017) in Minh Son commune, Bac Me district has shown the negative impact on the environment of mineral mining activities. They have destroyed the natural landscape, caused significant losses to forest resources, and gradually lost biodiversity.

Our results displayed the differences between the macroinvertebrate communities in impacted with unimpacted areas in terms of species composition and abundance. Each water bodies such as streams in natural forests, streams nearby rice and corn fields or residential areas are characterized by different macroinvertebrate assemblages. The sites considered as impacted showed low water quality. The species which indicators for organic pollution such as *Chironomus* sp., Oligochaeta, *Procloeon* sp., *Pomacea canaliculate*, *Orientogalba viridis*, *Gyraulus convexiusculus*, *Melanoides tuberculate*, *Plotia scabra*, *Tarebia granifera* presented in large numbers in the impacted sites. Subsequently, our results showed that the ecology status of these sites was impacted by human activities.

Introduction of the golden apple snail (*Pomacea* spp.) around early 1985 to 1988 to Vietnam was followed by their rapid range expansion and development as invasive agricultural pests, especially in wetland ecosystems, vegetables and other aquatic crops. The invasion of these species has caused significant economic and ecological damage (Do et al, 2018). Another alien invasive species, the Nile tilapia (*Oreochromis niloticus*) was observed as the most dominant species in several streams in Bac Me NR, Cham Chu RN and Nam Xuan Lac HSCA.

Macroinvertebrate with insects, crabs, shrimps and molluscs have a vital role in the freshwater ecosystems and the daily lives of Vietnamese, especially in the mountain area as Cham Chu, Bac Me, Nam Xuan Lac and Phia Oac-Phia Den. The poverty rate in this area and in Vietnam is still very high. The lives of poor people often depend primarily on the exploitation of the natural resources available around them including crabs, shrimps and molluscs. Therefore, if we have a better understanding, better conservation of biodiversity and rational exploitation, we will help to reduce poverty in our country.

In addition, freshwater crabs and snails are also medically important as intermediate hosts of parasites, particularly trematodes or "flukes" such as paragonimiasis. The fact that paragonimiasis is a food-borne zoonosis indicates that freshwater crabs are widely consumed by humans, which is under-lined by the more than 20 million people infected worldwide by one of the 15 species of lung flukes of the genus. There are also studies on parasites of freshwater crabs and snail in rural and mountainous areas of Vietnam (Doanh et al., 2011, Doanh et al., 2018, Dung et al., 2010). Many mountainous ethnic people in Vietnam are infected with dangerous parasites by eating uncooked crabs and snails. Communication to raise awareness for people on this issue is also very necessary. The correct identification of crabs and snail is basic for parasitology in macroinvertebrate group.

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3 Empowerment of young scientists

3.1 Guiding principles for education and training

The group leader and the key researchers guided and trained young scientists (assistants) in the field and lab work. In the field, the young scientists were trained in the survey techniques such as collecting samples. In the lab, they were learned about sorting samples, identifying the species and guided in and writing a scientific paper.

They showed progress as they can conduct the fieldwork independently, identified some common species, and write simple scientific papers. Especially, they were happy to work on the team.

3.2 Achievement of each young scientist

Listing all products and results realized by research assistants and/or young scientist during the time of project implementation and assessment of their progress

One of PhD student (Mss. Phan Thi Yen) of the key researcher, although not involved in the project from the beginning, was able to participate in a survey in Nam Xuan Lac NR. This PhD student also received training in biodiversity research methods and specimen analysis within the framework of the project activities.

4 Appendix

Appendix 1. The survey date, name and coordinate of the survey sites

Cham Chu NR

CC1

25/08/2018

Nậm Lương stream 1

N 22°12' 37.097" E 105°03'38.52"

CC2

26/10/2018

Stream in Lò Mốc cave

N 22°13'28.90" E 105°02'58.51"

CC3

27/07/2018

Nậm Lương stream (behind the Nậm Lương)

N 22°12' 40.09" E 105°02'59.00"

CC4

27/07/2018

Quang Tiên stream (near the water fall)

N 22°12'37.75" E 105°04'04.51"

CC5

28/10/2018

Khang stream 1, Minh Dân commune

N 22°10'22.40" E 105°00'26.13"

CC6

28/10/2018

Kiêng stream, Phù Lưu commune

N 22°10'15.31" E 105°00'45.69"

CC7

29/10/2018

Nậm Lương stream 2

N 22°12'36.84" E 105°03'28.07"

CC8

30/10/2018

Khang stream 2, Minh Dân commune

N 22°10’05.23” E 104°59’29.15”

CC9

13/04/2019

A stream in the forest, Cao Đường, Yên Thuận commune

N 22°15’23.1” E 104°59’22.7”

CC10

14/04/2019

Thật Thà stream, Cao Đường, Yên Thuận commune

N 22°19’13.4” E 104°58’46”

CC11

14/04/2019

A stream near rice field, Cao Đường, Yên Thuận commune

N 22°19’5.4” E 104°58’39”

CC12

15/04/2019

A stream near rice field, near Cao Đường forest ranger camp, Cao Đường, Yên Thuận commune

N 22°17’54.4” E 104°59’40”

CC13

4/14/2019

Lam village, Vô Điếm commune, Bắc Quang district, Hà Giang province

N 22°19’17.634” E 104°58’8.928”

CC14

16/04/2019

A cave near Bai Tro, Cao Đường village, Yên Thuận commune

N 22°17'09.6" E 104°59'13.2"

CC15

17/04/2019

A cave near Cao Đường central (small), Cao Đường village, Yên Thuận commune

N 22°17'36.6" E 104°59'31.6"

CC16

17/04/2019

A cave near Cao Đường central (near rice field), Cao Đường village, Yên Thuận commune

N 22°17’56.0” E 104°59’39.21”

CC17

16/04/2019

A trail near Cao Đường central

N 22°17’56.754” E 104°59’49.511”

Bac Me NR

BM1

25/5/2019

A stream in Lung Cang village, Minh Ngoc commune

N 22°42'58.176" E 105°11'18.780"

BM2

26/5/2019

A stream in Khuay Nang village, Thuong Tan commune

N 22°41'4.547" E 105°15'41.244"

BM3

26/5/2019

A cave in Ta Luong village, Thuong Tan commune (near boat station)

N 22°43'12.107" E 105°13'45.906"

BM4

27/5/2019

A stream near headquarter of Bac Me-Du Gia PA, Ngoc Chi village, Minh Son commune

N 22°48'45.881" E 105°12'19.973"

BM5

28/5/2019

Thau stream, Minh Son commune

N 22°50'7.584" E 105°12'12.150"

BM6

15/10/2019

A stream near the bridge, near the headquater of Bac Me-Du Gia PA, Minh Son commune

N 22°49'14.754" E 105°12'6.359"

BM7

15/10/2019

A stream in Binh Ba, Minh Son commune

N 22°49'53.255" E 105°11'4.223"

A stream in Ngoc Chi, Minh Son commune, near the corn field

N 22°48'47.004" E 105°12'19.271"

BM8

15/10/2019

A stream in Ngoc Chi, Minh Son commune, near the corn field

N 22°48'47.004" E 105°12'19.271"

BM9

16/10/2019

A small stream in Lac Nong commune

N 22°44'18.635" E 105°15'37.397"

BM10

16/10/2019

A very small stream in Lac Nong commune

N 22°44'24.894" E 105°14'9.989"

BM11

17/10/2019

A stream in Lung Cang village, Minh Ngoc commune

N 22°43'2.483" E 105°11'12.978"

BM12

17/10/2019

A stream in Lung Cang village, Minh Ngoc commune

N 22°42'58.596" E 105°11'20.634"

BM13

17/10/2019

A stream in Lung Cang village, Minh Ngoc commune

N 22°42'48.551" E 105°11'17.700"

BM14

18/10/2019

A stream in Khen village, Lac Nong commune

N 22°45'20.525" E 105°14'45.342"

Phia Oac-Phia Den NP

PO1

21/5/2020
A stream in Phia Oac, Phan Thanh
N 22°35'30" E 105°51'19"
PO2

21/5/2020
A stream in Phia Oac, Phan Thanh
N 22°35'33" E 105°51'17"
PO3

21/5/2020
A stream near the bridge, Phia Oac
N 22°35'09" E 105°52'02"
PO4

22/5/2020
A stream near the old French house (on the way to the top), Phia Oac, Thanh Cong
N 22°36'30" E 105°52'13"
PO5

22/5/2020
A stream near the main road, Phia Oac
N 22°37'17" E 105°52'35"
PO6

22/5/2020
A stream in The Duc
N 22°39'11" E 105°55'22"
PO7

22/5/2008
A small stream in The Duc
N 22°39'08" E 105°55'23"
22/5/2012
A small stream in The Duc
N 22°39'08" E 105°55'23"
22/5/2016
A small stream in The Duc
N 22°39'08" E 105°55'23"
22/5/2020
A small stream in The Duc
N 22°39'08" E 105°55'23"
22/5/2021
A small stream in The Duc
N 22°39'08" E 105°55'23"
22/5/2022
A small stream in The Duc
N 22°39'08" E 105°55'23"
22/5/2023
A small stream in The Duc
N 22°39'08" E 105°55'23"
22/5/2024
A small stream in The Duc
N 22°39'08" E 105°55'23"
PO8

23/5/2020
A stream near Nam Toong bridge, Thanh Cong
N 22°32'38" E 105°51'41"

PO9

24/5/2020
A stream in Hoai Khao, Quang Thanh
N 22°34'44" E 105°55'25"

PO10

24/5/2020
A stream near the road, Thanh Cong
N 22°32'52" E 105°54'03"

PO11

25/5/2020
A very small stream in Phan Thanh
N 22°38'18" E 105°50'26"

PO12

25/5/2020
A stream near the road, Tinh Tuc
N 22°39'32" E 105°52'49"

PO13

25/5/2020
A very small stream run in bambo forest, Thanh Cong
N 22°35'39" E 105°53'08"

PO14

25/5/2020
A very small stream (higher) run in bambo forest, Thanh Cong
N 22°35'43" E 105°52'59"

PO15

5/10/2020
A small stream near the road
N 22°38'16.626" E 105°58'32.135"

PO16

5/10/2020
A stream near the road, Tam Kim
N 22°37'4.956" E 106°0'21.216"

PO17

6/10/2020
A small tream near the road, Quang Thanh
N 22°36'48.570" E 105°56'22.824"

PO18

7/10/2020
A small stream from Ong cave, Quang Thanh
N 22°34'35.316" E 105°55'25.998"

PO19

7/10/2020
A small stream near Ong cave, Quang Thanh
N 22°34'38.694" E 105°55'24.222"

PO2_October

6/10/2020

A stream in Phia Oac, Phan Thanh

N 22°35'33" E 105°51'17"

PO20

8/10/2020

A big stream in Tam Kim, Tam Kim

N 22°36'38.604" E 105°59'30.233"

PO21

8/10/2020

A small stream run through rice field in Tam Kim

N 22°36'54.240" E 106°0'10.320"

PO22

8/10/2020

A very small stream in Tam Kim, Tam Kim

N 22°34'53.207" E 106°1'46.368"

PO23

8/10/2020

A well where small tream run into, in Tran Hung Dao forest, Tam Kim

N 22°35'37.902" E 106°2'35.897"

PO24

8/10/2020

A small tream near the road

Nam Xuan Lac HSCA

N 22°38'20.820" E 105°58'33.318"

NXL1

24/7/2020

A small swamp in Phja Khao, Ban Thi

N 22°17'35.292" E 105°31'2.717"

NXL2

24/7/2020

A stream in Hop Tien, Ban Thi

N 22°14'7.638" E 105°30'38.507"

NXL3

24/4/2021

A stream in Khuoi Ken, Ban Thi

N 22°16'45.210" E 105°28'49.884"

25/7/2020

A stream in Khuoi Ken, Ban Thi

N 22°16'45.210" E 105°28'49.884"

NXL4

24/4/2021

A stream near the Khuoi Ken jounior scholl, Ban Thi

N 22°16'13.949" E 105°29'3.690"

25/7/2020

A stream near the Khuoi Ken jounior scholl, Ban Thi

N 22°16'13.949" E 105°29'3.690"

NXL5

25/4/2021

A stream in Keo Lang, Ban Thi

N 22°15'24" E 105°29'13"

25/7/2020
A stream in Keo Lang, Ban Thi
N 22°15'24" E 105°29'13"

NXL6

26/7/2020
A stream in front of Nam Xuan Lac Protected Area, Ban Nhuong, Ban Thi
N 22°12'58.271" E 105°29'26.429"

NXL7

27/7/2020
A stream in Ban Khang, Na Da, Xuan Lac
N 22°20'37.115" E 105°33'0.972"

NXL8

28/7/2020
A stream in Nam Phieng, Xuan Lac
N 22°18'23.1839" E 105°29'31.818"

NXL9

28/7/2020
A stream near the bridge of Xuan Lac
N 22°19'42.623" E 105°31'29.957"

NH1

25/7/2020
Son Phu, Na Hang, Tuyen Quang
N 22°17'33.149" E 105°28'19.434"

NXL10

26/4/2021
A stream in Ta Vao, Na Ang, Dong Lac
N 22°17'36.720" E 105°33'26.244"

29/7/2020
A stream in Ta Vao, Na Ang, Dong Lac
N 22°17'36.720" E 105°33'26.244"

NXL11

27/4/2021
A small cave in Ta Vao, Na Ang, Dong Lac
(blank)

NXL12

27/4/2021
A cave in Ta Vao, Na Ang, Dong Lac
N 22°17'35.376" E 105°33'24.912"

NXL13

24/7/2020
A cave in Phja Khao, Ban Thi
N 22°17'38.610" E 105°31'4.007"

NXL14

28/7/2020
A small stream in Nam Phieng, Xuan Lac
N 22°18'33.864" E 105°29'51.809"

NXL15

28/7/2020
A stream in Nam Phieng (near Nhu's camp), Xuan Lac

N 22°19'4.380" E 105°30'32.837"

Appendix 2. The photos of some crabs and shrimps considered as endemic species. The crab and shrimp taxa have not been identified species level possibly new species.

Caridina sp.2 in Cao Duong village, Cham Chu NR

Caridina tricincta in Lac Nong commune, Du Gia-Bac Me NP

Caridina cf. *pabo* in Tran Hung Dao forest, Phia Oac-Phia Den NP

Caridina sp.6 in Nam Phieng, Xuan Lac commune, Nam Xuan Lac HSCA

Caridina sp.7 in Nam Phieng, Xuan Lac commune, Nam Xuan Lac HSCA

Caridina sp.4 in Quang Thanh commune, Phia Oac-Phia Den NP

Macrobrachium vietnamense in Cao Duong village, Yen Thuan commune, Cham NR

Indochinamon sp.2 in Cao Duong village, Yen Thuan commune, Cham Chu NR

Indochinamon sp.1 in Cao Duong village, Cham Chu NR

Tiwaripotamon sp. in Cao Duong village, Cham Chu NR

Indochinamon sp.1 in Lac Nong commune, Bac Me NR

Indochinamon sp.2 in Lac Nong commune, Bac Me NR

Indochinamon sp.4 in Phia Oac, Phan Thanh commune, Phia Oac-Phia Den NP

Indochinamon sp.5 in Thanh Cong commune, Phia Oac-Phia Den NP

Indochinamon sp.6 in Khuoi Ken commune, Phan Thanh commune, Nam Xuan Lac HSCA

Indochinamon sp.7, Nam Xuan Lac HSCA

Appendix 3. Some photos show the impact of human activities on the protected areas

Local people cut the forest for rice culture in Thuong Tan commune, Bac Me NR

The forests were destroyed for agriculture in Bac Me NR

A rice field in Cao Duong village, nearby the core zone of Cham Chu NR

A corn field in the Cao Duong village, inside the core zone of Cham Chu NR

The forests were replaced by cornfields in Phja Khao, Ban Thi commune (NXL1), Nam Xuan Lac HSCA

The forests were destroyed for agriculture rice field in Xuan Lac commune, Nam Xuan Lac HSCA

Road expanding in Ban Nhuong, Ban Thi commune, Nam Xuan Lac HSCA

The polluted water from the residential area running into the stream in Hop Tien, Ban Thi commune, Nam Xuan Lac HSCA

The corn field in The Duc commune (PO6), Phia Oac-Phia Den NP

The forests were destroyed for agriculture in Thanh Cong commune (PO8), Phia Oac-Phia Den NP

Deforestation for the terraces in Vu Nong commune, Phia Oac-Phia Den NP

Mining area in Vu Nong commune, Phia Oac-Phia Den NP