



## Water bugs (Hemiptera) and water beetles (Coleoptera) across different ecosystems in U Minh Thuong and Phu Quoc National Parks, Vietnam

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### Abstract

In this study, the diversity index and relationships of water bugs (Hemiptera) and water beetles (Coleoptera) in ecosystem of agroforestry-aquaculture in the buffer zone in U Minh Thuong and Phu Quoc National Parks (EAAB), ecosystem of melaleuca swamp forest on peat layer at U Minh Thuong National Park (EMSF), and ecosystem of acid-sulphate water forest at Phu Quoc National Park (EAWF) were studied and evaluated. From 12 sampling sites of three ecosystems in U Minh Thuong and Phu Quoc National Parks were collected 577 individuals of the water bugs and water beetles representing 40 species of 27 genera of 11 families.

The number of species in the family Nepidae, Naucoridae, Gerridae (Hemiptera), Dytiscidae, Hydrophilidae (Coleoptera) were highest in ecosystem of agroforestry-aquaculture in the buffer zone in U Minh Thuong and Phu Quoc National Parks. The diversity index (Dominance\_D, Simpson\_1-D, Shannon\_H, Evenness\_e<sup>H/S</sup>, Brillouin, Menhinick, Margalef, Equitability\_J, Fisher\_alpha, Berger-Parker, Chao-1) and species richness have value in EAAB > EMSF > EAWF. EAAB showed the highest alpha diversity, EMSF moderate, and EAWF the lowest. Community similarity was highest between EAAB and EMSF, and much lower between EAAB–EAWF and EMSF–EAWF. Evenness analysis separated EAAB into its own cluster, while EMSF and EAWF grouped together. Synchrony between water bugs and water beetles was strongest in the more stable EAAB–EMSF ecosystems and weakest in the environmentally stressed EAAB–EAWF and EMSF–EAWF pairs.

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### Introduction

The high abundance of aquatic insects in the orders Hemiptera and Coleoptera, along with their sensitivity to environmental change, makes them key indicators for assessing the impacts of human activities on water quality (Adu & Oyeniyi, 2019) <sup>[2]</sup>. These insects are widely used in the monitoring of freshwater ecosystems (Souto *et al.*, 2019) <sup>[36]</sup>. Aquatic insects constitute an integral component of aquatic and wetland ecosystems, serving as indicators of ecological diversity and habitat conditions (Khaghani *et al.*, 2021) <sup>[26]</sup>.

Approximately 18,000 species of aquatic beetles (Coleoptera) are known worldwide, and at least 50% of the species in 30 families are considered fully aquatic. Among the major biogeographic regions, the Oriental Region (2,200 described species / 3,580 estimated), the Australian–Pacific Realm (1,340 / 2,100), and the Nearctic Region (1,420 / 1,550) are the poorest in terms of water beetle diversity (Jäch & Balke, 2008) <sup>[17]</sup>.

Research on aquatic Hemiptera has expanded considerably following studies by Damgaard (2008) [10] and Chen *et al.* (2008) [7], documenting 23 families and more than 5,000 species across 350 genera, making this group the most diverse among hemimetabolous insects (Henry, 2009) [21].

Species of aquatic Hemiptera are commonly found in a wide range of freshwater habitats, including ponds, lakes, rivers, streams, and waterfalls, and some even occur in marine environments. They have a broad geographic distribution, being present on all continents except Antarctica, and are most abundant in tropical regions. In terms of species richness, the highest diversity occurs in the Neotropical region (southern Mexico, Central and South America) and the Oriental region. Species richness gradually declines across the Afrotropical region, Australia, the Palearctic region, the Nearctic region, and the Pacific region (Andersen *et al.*, 2002) [1].

Surveys conducted in six different habitats within Lonjsko Polje Nature Park recorded a total of 341 Coleoptera specimens (Hydradeptera) representing 29 species (Joanna *et al.*, 2016). In Saxony, Germany, a study examining the influence of ecosystem characteristics on water bug communities documented 40 water bug species in most ponds. Canonical correspondence analysis (CCA) indicated that soil, vegetation, and pesticide use were the main factors affecting the structure of Corixidae and Notonectidae communities (Armin *et al.*, 2010) [3]. A study along the Ganges River recorded 29 aquatic insect species, including three Coleoptera species from two families and four Hemiptera species from four families across 14 sampling sites. Diversity indices, including the Shannon diversity index, Pielou's evenness index ( $J'$ ), and Berger-Parker dominance index, were calculated. Gerridae dominated at over 92% of the sites, while Notonectidae were dominant at more than 28% of the sites (De *et al.*, 2021) [11]. Renato *et al.* (2019) [32] investigated the relationships between Hemiptera and Coleoptera diversity and habitat type, altitude, and forest cover in the Los Tuxtlas rainforest. They found that species richness and abundance of both orders were significantly higher in forests than in grasslands. In Kampong Speu Province, Cambodia, a study on the diversity, distribution, and habitat associations of water beetles recorded 152 individuals representing 22 species, 10 genera, and 9 families across 10 sampling sites. The Scirtidae family was the most abundant and showed positive associations with primary forest and shrub habitats, but negative associations with agricultural crop habitats. Limnichidae were positively associated with elevation and erosion, while Dytiscidae were positively associated with streambeds characterized by small stones but negatively associated with water depth and streambeds with large stones (Doeruk *et al.*, 2022) [15]. The diversity and abundance of water beetles were investigated at five sites in the Kolkas region of India. Diversity indices indicated that forest habitats were the richest, with 11 species, followed by agricultural crop and shrub habitats, each with 10 species, and secondary forests with 9 species. Analysis of species richness revealed that shrub habitats contained fewer

rare species and a higher proportion of common species compared to the other sites (Vaibhao *et al.*, 2011) [39].

In Vietnam, research on the diversity of water insects (Hemiptera, Coleoptera) is still scarce and limited. The studies on the water insects in tropical ecosystems have mainly focused on taxonomy. Sato (1972) [33] listed the species composition and recorded 6 species of the Noteridae family (Coleoptera) in the provinces of Lao Cai, Bac Kan, Tuyen Quang, Nghe An, Quang Ngai, Kon Tum, Hoa Binh, Quang Tri, Ninh Thuan, Dak Lak, Gia Lai, Lam Dong. The water beetle fauna in Hanoi is a typical lowland fauna in mainland Southeast Asia, including many species with a wide distribution range (Duc *et al.*, 2010) [13]. In some streams in Ha Giang Province, a total of 44 species of Hemiptera were recorded, belonging to 32 genera of 16 families (Duc *et al.*, 2016) [14]. Research on water insects conducted at Cuc Phuong National Park, Ninh Binh province, Ba Be National Park, Nam Xuan Lac Species and Habitat Conservation Area, Bac Kan province, Vu Quang, Ha Tinh province showed that at the research sites, 19 species belonging to 11 genera in 3 families of water beetles were recorded in both undisturbed and disturbed ecosystems. The protected undisturbed ecosystem had relatively high Margalef ( $d$ ) and Shannon - Weiner ( $H'$ ) diversity coefficients,  $d = 2.23-3.87$  (good diversity) and  $H' = 2.15-3.85$  (medium diversity), respectively. Six indicator species of undisturbed aquatic ecosystems were recorded at the study sites. 30 species of water bugs of Hemiptera with 25 genera in 10 families were recorded, the Margalef index ( $d$ ) in Ninh Binh, Bac Kan has a rich diversity, Gia Lai has normal diversity. Shannon - Weiner index ( $H'$ ) in Ninh Binh has average diversity. Bac Kan has average diversity and Gia Lai has low diversity. Some species of water bugs and water beetles are biological indicators for ponds, lakes, and swamps containing dirty water, and some other species are indicators for wetland ecosystems and natural streams containing clean (Lam *et al.*, 2022; Tran *et al.*, 2022; Truong *et al.*, 2023) [22, 37, 38].

Research and assessments of diversity indices of aquatic Hemiptera across various landscapes—including forest habitats, agricultural land, ponds, and streams—were conducted at 16 sampling sites in the provinces of Bắc Kạn, Lào Cai, Ninh Binh, and Hà Tĩnh. The results recorded a total of 43 species belonging to 23 genera and 10 families. The evenness levels of aquatic Hemiptera at the 16 sampling sites were classified into four main groups. The Shannon index ( $H'$ ), Simpson index ( $1-D$ ), species richness, and individual-based rarefaction curves in forest habitats were higher than those in agricultural land. However, species richness did not differ significantly between ponds and streams (Phan Thi Giang *et al.*, 2023) [29]. From 75 sampling sites across four habitat types in three national parks, a total of 1,892 aquatic insect specimens (Hemiptera, Coleoptera) were collected, representing 73 species, 48 genera, and 14 families. Among them, 42 species of water bugs (Hemiptera), belonging to 27 genera and 10 families, were recorded. Species richness in the families Nepidae and Gerridae (Hemiptera) was highest in secondary forests and shrublands, and lowest in

agricultural land and shrublands. For water bugs (Hemiptera), the values of the Simpson\_1-D, Shannon\_H, and Margalef indices decreased in the following order: primary forest > secondary forest > agricultural land > shrubland.

The relationship between the abundance of water bugs (Hemiptera) and water beetles (Coleoptera) across different habitats in the three national parks was generally weak and varied. In primary forests, this relationship showed a weak positive correlation. The species packing model displayed a concave parabolic pattern, indicating simultaneous increases and decreases in both water bugs and water beetles. In secondary forests, the relationship was a very weak positive correlation, and the analysis model showed a curved trend, reflecting an overall increase in both groups. In agricultural land and shrubland, the relationship was a very weak negative correlation. The analytical model was linear, showing no opposite fluctuation pattern between water bugs and water beetles (Nguyen Quang Cuong *et al.*, 2024a, b)<sup>[8, 9]</sup>.

U Minh Thuong and Phu Quoc National Parks, which form the core zone of the Kien Giang Biosphere Reserve in An Giang Province, were recognized by UNESCO on 27 October 2006. These parks possess exceptionally rich and unique faunal diversity, including many rare and endangered species. U Minh Thuong National Park, with an area of approximately 21,122 ha, has recorded 72 vertebrate species listed as rare and precious in the Vietnam Red Data Book (2024)<sup>[40]</sup> and the IUCN (2014)<sup>[25]</sup>. Phu Quoc National Park, located on Phu Quoc Island and covering a total area of 31,422 ha, has 41 vertebrate species listed as endangered, rare, and precious forest animals; 6 species classified as endangered and prioritized for protection; 42 species recorded in the Vietnam Red Data Book (2024)<sup>[40]</sup>; and 1 endemic species. Previous faunal studies in these two national parks have mainly focused on the diversity of vertebrates, especially endemic, endangered, rare, and precious species (Safford, 2000)<sup>[34]</sup>. Research specifically addressing insects has only dealt with butterflies (Lepidoptera) in Phu Quoc, such as the works of Phuong (2014)<sup>[31]</sup>, which collectively recorded 120 butterfly species.

At present, U Minh Thuong and Phu Quoc National Parks harbor high diversity, richness, and distinctive characteristics of several insect groups, notably aquatic Hemiptera and Coleoptera, which possess highly valuable and unique ecological attributes. However, research data on aquatic Hemiptera and Coleoptera in these two national parks are almost nonexistent, with little to no studies conducted or documented to date. That's why, in this study, diversity indices and relationships in the number of individuals of species between the water bugs (Hemiptera) and water beetles (Coleoptera) in different ecosystems including ecosystem of agroforestry-aquaculture in the buffer zone in U Minh Thuong and Phu Quoc National Parks, ecosystem of

melaleuca swamp forest on peat layer at U Minh Thuong National Park and ecosystem of acid-sulphate water forest at Phu Quoc National Park were studied and evaluated.

## Materials and Methods

### Water Insects Surveys

Water insect surveys were conducted at 12 sampling points across U Minh Thuong and Phu Quoc National Parks (Table 1). The sampling sites represented three ecosystem types: the agroforestry-aquaculture ecosystem in the buffer zone of both parks (EAAB), the melaleuca swamp forest on a peat layer in U Minh Thuong National Park (EMSF), and the acid-sulfate water forest ecosystem in Phu Quoc National Park (EAWF) (Appendix 3). The elevations of the sampling sites ranged from 19 to 300 m. The water insects were collected in September, October and November 2024-2025.

During this period, 25 samples were collected at each sampling point. Sampling was conducted between 10:00 a.m. and 5:00 p.m. using a pond net with a surface area of 0.5 m<sup>2</sup>, an extension rod 180 cm in length, and a mesh size of 0.5 mm. For each sample, the pond net was swept approximately 10 times per sampling to ensure coverage of different vegetational units, substrates, pond and stream banks, and open water areas.

All samples of Hemiptera and Coleoptera were preserved in 70% ethanol and brought to the laboratory for further analysis. They were later identified at the species level using a stereo-zoom microscope a Nikon SMZ 800N Digital Stereo Microscope, using Helicon Focus 7 software. The identification of water beetles according to Delève (1968)<sup>[12]</sup>, Brancucci (1983)<sup>[6]</sup>, Mazzoldi (1995)<sup>[28]</sup>, Jäch (1998, 2008)<sup>[18, 17]</sup>, Jäch & Balke (2003)<sup>[19]</sup>, Komarek (2003)<sup>[27]</sup>, Grey & Kelly (2016)<sup>[16]</sup>; of water bugs according to Andersen *et al.* (2002)<sup>[1]</sup>, Jansson (1986)<sup>[20]</sup>, Bal & Basu (1994)<sup>[4]</sup>, Schuh & Slater (1995)<sup>[35]</sup>, Berend *et al.* (2013)<sup>[5]</sup>, Lanna *et al.* (2001)<sup>[23]</sup>, Zettel *et al.* (2012)<sup>[42]</sup>, Zettel & Lane (2011)<sup>[43]</sup>, Lansbury (1968)<sup>[24]</sup>, Lansbury (1972), Polhemus & Polhemus (1998)<sup>[30]</sup>.

### Data Analysis

Biodiversity indexes including Dominance\_D, Simpson\_1-D, Shannon\_H, Evenness\_e<sup>H/S</sup>, Brillouin, Menhinick, Margalef, Equitability\_J, Fisher\_alpha, Berger-Parker, Chao-1, mean of individuals, diversity index alpha, species richness, correlation number individual between water bugs and water beetles were calculated using the software Fast 4.03. The dominant status of the water bugs and water beetles was calculated according to Vu Quang Manh (2004)<sup>[41]</sup> including:  $n'(\%) = (n_i/N) * 100$  ( $n'$  - dominant status;  $n_i$  - number of individuals of species I;  $N$  - number of individuals of all species;  $n' > 10$ : Most dominant;  $n' = 5-10$ : Dominant;  $n' = 3-5$ : Potentially dominant;  $n' < 3$  Non-dominant)

**Table 1:** The localities of specimen collection in ecosystems of U Minh Thuong and Phu Quoc National Parks

No	Localities of specimen collection	Elevation (m)	Ecosystems	Coordinates	Aquatic habitats
S1	U Minh Thuong NP.	5	Ecosystem of Agroforestry - Aquaculture in the Buffer Zone	9°36'40.4"N, 105°05'47.7"E	Pond
S2	U Minh Thuong NP.	3	Ecosystem of Agroforestry - Aquaculture in the Buffer Zone	9°45'62.8"N, 105°41'87.2"E	Pond
S3	Phu Quoc NP	110	Ecosystem of Agroforestry - Aquaculture in the Buffer Zone	10°19'25"N, 103°56'08"E	Pond
S4	Phu Quoc NP	104	Ecosystem of Agroforestry - Aquaculture in the Buffer Zone	10°22'40"N, 103°95'43"E	Pond
S5	U Minh Thuong NP.	7	Ecosystem of Melaleuca Swamp Forest on Peat Layer	9°65' 63'' N, 105° 62' 60''E	Canal
S6	U Minh Thuong NP.	6	Ecosystem of Melaleuca Swamp Forest on Peat Layer	9°34'43.9"N 105°05'07.4"E	Canal
S7	U Minh Thuong NP.	11	Ecosystem of Melaleuca Swamp Forest on Peat Layer	9°37'10.8"N 105°02'31.0"E	Lake
S8	U Minh Thuong NP.	6	Ecosystem of Melaleuca Swamp Forest on Peat Layer	9°64'74"N 105°11'14.0"E	Canal
S9	Phu Quoc NP	168	Ecosystem of Acid-Sulphate Water Forest	10°13'26.40"N, 103°57'15.59"E	Stream
S10	Phu Quoc NP	186	Ecosystem of Acid-Sulphate Water Forest	10°19'30"N, 103°57'00"E	Stream
S11	Phu Quoc NP	138	Ecosystem of Acid-Sulphate Water Forest	10°17'13.7"N 104°0.628"E	ponds
S12	Phu Quoc NP	130	Ecosystem of Acid-Sulphate Water Forest	10°13'1.78"N, 103°57'33.44"E	ponds

**Results**

**Species composition of water insects (Hemiptera, Coleoptera)**

A total of 577 individuals of aquatic Hemiptera and Coleoptera, representing 40 species in 27 genera and 11

families were recorded (Appendix 1). Of these, 24 species of water bugs (Hemiptera) belonging to 17 genera and 8 families, and 16 species of water beetles (Coleoptera) belonging to 10 genera and 3 families, were identified.

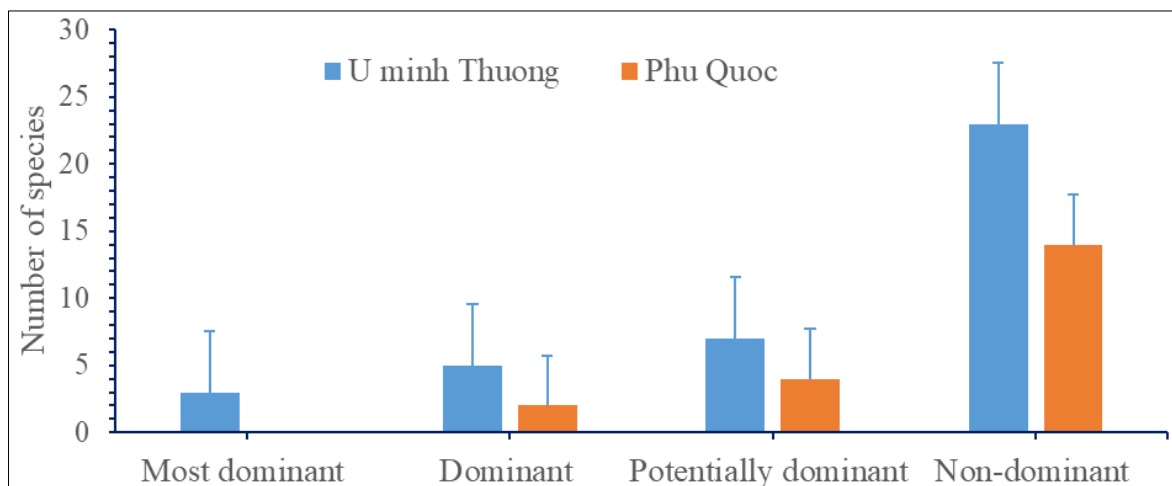
**Table 2:** Species composition structure of water bugs (Hemiptera) and water beetles (Coleoptera) across different ecosystems in U Minh Thuong and Phu Quoc National Parks

Ecosystems	Species composition structure					
	Family		Genus		Species	
	Number	(%)	Number	(%)	Number	(%)
EAAB	11	100	26	96.30	38	95.00
EMSF	11	100	24	88.89	32	80.00
EAWF	9	81.81	15	55.56	20	50.00

**Note:** EAAB: ecosystem of agroforestry-aquaculture in the buffer zone in U Minh Thuong and Phu Quoc National Parks; EMSF: ecosystem of melaleuca swamp forest on peat layer at U Minh Thuong National Park; EAWF: ecosystem of acid-sulphate water forest at Phu Quoc National Park.

Table 2 shows the species composition of water bugs (Hemiptera) and water beetles (Coleoptera) across different ecosystems in U Minh Thuong and Phu Quoc National Parks.

The numbers of families, genera, and species followed the order EAAB > EMSF > EAWF.



**Fig 1:** Number of dominant species in U Minh Thuong and Phu Quoc National Parks

In the EAAB ecosystem, the most diverse Hemipteran families were Gerridae and Nepidae, each represented by five species (12.5% of the total species), with 85 and 60 individuals, respectively. In the EMSF ecosystem, Gerridae was also the most diverse family, comprising five species (12.5% of the total species) with 20 individuals. In contrast, Hemipteran diversity in the EAWF ecosystem was very low.

The most diverse Coleopteran family in the EAAB ecosystem was family Dytiscidae, represented by 11 species (25.5% of the total species) and 63 individuals, followed by Hydrophilidae with 4 species (10.0%) and 23 individuals. In the EMSF ecosystem, Dytiscidae was also the most diverse family, comprising 10 species (25.00%) and 41 individuals. In contrast, Coleopteran diversity in the EAWF ecosystem

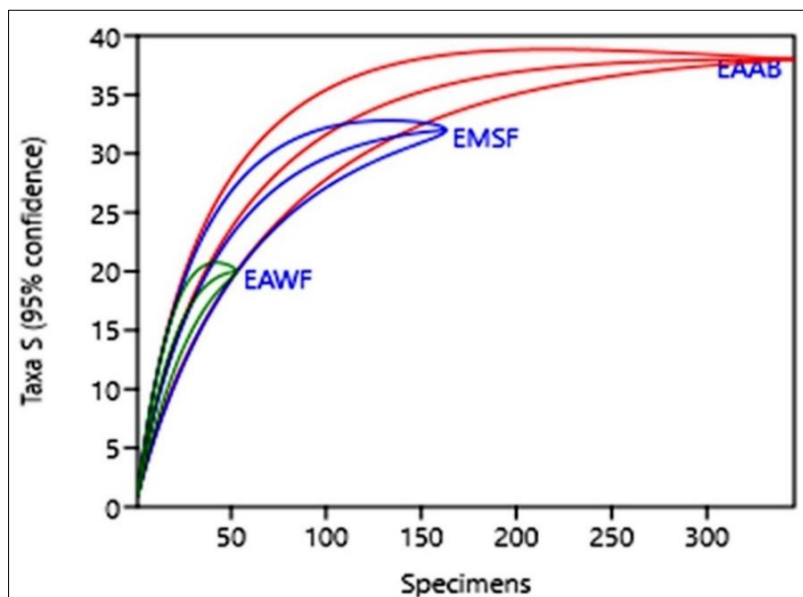
was very low.

The diversity indices across different ecosystems in U Minh Thuong and Phu Quoc National Parks (including Dominance\_D, Simpson\_1-D, Shannon\_H, Evenness\_e^H/S, Brillouin, Menhinick, Margalef, Equitability\_J, Fisher\_alpha, Berger-Parker, and Chao-1) varied considerably (Appendix 2). Several key indices Taxa\_S, number of individuals, Simpson\_1-D, Shannon\_H, Brillouin, Margalef, and Chao-1 showed a decreasing trend in the order EAAB ecosystem > EMSF ecosystem > EAWF ecosystem.

Figure 1 illustrates the number of dominant species of water bugs (Hemiptera) and water beetles (Coleoptera) recorded across different ecosystems in U Minh Thuong and Phu Quoc National Parks. In U Minh Thuong National Park, three species of water bugs were identified as the most dominant, namely *Ranatra filiformis* Fabricius, 1790 ( $n' = 14.56$  in

EAAB), *Laccotrephes japonensis* Scott, 1874 ( $n' = 15.92$  in EMSF), and *Diplonychus rusticus* (Fabricius, 1781) ( $n' = 10.43$  in EAAB;  $n' = 11.46$  in EMSF). In addition, five dominant species were recorded, including *R. filiformis* ( $n' = 7.64$  in EMSF), *L. japonensis* ( $n' = 8.38$  in EAAB), *Gerris lacustris* (Linnaeus, 1758) ( $n' = 7.28$  in EAAB), *Amemboa intermedia* Zettel & Chen, 1996 ( $n' = 5.73$  in EMSF) among water bugs, and *Sternolophus rufipes* (Fabricius, 1792) ( $n' = 5.10$  in EMSF) among water beetles.

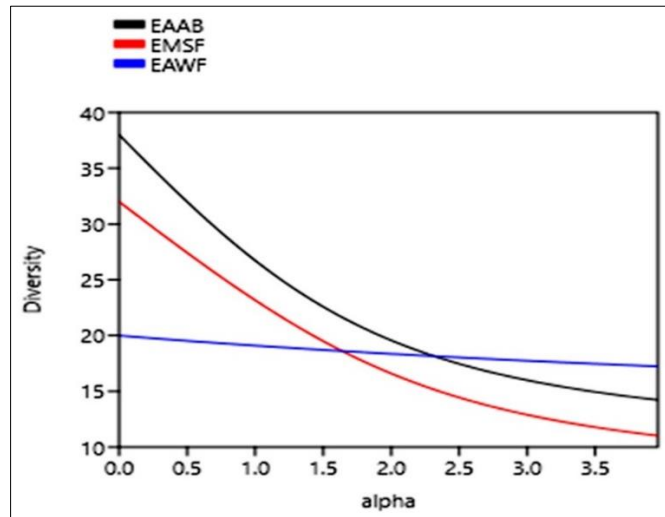
In Phu Quoc National Park, two dominant water bug species were recorded: *R. filiformis* ( $n' = 14.56$  in EAAB) and *D. rusticus* ( $n' = 10.43$  in EAAB). Additionally, three species were classified as dominant in the EAWF ecosystem, including *D. rusticus* ( $n' = 5.80$ ), *A. intermedia* ( $n' = 5.80$ ), and *Hydrometra annamana* Hunger & Evans, 1934 ( $n' = 5.80$ ).



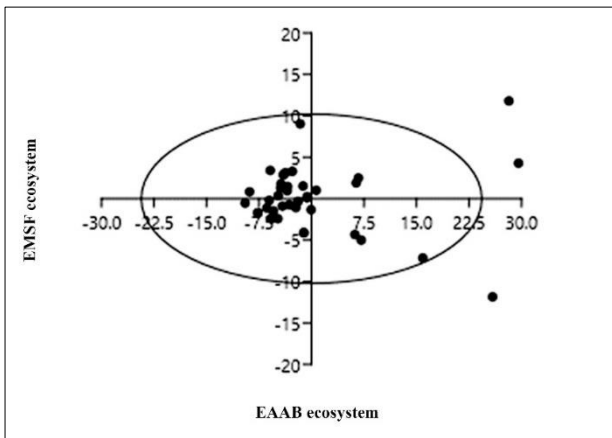
**Fig 2:** The species richness in different ecosystems in U Minh Thuong and Phu Quoc National Parks. EAAB: Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in U Minh Thuong and Phu Quoc National Parks; EMSF: Ecosystem of Melaleuca Swamp Forest on Peat Layer at U Minh Thuong National Park; EAWF: Ecosystem of Acid-Sulphate Water Forest at Phu Quoc National Park

Species richness varied substantially across the different ecosystems of U Minh Thuong and Phu Quoc National Parks, and these patterns differed between water bugs (Hemiptera) and water beetles (Coleoptera) (Fig. 2). Overall, the three surveyed ecosystems exhibited distinct levels of species richness, indicating that ecosystem type played a decisive role in shaping community composition. The highest richness was consistently recorded in the EAAB ecosystem, followed by the EMSF ecosystem, whereas the EAWF ecosystem supported the lowest number of species. This declining gradient (EAAB > EMSF > EAWF) was observed for both taxonomic groups, although the magnitude of variation differed between water bugs and water beetles, suggesting that each group responded differently to habitat characteristics and environmental conditions (Fig. 2).

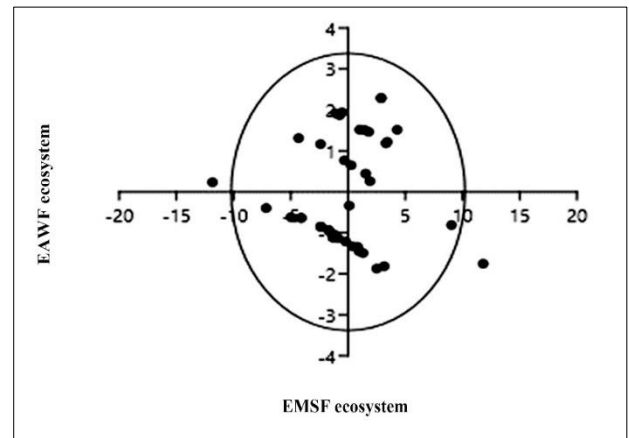
The analysis of alpha diversity revealed clear and taxon-specific patterns across the three ecosystem types within the two national parks (Fig. 3). For both water bugs (Hemiptera) and water beetles (Coleoptera), alpha diversity varied significantly among ecosystems, indicating that habitat characteristics strongly shaped community composition. In both taxa, the ecosystems followed a consistent diversity gradient, with the highest alpha diversity recorded in EAAB, followed by EMSF, and the lowest in EAWF (EAAB > EMSF > EAWF; Fig. 3). This pattern suggests that EAAB provides more heterogeneous or resource-rich conditions conducive to supporting a greater number of species, whereas EAWF appears to offer comparatively limited ecological niches for these aquatic insect groups.



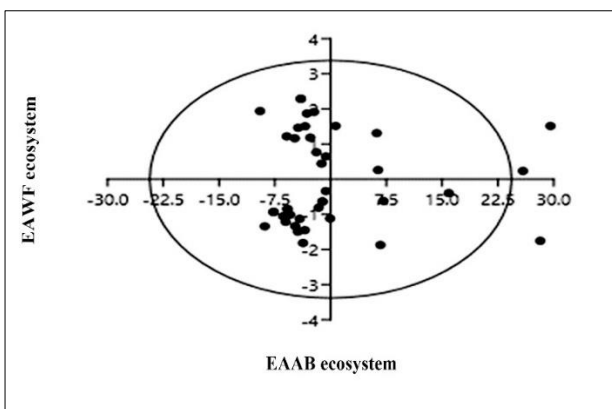
**Fig 3:** The diversity index alpha in EAAB: Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in U Minh Thuong and Phu Quoc National Parks; EMSF: Ecosystem of Melaleuca Swamp Forest on Peat Layer at U Minh Thuong National Park; EAWF: Ecosystem of Acid-Sulphate Water Forest at Phu Quoc National Park



(a) Correspondence between EAAB and EMSF



(c) Correspondence between EMSF and EAWF



(b) Correspondence between EAAB and EAWF

**Fig 4:** Correspondence analysis in EAAB: Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in U Minh Thuong and Phu Quoc National Parks; EMSF: Ecosystem of Melaleuca Swamp Forest on Peat Layer at U Minh Thuong National Park; EAWF: Ecosystem of Acid-Sulphate Water Forest at Phu Quoc National Park (mean  $\pm$  95% confidence intervals)

The correspondence analysis conducted on the water bug (Hemiptera) and water beetle (Coleoptera) communities across the ecosystems of U Minh Thuong and Phu Quoc National Parks, Vietnam, revealed distinct ecological patterns of species distribution. The analysis demonstrated that the community structures of water bugs and water beetles in the EAAB and EMSF ecosystems were highly similar (64.42%), with the two ecosystems clustering closely together in the ordination space (Fig. 4a).

This suggests that both EAAB and EMSF offer similar environmental conditions, which may support comparable assemblages of these aquatic insect taxa.

In contrast, the ordination plots for the EAAB and EAWF (27.65%), as well as for EMSF and EAWF (33.44%), exhibited notable divergence (Figs. 4b, c), indicating significant ecological differences between these ecosystems. These divergences could be attributed to variations in habitat complexity, resource availability, or water quality, all of which likely influence species composition in distinct ways. Specifically, the EAWF ecosystem appears to offer less favorable conditions for both water bugs and water beetles, as indicated by its separation from both EAAB and EMSF in the correspondence analysis.

This suggests that while EAAB and EMSF share some common environmental factors that influence species distribution, EAWF represents a distinct ecological niche that may be less conducive to supporting the same range of species found in the other two ecosystems.

**The Relationship of Three Surveyed Ecosystems**

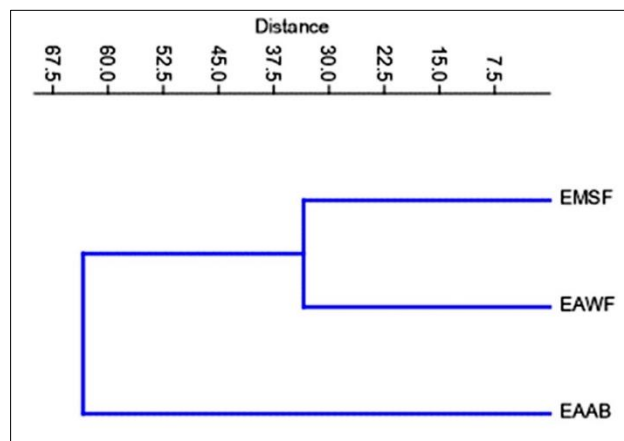
The evenness distance (Evenness index) of water bug (Hemiptera) and water beetle (Coleoptera) communities across the EAAB, EMSF, and EAWF ecosystems at 12 sampling sites in U Minh Thuong and Phu Quoc National Parks is illustrated in Figure 5. The analysis revealed a clear hierarchical grouping pattern. Species evenness was first divided into two major clusters: Group 1, consisting exclusively of the EAAB ecosystem, and Group 2, which

included both the EMSF and EAWF ecosystems. Within Group 2, a further subdivision was observed, with EMSF and EAWF forming two distinct subgroups.

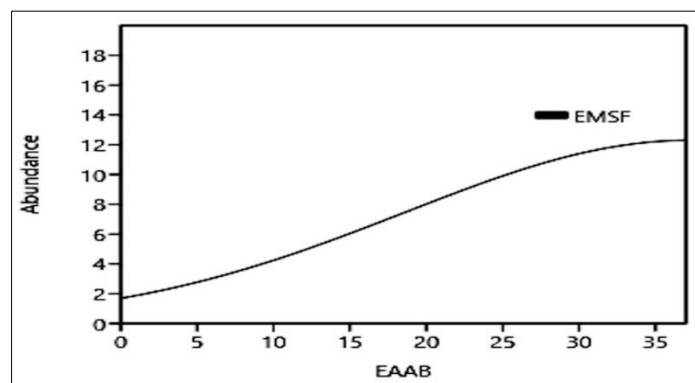
From an ecological perspective, the separation of EAAB into its own major group suggests that this ecosystem supports a more balanced distribution of species, where dominant taxa do not overwhelmingly outnumber rare ones. Such high evenness typically reflects greater habitat stability, higher resource diversity, or more uniform microhabitat conditions, which may reduce competitive exclusion and allow co-occurring species to maintain comparable abundances.

In contrast, the grouping of EMSF and EAWF, followed by their subsequent separation into distinct subclusters, indicates that these ecosystems share some structural similarities but differ in important ecological attributes. The EMSF ecosystem may exhibit moderate habitat heterogeneity, leading to intermediate levels of species dominance, whereas the EAWF ecosystem—often characterized by more variable hydrological conditions or lower habitat complexity—likely supports communities where a few species become dominant. This reduced evenness can be associated with environmental stress, limited resource availability, or specialized habitat conditions, all of which can constrain species coexistence.

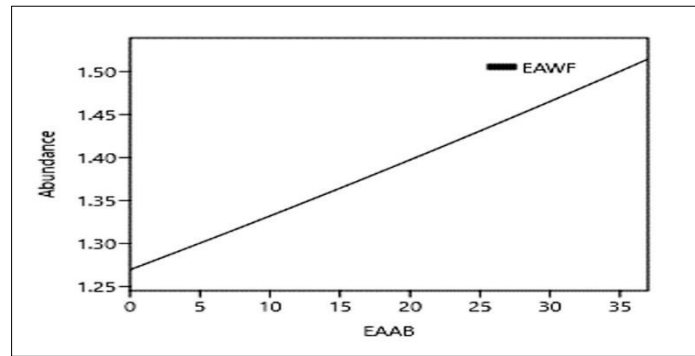
Overall, the evenness-based clustering highlights how subtle ecological gradients among the three ecosystems shape the distributional balance of water bug (Hemiptera) and water beetle (Coleoptera) communities, reflecting underlying differences in habitat quality and ecological processes.



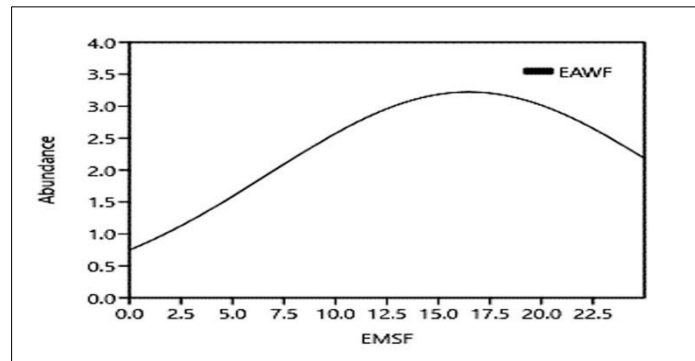
**Fig 5:** Evenness distance (Evenness index) in EAAB: Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in U Minh Thuong and Phu Quoc National Parks; EMSF: Ecosystem of Melaleuca Swamp Forest on Peat Layer at U Minh Thuong National Park; EAWF: Ecosystem of Acid-Sulphate Water Forest at Phu Quoc National Park.



(a) EAAB and EMSF



(b) EAAB and EAWF



(c) EMSF and EAWF

**Fig 6:** The analysis model species packing of the number of individual water bugs (Hemiptera) and water beetles (Coleoptera) in EAAB: Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in U Minh Thuong and Phu Quoc National Parks; EMSF: Ecosystem of Melaleuca Swamp Forest on Peat Layer at U Minh Thuring National Park; EAWF: Ecosystem of Acid-Sulphate Water Forest at Phu Quoc National Park

The investigation revealed the presence of a relationship between the abundances of water bugs (Hemiptera) and water beetles (Coleoptera) across the different ecosystems in the two national parks. However, this relationship was generally weak and varied among ecosystems, indicating that the two taxa respond differently to local environmental conditions and do not exhibit strong co-variation in their population patterns.

The relationship between the abundances of water bugs (Hemiptera) and water beetles (Coleoptera) varied markedly among the three ecosystem pairings. In the EAAB and EMSF ecosystems, the correlation was positive and moderate ( $R = 0.54$ ), suggesting that the two taxa responded in a broadly similar manner to environmental conditions within these habitats. The species-packing model for this ecosystem pair produced a smooth curve, indicating co-increase and co-decrease trends between the two groups. The estimated ecological parameters—optimum (37.34), tolerance (18.74), and maximum (12.31)—fell within average and relatively stable ranges, implying that both taxa experienced comparable environmental suitability and moderate ecological pressure (Fig. 6a).

In contrast, the relationship between EAAB and EAWF ecosystems was positive but extremely weak ( $R = 0.04$ ), reflecting a near absence of coordinated population responses. The species-packing model for this pair generated a nearly linear and unstable pattern. The ecological parameter values were exceptionally high—optimum (1696.40), tolerance (593.29), and maximum (75.66)—indicating that species abundance in these environments was shaped by

substantial environmental stress. Such elevated values suggest that populations in the EAWF ecosystem experience harsh or highly variable conditions, making them more susceptible to decline and reducing synchrony with those in the EAAB ecosystem (Fig. 6b).

For the EMSF and EAWF ecosystems, the correlation was positive but weak ( $R = 0.32$ ), indicating limited but present co-variation between the two taxa. The species-packing model in this case produced a parabolic curve with upward concavity, reflecting unstable and environmentally sensitive species responses. The corresponding ecological parameter values—optimum (16.47), tolerance (9.64), and maximum (3.22)—were notably low, suggesting narrow ecological niches and high susceptibility to environmental fluctuations. Such low values indicate that species in the EAWF ecosystem face substantial ecological constraints, leading to reduced stability and a greater likelihood of population decline (Fig. 6c).

Overall, these results demonstrate that the degree of synchrony between water bugs and water beetles varies considerably across ecosystem types, with stronger relationships occurring in more stable or structurally complex habitats (EAAB–EMSF) and weaker or unstable relationships occurring where environmental stress is more pronounced (EAAB–EAWF and EMSF–EAWF). The species-packing models further highlight that environmental pressure plays a major role in shaping species distributions, niche widths, and population sensitivity within these aquatic insect communities.

## Discussion

The observed relationship between the abundances of water bugs (Hemiptera) and water beetles (Coleoptera) across the different ecosystems in the two national parks was weak and inconsistent, suggesting that these two taxa respond differently to environmental gradients and habitat characteristics. This weak correlation implies that the population dynamics of Hemiptera and Coleoptera are not strongly coupled and may be regulated by distinct ecological processes.

Several ecological mechanisms may explain this pattern. Water bugs, which include a number of predatory and surface-dwelling species, often show strong sensitivity to microhabitat features such as water surface stability, vegetation cover, and oxygen availability. In contrast, many water beetles—particularly diving beetles (Dytiscidae) and scavenger beetles (Hydrophilidae)—tend to be influenced more by submerged habitat complexity, prey availability, and water depth. As a result, variation in habitat structure among ecosystems (EAAB, EMSF, and EAWF) may differentially shape the abundance of these groups.

Additionally, the weak relationship may reflect niche partitioning, where Hemiptera and Coleoptera exploit different ecological resources, reducing the likelihood of parallel fluctuations in abundance. Their differing life-history traits—such as reproductive strategies, dispersal ability, and tolerance to environmental stress—could further decouple their responses to ecological drivers such as hydrological fluctuation, nutrient gradients, or levels of anthropogenic disturbance.

Ecosystem-specific differences also appear to play an important role. In more structurally complex or resource-rich environments, the two taxa may respond independently to distinct habitat cues, whereas in more simplified ecosystems, environmental constraints may suppress or amplify the abundance of one group without affecting the other. The variability among ecosystems therefore highlights the importance of local habitat conditions in determining community composition and cross-taxon relationships.

Overall, these findings underscore the complexity of aquatic insect assemblages and demonstrate that taxonomic groups cannot be assumed to show consistent abundance relationships across heterogeneous environments. Future studies incorporating functional traits, microhabitat measurements, or species-specific ecological requirements may provide deeper insights into the mechanisms governing these patterns.

A total of 40 species belonging to 27 genera and 11 families were collected from the three ecosystems surveyed in U Minh Thuong and Phu Quoc National Parks. Of these, 24 species were water bugs (Hemiptera), representing 17 genera and 8 families, while 16 species were water beetles (Coleoptera), representing 10 genera and 3 families. This species composition differs substantially from earlier studies conducted in other regions of Vietnam. For example, Sato (1972)<sup>[33]</sup> recorded only six species of Noteridae (Coleoptera) from several northern and central provinces, including Lao Cai, Bac Kan, Tuyen Quang, Nghe An, Quang Ngai, Kon Tum, Hoa Binh, Quang Tri, Ninh Thuan, Dak Lak, Gia Lai, and Lam Dong. Similarly, studies by Tran Anh Duc *et al.* (2010, 2016)<sup>[13, 14]</sup> reported 31 species belonging to 20 genera and 7 families of aquatic insects in surveys conducted

in Hanoi City and Ha Giang Province. More recently, Nguyen Quang Cuong *et al.* (2024)<sup>[8, 9]</sup> investigated the diversity and abundance relationships of water bugs (Hemiptera) and water beetles (Coleoptera) across 75 sampling sites in four habitat types—primary forest, secondary forest, agricultural land, and shrubland—within Ba Be National Park (Bac Kan Province), Vu Quang National Park (Ha Tinh Province), and Hoang Lien National Park. Their study documented 1,892 individuals representing 73 species, 48 genera, and 14 families, including 42 species of water bugs (27 genera, 10 families) and 31 species of water beetles (21 genera, 4 families).

These comparisons highlight the high variability in species richness and composition of aquatic Hemiptera and Coleoptera across different regions and habitat types in Vietnam. Such differences likely reflect a combination of habitat heterogeneity, environmental gradients, sampling effort, and biogeographic factors that influence the structure of aquatic insect assemblages.

In the present study, the diversity-related indices—including Taxa\_S, number of individuals, Simpson\_1-D, Shannon\_H, Brillouin, Margalef, and Chao-1—exhibited a clear decreasing trend following the order EAAB ecosystem > EMSF ecosystem > EAWF ecosystem. This pattern closely aligns with the findings of Nguyen Quang Cuong *et al.* (2024)<sup>[8, 9]</sup> and Phan Thi Giang *et al.* (2023)<sup>[29]</sup>, who reported similarly decreasing gradients of water bug (Hemiptera) and water beetle (Coleoptera) diversity from primary forest habitats to secondary forests, shrublands, and agricultural crop habitats across four habitat types within Ba Be National Park (Bac Kan Province), Vu Quang National Park (Ha Tinh Province), and Hoang Lien National Park.

Comparable results were also observed by Renato *et al.* (2019)<sup>[32]</sup>, who examined Hemiptera and Coleoptera assemblages in the Los Tuxtlas rainforest and found that species richness and abundance were significantly higher in forested habitats than in grasslands. Together, these studies support the broader ecological pattern that structurally complex and less disturbed habitats—such as primary or mixed semi-forest ecosystems—tend to sustain higher diversity and more stable assemblages of aquatic insects compared with more open or environmentally stressed habitats.

## Conclusion

Maintaining undisturbed and complex wetland habitats is crucial for sustaining high species diversity and balanced community structures of water bugs and water beetles in U Minh Thuong and Phu Quoc National Parks. Conservation efforts should prioritize the protection of ecosystems like EAAB that provide stable environmental conditions, which support both taxonomic richness and population synchrony.

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**Appendix 1:** Species composition and abundance of water bugs (Hemiptera) and water beetles (Coleoptera) in different ecosystems of U Minh Thuong and Phu Quoc National Parks, Vietnam

No	Species composition	Ecosystems of U Minh Thuong and Phu Quoc National Parks											
		EAAB				EMSF				EAWF			
		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
<b>ORDER HEMIPTERA</b>													
<b>Family Corixidae</b>													
	<i>Sigara distorta</i> (Distant, 1910)	2	1	6		2		1					
<b>Family Notonectidae</b>													
	<i>Enithares sinica</i> (Stål, 1854)	1	2		4		2	1		1		1	
	<i>Anisops breddini</i> Kirkaldy, 1901	4		1					2				
<b>Family Nepidae</b>													
	<i>Ranatra filiformis</i> Fabricius, 1790	11	21	18	4	2	3	4	3	1			1
	<i>Ranatra gracilis</i> Dallas, 1850	3	2	3	1								
	<i>Cercometus asiaticus</i> Amy. & Ser., 1843	3	4	1	1								
	<i>Laccotrephes japonensis</i> Scott, 1874	13	7	3	8	9	5	6	5		1	1	
	<i>Laccotrephes maculatus</i> (Fabr., 1775)	2	1	1	3		1		1	2		1	
<b>Family Naucoridae</b>													
	<i>Naucoris scutellaris</i> Stal, 1860										1		2
	<i>Heleocoris strabus</i> Montandon, 1897	1	1	4	2		2		2		2		
	<i>Heleocoris breviceps</i> Montandon, 1897					1		1					
	<i>Heleocoris ovatus</i> Montandon, 1897		1	1									
<b>Family Belostomatidae</b>													
	<i>Diplonychus rusticus</i> (Fabricius, 1781)	19	4	11	1	8	5	2	3	2	1		1
	<i>Lethocerus indicus</i> (Serville, 1825)	5	2		1	1	2		1				1
<b>Family Gerridae</b>													
	<i>Gerris lacustris</i> (Linnaeus, 1758)	19	7	5	6		2						
	<i>Amemboa intermedia</i> Zettel & Chen, 1996	2	6	1	5	2	5	1	1				
	<i>Aquarius paludum</i> (Fabricius, 1794)	1	14	11		1		2					
	<i>Linnogonus fossarum</i> (Fabricius, 1775)	2	1	1		1							
	<i>Metrocoris acutus</i> Chen & Nieser, 1993			2	2		2	1	2		2		2
<b>Family Micronectidae</b>													
	<i>Micronecta quadristrigata</i> Breddin, 1905	2		1	1	1	1		1				
	<i>Micronecta ludibunda</i> Breddin, 1905	1	1	1	2		2	2	2		2	1	
	<i>Micronecta scutellaris</i> (Stål, 1868)	1	1	1	2								2
<b>Family Hydrometridae</b>													
	<i>Hydrometra albolineata</i> (Scott, 1874)	2		1	1		1	1	3		1	1	2
	<i>Hydrometra annamana</i> Hunger & Evans, 1934	2		1	3				2	2			1
<b>ORDER COLEOPTERA</b>													
<b>Họ Dytiscidae</b>													
	<i>Hyphydrus lyratus</i> Swartz, 1808	3							2				
	<i>Laccophilus chinensis</i> Boheman, 1858	2				1	1	2	1	1	1		1
	<i>Cybister sugillatus</i> Erichson, 1834	8	3	1	4			1	1			1	1
	<i>Cybister tripunctatus</i> (Fabricius, 1798)	2		3		1		3					
	<i>Hydaticus bipunctatus</i> Wehncke, 1876	1	4		2	2	2		1	1			1
	<i>Hydaticus vittatus</i> (Fabricius, 1775)	1		3			1	1	2	1	1	1	
	<i>Hydaticus bengalensis</i> Régimbart, 1899	1		1	2								
	<i>Hydaticus concolor</i> Sharp, 1882		3	1		3	2	1					
	<i>Hydaticus pacificus</i> Aubé, 1838	1		2	2		1	2	1		1	1	1
	<i>Sandracottus mixtus</i> (Blanchard, 1843)	1	1		2	1		2	1				
	<i>Platambus regulae</i> Brancucci, 1991	1	3	1	4	1	2		2			1	2
<b>Họ Gyrinidae</b>													
	<i>Gyrinus orientalis</i> Regimbart, 1883	9	3	2	3	2							
<b>Họ Hydrophilidae</b>													
	<i>Cercyon incretus</i> Orchymont, 1941	1		1	1		1		1				
	<i>Cryptopleurum sulcatum</i> Motsch., 1863	1	1		2								
	<i>Sternolophus rufipes</i> (Fabricius, 1792)	6	2	2	4	3	1	3	1		1		1
	<i>Sternolophus inconspicuus</i> (Nietner, 1856)	1		1									

Note: EAAB: Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in U Minh Thuong and Phu Quoc National Parks; EMSF: Ecosystem of Melaleuca Swamp Forest on Peat Layer at U Minh Thuong National Park; EAWF: Ecosystem of Acid-Sulphate Water Forest at Phu Quoc National Park

**Appendix 2:** The diversity index of water bugs (Hemiptera) and water beetles (Coleoptera) in different ecosystems of U Minh Thuong and Phu Quoc National Parks

Diversity indices	Ecosystems of U Minh Thuong and Phu Quoc National Parks		
	EAAB	EMSF	EAWF
Taxa_S	38	32	20

Individuals	346	163	53
Dominance_D	0.05	0.06	0.05
Simpson_1-D	0.95	0.93	0.94
Shannon_H	3.29	3.14	2.95
Evenness_e^H/S	0.70	0.72	0.96
Brillouin	3.09	2.84	2.47
Menhinick	2.04	2.50	2.74
Margalef	6.33	6.08	4.78
Equitability_J	0.90	0.91	0.98
Fisher_alpha	10.89	11.91	11.69
Berger-Parker	0.10	0.15	0.08
Chao-1	38.12	32.11	20.23

**Note:** EAAB: Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in U Minh Thuong and Phu Quoc National Parks; EMSF: Ecosystem of Melaleuca Swamp Forest on Peat Layer at U Minh Thượng National Park; EAWF: Ecosystem of Acid-Sulphate Water Forest at Phu Quoc National Park



(a) Pond in Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in U Minh Thuong NP.



(b) Pond in Ecosystem of Agroforestry - Aquaculture in the Buffer Zone in Phu Quoc NP.



(c) Pond in Ecosystem of Melaleuca Swamp Forest on Peat Layer in U Minh Thuong NP.



(d) Canal in Ecosystem of Melaleuca Swamp Forest on Peat Layer in U Minh Thuong NP.



(e) Stream in Ecosystem of Acid-Sulphate Water Forest in Phu Quoc NP.



(f) Pond in Ecosystem of Acid-Sulphate Water Forest in Phu Quoc NP.

**Appendix 3:** Aquatic habitats in in different ecosystems of U Minh Thuong and Phu Quoc National Parks

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